TECHNOLOGY AS HANDMAIDEN TO GENERATIVE DRAWING

(IN INDUSTRIAL DESIGN)

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Abstract

This thesis describes a reflective practice research project which explores the potential for taking the technology to the drawing surface in generative drawing for industrial design practice.

The research arose from an apparent contradiction between my own experience of the usefulness of 'paper and pencil' generative drawing in professional practice and the experience of others in the field. They appeared to be, publicly at least, questioning or dismissing the relevance of 'traditional' methods of design idea generation and manipulation in favour of a professional practice that was completely computer based. I developed an approach to this apparent contradiction which involved consciously bringing the two contradictory extremes together and turning the problem upside down to consider the potential for taking technology to the generative drawing site; the physical work space. This approach was made with a view to qualitatively assessing its resultant benefits and hindrances in relation to the goal driven activity of generative drawing.

Pursuing this approach, reflective practice was used to generate a number of inter-related practical areas (see Schön, 1983). Regular reframing of the research occurred stimulated by my own on-going research action, my own design practice, a search for new literature, the evaluation of new equipment or practices and the contributions of other practitioners. This constant reflection and reframing led to the generation and exploration of previously unexpected areas of practical interest in a broadly systematic way, not dissimilar to a design process. There were four main inter-related phases of practical work generated and these are described in a narrative structure. The research methodology is also explained and discussed as are the connections between adjacent phases of practical work.

Phase 1 of the practical work was involved with the recording of verbal activity during generative drawing and its storage 'within' the drawing; by appending discrete devices to the surface of the drawing. This appears to be a feasible concept and may, as indicated by the literature, act to 'free working memory' in order to develop ideas or generate new ones. However, there were concerns that the process of using the sound devices was too invasive to the process of drawing and these are discussed. There was also evidence to suggest that the function of generative drawing notes (whether by speech or handwriting) may relate to long term memory and may relate to ideas of repertoire or 'seeing as' as described by Goldschmidt (1991) and Schön (1983).

Phase 2 of the practical work was involved with the development of a site for ideas generation, in the form of a series of drawing tables. These were used largely as shared drawing spaces and an attempt was made at preliminary cataloguing of the whole drawing/design process using a digital video camera and playback via a computer file. This was explored in this phase as a tool for the practitioner, but later in the process of reflective practice it was also reinterpreted as a research tool. The use of the computer to review the drawing/design process suggested the development of some symbolic objects for use 'in camera'. The use of a projection dice, node marker, orientation marker and tangential marker was explored practically and is described. The symbolic review objects were a bare minimum of notational symbols which, when used with the dense and ambiguous symbolism of the generative drawing, overlaid points of reference which themselves could become focal points of meaning and possibly reinterpretation. It was observed that it is possible to introduce objects which have a useful, if momentary, role to play in generative drawing, at least in a cooperative working situation. In this situation, the object becomes a communication 'prop' and serves to focus and externalise natural language discussions, by introducing another level of symbolism.

Phase 3 came from reflection on the concepts of goal image and image-percept hybrids in the literature (particularly Arnheim 1995, but also Goldschmidt (1991), Fish (1996) and Hockney (1999)) which resulted in the idea of evaluating the use of a temporary image brought to the drawing surface for use in the generative drawing process. The cataloguing digital video camera (DVC) from phase 2 was used to capture and replay images on and off-line with regard to the drawing. The image was brought to the drawing by back projection onto a glass top drawing table. Practically, the interplay between the drawing and the projected image appeared to influence perceived depth and allowed basic layering to take place. It also allowed structuring of the drawing to take place, whereby the frames of reference evident in an image could be appropriated for the drawing. This appropriation sometimes took the form of a corruption of the original frames of reference and could therefore be said to initiate reinterpretation, instigated by the image, not the drawing. This was considered to be, at times, a serendipitous process and was assumed to be analogous to the 'reference frame reversals' described by Purcell and Gero (1998).

The idea of bringing the image to the drawing was continued in phase 4, with the integration of a serendipitously discovered, commercially available, drawing interface into its own drawing table. This was used with a series of selectable CCTV camera 'tools' enabling images to be fed back around the loop of being displayed under the drawing surface (on an LCD screen). Practically, these CCTV camera 'tools' allowed a variety of image types to become available at the drawing surface including silhouette, macroscopic view, instantaneous drawing 'scan' and images of objects or large scale sites. Taking the CCTV camera 'tool' to the drawing surface was seen to instantly produce a reinterpretation of the marks through a change of scale and reframing.

In addition to mark-making, the drawing interface stylus was also used (in phase 4) as a spatially sensitive switch to activate a number of functions including instantaneous 'figure-

ground reversals'. Whilst 'figure-ground reversals' were found to be extremely simple to arrange in the digital domain, within the hybridized domain, the use of the CCTV camera capture was seen as an advantage so that paper drawings could also benefit from image manipulation. This provision is significant for the reasons outlined in Brandimonte and Gerbino (1993), who propose the link between the perceptual processes which act during 'figure-ground reversals' and the mechanisms which drawing provides in terms of mental imagery and reinterpretation in the design process.

All of the practitioners who tried generative drawing using the phase 4 drawing interface attempted to annotate their drawings through handwriting and there was some concern over the relative difficulty in using the drawing interface for this function. I took this as evidence that the structuring of design process often occurs in parallel with generative drawing. Furthermore, the need for provision of speech or writing capacity in the digitally mediated drawing system was demonstrated and this was in accordance with the conclusions of Fish (1996).

The idea of the unedited paper roll which was developed in the phase 2 work was reconsidered within the digital domain of phase 4 as a scrolling window. In a sense the scrolling drawing became a truly hybridized record of the drawing activity in one continuous medium and unexpectedly, the accidental was seen to play a part in the digital domain drawing. It was felt that this 'digital paper roll' offered closure to a much earlier idea (phase 2) and in effect the research had gone full circle.

As a context for this practical work, an attempt has been made to relate the practice of drawing in industrial design to a broad selection of the relevant practical and theoretical works and to use recent research to illuminate the reasons for the usefulness of drawing for conceptualisation. Some cognitive and practical aspects of generative drawing have been

juxtaposed with descriptions of some of the spectrum of relatively recent forays into drawing using technology. The nature of this project as reflective practice meant that the discovery of the published research in and around the field was an ongoing process. The discovered material was found to be useful for three, often related purposes and these are discussed.

In summary, a hybridized approach to drawing emerged which was constantly assessed within the context of my own industrial design practice (Gusto: Design Studio Ltd). Some attributes of the digital domain were observed to actually assist in encouraging some of the cognitive processes identified (through the literature) as important in generative drawing. Practically, examples of figure/ground reversals, density and ambiguity of symbolism, reinterpretations and the lateral transformation of ideas were all observed when the technology was taken to the generative drawing site. However, the materiality of the technological side of things was felt to be lacking and it was difficult to remove Petherbridge's 'technical considerations', introduced at the start of the thesis, from much of the practical phases. This resulted in equipment which was often difficult to use and certainly not as flexible, economical or spontaneous as paper and pencils.

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List of Illustrations

List of Accompanying Material

1. CD ROM containing video footage and stills of generative drawing 'reflective practicals' and equipment.

Preface

This MPhil has been carried out by project. Therefore, this thesis attempts to represent the whole project, which was conducted by reflective practice, where the search for new literature, my own reflection-in-action and reflection-on-action all influenced the direction of the practical work. Whilst the accompanying CD-ROM is intended to provide an insight into equipment and techniques, along with the drawings presented herewith as illustrations and appendices, it is not an exhaustive account of the exploratory practical work. There can be no substitute for seeing and experiencing a description of the practical work first hand. I hope that the information presented is clear and at least offers a flavour for what I feel has been a very interesting and illuminating project.

Neil Barron

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I must also thank all those who have been kind enough to participate in the drawing experiments. Even though they appear anonymously within this work, they know who they are!

Thanks also go to Simon Waterfall and Alec Hendry of Deepend Design for help in compiling the video footage into the accompanying CD-ROM. Further thanks also go to Terry Rosenberg for allowing the inclusion, in the appendices, of some of his Royal College of Art drawing course briefs. I am very grateful to Mr John Arnott and colleagues at Input Technologies Inc, Canada, for help and support in relation to their drawing interface product, the 'VisionMaker Sketch 14', which they most kindly donated to the project.

Last but not least, I am indebted to my fiancé, Claudia, who has supported and encouraged me immensely during this project.

Author's Declaration

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Definitions

At the outset, a clarification of terms may be useful. Rather than use the terms 'sketch' and 'sketching', which, in some spheres have connotations of observational drawing or drawing from life and in other spheres completely different ones (for example, the term 'sketch' is used by Marr in the context of '2 1/2 D sketch' to represent the visual field within the context of seeing and perception[1]), it is proposed that the expression **generative drawing** be used throughout this work. This is intended to refer to the broad activity of drawing which is used by designers and other practitioners to think in the action of designing, normally, but not exclusively, within the conceptual phase of a project.

The expression **information technology** is intended to indicate any computer based tools which are used in the design process and is used in the place of a better alternative.

[1] Marr, D (1982) Vision. San Francisco: DH Freeman.

Introduction

Aims and Objectives

This thesis outlines a programme of research conducted primarily through reflective practice, which considers the potential for taking technology to the generative drawing site (work space) in industrial design.

Background

The research arose from an apparent contradiction between my own experience of the usefulness of paper and pencil generative drawing in professional practice and the experience of others in the field. They appeared to be, publicly at least, questioning or dismissing the relevance of 'traditional' methods of design idea generation and manipulation in favour of a professional practice that was completely computer based. At one memorable conference I recall that one prominent industrial designer stated 'of course all of our work is now done on computer - we don't draw on paper any more'. This was at a conference about generative drawing, not computing; and quickly became the motivating contradiction which drove the project forward.

Quite early on, I felt that one way to approach this apparent contradiction would be to consciously bring the two contradictory extremes together and to turn the problem upside down and consider the potential for taking technology to the generative drawing site - the physical work space. This approach was made with a view to qualitatively assessing its resultant benefits and hindrances in relation to the goal driven activity of generative drawing.

Reflective Practice

The relationship between research and professional practice has always been identified as an implicit area of interest within this project. The research methodology which seemed the most

natural and appropriate was reflective practice[2] and the project was progressed largely through this, although Schön (1983) was not encountered until some way into the project.

A cycle of action and reflection was established over the course of the project resulting in the generation of a number of practical areas which were bound up together. The initial setting of overall project boundaries was relatively unproblematic since scale, cost, time, technology etc were relatively straightforward to establish and did not allow too much latitude. However, as expected with reflective practice, regular reframing of the research occurred stimulated by my own on-going research action, my own design practice, a search for new literature, the evaluation of new equipment or practices and the contributions of other practitioners. This constant reflection and reframing led to the generation and exploration of previously unexpected areas of practical interest. See illustration 1 for an overall representation of the project and illustration 1a for a representation of the connections between adjacent practical phases of work (this will be explained later).

One of the problems with research through reflective practice is that of identifying satisfactory closure. This is analogous to closure in an industrial design project (itself reflective practice, of course), which tends to be a function of the skill and experience of the designer. I would acknowledge that the analogous skill and experience within the research project had to develop in parallel with the research itself and was, in fact, a personal objective of the research project.

Ultimately, I have come to see myself as what Schön (1983, p323) calls a 'practitioner-researcher' where the origins of my reflective research are practice biased. Executing the research through reflective practice implicitly implied that any outcomes would have a relevance to a significant number of other practitioners and small design studios. The

[2] Schön, D, A. (1983) The Reflective Practitioner: How professionals think in action. London: Temple Smith.

importance of small design studios should not be underestimated. Despite their size, they serve as the 'hothouses of creativity[3] to industry.

The actual cognitive and perceptual processes involved in the act of generative drawing, as with other creative acts, are by their very nature not fully understood within one discipline and debate rages within and between disciplines. There is a body of research work emerging which is immensely helpful to an exploratory study such as this, if only for the purposes of contextualisation. This was purposely tackled in order to attempt to make sense of the tacit knowledge employed by designers and will be reviewed in the first chapter.

The area of architectural design has been a particular focus in several analytical protocol studies (Goldschmidt[4 5 6 7], Schön and Wiggins[8], Lawson[9] and Robbins[10] etc, see chapter 1[11]), perhaps indicating its maturity in relation to other design disciplines. Research with the goal of assisting in the development of computer based drawing and visualising tools is

[3] Anecdotally, most designers would agree that a small studio would consist of anything from one to several designers. In the UK, this represents a significant proportion of the design industry. In the 1990 Directory of Designers, published by the Design Council, there were 279 design consultancies listed offering industrial design services, of which 100 were employing between 1 and 5 employees. It is unlikely that the companies of 5 employees would all be designers.
1990 Directory of Designers London: Design Council Publications, 1990.

[4] Goldschmidt, G. (1991) 'The Dialectics of Sketching'. Creativity Research Journal, Vol 4, number 2. 1991 pp123-143.

[5] Goldschmidt, G (1992) 'Serial sketching: visual problem solving in designing'. Cybernetics and Systems: An International Journal. Vol 23. 1992. pp 191-219.

[6] Goldschmidt, G. (1994) 'On visual design thinking: the vis kids of architecture'. Design Studies, Vol 15 no 2. April 1994.

[7] Goldschmidt, G (1995) 'Visual displays for design : imagery, analogy and databases of visual images'. Published in Koutamanis, A, Timmermans, H, Vermeulen, I (eds), 'Visual databases in architecture: recent advances in design and decision-making' Averbury, Aldershot, pp 53-76.

[8] Schön, D A and Wiggins, G. (1992) 'Kinds of Seeing and Their Functions in Designing'. Design Studies 13 (number 2) pp135-156.

[9] Lawson, B. (1994) Design in Mind. Oxford: Architectural Press.

[10] Robbins, E. (1994) Why Architects Draw. Cambridge, MA: MIT Press.

[11] See also the paper by Purcell and Gero, which is an excellent detailed review of much of the experimental work in the field:-
Purcell, A.T. and Gero, J.S. (1998) 'Drawings and the design process'. Design Studies, 19 (number 4) pp 389-430.

wide and varied[12] [13] , and normally seeks to replace 'pencil and paper' approaches to drawing. There were very few examples of reflective practice research discovered in the literature searches.

Thesis Structure

> 'Drawing is the primal means of symbolic communication, which predates and embraces writing and functions as a tool of conceptualisation parallel with language. It is the artistic medium which is least interrupted by technical considerations and therefore the chosen means for the initial formulation of visual ideas and the transfer of appropriation of visual culture.'

This quote from Deanna Petherbridge's 'The Primacy of Drawing'[14] eloquently encompasses many issues with which this thesis will attempt to deal.

Since this is largely a reflective practice research project, the published literature of others in the field and my own framing and reframing of the situation and personal observations and decision-making are bound up together in one amorphous entity upon which to reflect and within which to work. For the purposes of a thesis it has been necessary to decant everything into some kind of order. Therefore, the first chapter appears to be the traditional Technical Rationalist thesis literature review, for want of a better model. However, I have attempted to indicate the relevance of the literature to the development of the practical work, where possible. This breaks any kind of narrative, but is essential to allow the reader to understand the relevance of the individual material. In the original thesis draft I also tried to establish a 'Focal Theory' chapter, but this was later abandoned because I felt that it was artificially elevating certain literature, whereas the process of reflective practice has been influenced by all of the literature to some extent.

[12] Gross, M D. (1996) 'The Electronic Cocktail Napkin - a computational environment for working with design diagrams'. Design Studies 17, pp53-69.

[13] Ishii, H & Kobashi, M. (1991) 'Clearboard: a seamless medium for shared drawing and conversation with eye contact'. CHI '91. Monterrey, CA, pp525-532.

[14] Petherbridge, D. (1991) The Primacy of Drawing: An Artist's View. (Exhibition Catalogue). London: The South Bank Centre.

In chapter 1, an attempt has been made to relate the practice of drawing in industrial design to the relevant practical and theoretical works and to use recent research to illuminate the reasons for the usefulness of drawing for conceptualisation. The cognitive aspects of generative drawing are juxtaposed with descriptions of some of the spectrum of relatively recent forays into drawing using technology. Chapter 1 ends with a summary of concepts and language for use in the 'practical reflective' work.

Chapter 2 presents a narrative description of the investigation into the potential for taking technology to the generative drawing through four inter-related areas of practical work: the focus of the research project. The narrative includes the blind alleys and non-sequiturs encountered. The research methodology is also explained and discussed as are the connections between adjacent phases of practical work.

Chapter 3 attempts the extraction of any original findings and conclusions for each of the phases of practical work. It will be particularly interesting to return to Petherbridge's quote at the end of the thesis to ascertain whether the addition of 'technical considerations' does indeed have an interrupting effect on the 'initial formulation of visual ideas' and also to establish any benefits.

Any work which takes drawing and perhaps even more so, generative drawing, as its subject is necessarily discursive since so many faculties and processes are brought to bear in what is essentially the application of tacit knowledge. It is hoped that this comes across as a positive and creative attribute.

Chapter 1

Drawn to the Surface

Background Theory, Research Precedent & Practical Stimulus

This research is focused around exploring the potential of taking technology to the generative drawing in the conceptual stages of the industrial design process. Consequently, the relationships between physical mark-making, reflection-in-action (Schön, 1983) and the mechanisms of cognition and perception employed in designing through drawing all underpin the exploratory work. Since the research was conducted primarily through reflective practice, which itself draws largely on tacit knowledge, for the purposes of the research the relevant literature was consciously introduced as it was discovered and this is laid out in this chapter. This literature should be considered as the context of the project and the search for language and concepts to describe it. It also provided a means by which to predict practical outcomes and also acted, often serendipitously, as a direct stimulus to the 'reflective practical' work.

In relation to generative drawing in general, there are rich and varied propositions from a number of other fields which are of relevance: most notably cognitive psychology and cognitive science[15] , perception, information technology, human communication, human-computer interaction (HCI) and architecture.

Generative drawing is used by many professionals across a diverse range of disciplines, for a

[15] Another field, Cognitive Technology (CT), is emerging. This is concerned with how technologically constructed tools '(a) bear on dynamic changes in human perception (b) affect natural human communication and (c) act to control human cognitive adaption'. CT takes the approach of focusing more on the human than on the interface compared with, say, HCI and promotes increased 'human socio-cognitive awareness' over just advancements in Information Technology.
Gorayska, B, Marsh, J and Mey, J. L. (1997) Proceedings of the 2nd International Conference on Cognitive Technology (CT'97). University of Aizu, Japan. 25-28 August 1997. URL: http://www.computer.org/

variety of tasks. The language of drawing in general is well explored and documented[16] [17] as is the symbolism used in drawing (see Goodman[18], Edwards[19] and Ashwin[20] writing in Margolin). The formal aspects of drawing which tend to be associated with the latter stages of any design process (detail, synthesis) are rooted in notational symbolism and professional convention.

However, the drawing strategies used in the conceptual stages of a design process are more open-ended, since there are no hard and fast rules in generative drawing; it is a 'cycle of reflective conversation' (see Schön and Wiggins (1992)) and that which works for one individual or project, may not work for another. This chapter will try to identify those aspects of drawing and industrial design process which, I would argue, make generative drawing the most widely used modelling[21] tool for the conceptual stages of an industrial design project.

Drawing and the professional practice of industrial design

The concept of industrial design as a distinct, professional activity is a relatively recent one[22], although the fields from which it draws the majority of its knowledge (eg engineering, architecture, craft etc.) are much more established (see Heskett 1980). Nevertheless, in its short history, it is well accepted that the use of drawing in many aspects of industrial design

[16] Dubery & Willats. (1983) Perspective & Other Drawing Systems. London: Herbert Press.

[17] Petherbridge (1991).

[18] Goodman, N. (1976) Languages of Art: An Approach to a Theory of Symbols. 2nd Edition. Indianapolis: Hackett.

[19] Edwards, Betty. (1979) Drawing on the Right Side of the Brain. Souvenir Press. 1979-87.

[20] Ashwin, C . (1989) 'Drawing, Design and Semiotics' in Margolin, Victor (Ed). Design Discourse: History, Theory, Criticism. University of Chicago Press. Chicago and London. 1989. pp199-209.

[21] This is a commonly used term for categorising tools which assist cognition in design, see Fish and Scrivener:- Fish, J., & Scrivener, S. (1990) 'Amplifying the mind's eye: Sketching and visual cognition'. Leonardo, 23, pp 117-126.

[22] This in itself may be a point of contention; it may or may not be beneficial to describe the creative activity of industrial design as a profession, see Schön (1983, pp21-30) for a general discussion, also Lawson (1997) and Heskett (1980):-
Lawson, B. (1997) How Designers Think - The Design Process Demystified. 3rd edition. Oxford: Architectural Press. 1997, pp20-28.
Heskett, J. (1980) Industrial design. London: Thames and Hudson, pp105-119.

practice is important[23] . But why is this use of drawing so important? And does it continue to be so, now that the commercial practice of industrial design relies so heavily on computers and other information technologies for its integration and communication with other activities, for example, engineering, manufacturing, marketing etc.?

Much of the practical evidence of the importance of drawing in industrial design is either anecdotal or based on the deconstruction of the design processes of designers as protocol or case studies. There are limitations to either source and these will be discussed later, in comparison with the reflective practice used in this project.

It is possible that a preliminary approach to answering these questions can be achieved by considering, in some detail, drawing attributes and strategies employed during designing and the cognitive processes which they access or assist.

Drawing attributes

Generative drawing is informal, private, pluralistic, reflective, symbolic, implicit, serialistic, ambiguous, immediate, indeterminate, flexible, economical, expressive and universally accessible, to list just some of its attributes. Obviously, something as multifaceted as drawing must be useful in the early stages of a design process for a number of reasons. One of the most elementary reasons for using drawing is for economy: economy of time and economy of materials and complexity. In many cases it would be extremely complex and time consuming, not to mention expensive, to manipulate the actual object which is the subject of the design process[24].

[23] Here, the focus is generative drawing and not drawing per se. It is acknowledged that drawing, for communication, became important, if not essential, once designing and making were separated. See Lawson (1997) and Robbins (1994).
[24] In any case this would be futile, since industrial design is, by definition, involved with design for volume production.

Therefore a system of symbols is manipulated as a representation (see Goodman, 1976). Whilst there are many useful forms of representation (verbal, written, diagrammatical, maquette, drawing etc.), here, the representational system of prime interest is that of the generative drawing[25] . The language and symbolism of drawing have been constructed over hundreds, if not thousands, of years to the extent that the knowledge they access and represent has become tacit. Indeed, this is true to such an extent that it is difficult to express ideas about drawing without using drawing itself, as pointed out by Ashwin (1989). This is a practical problem for those engaged with drawing research. Petherbridge's observation that drawing 'predates and embraces writing and functions as a tool of conceptualisation parallel with language' positions drawing clearly as a basic form of human communication. Ideas of representation and the description-depiction debate (see later) are important in understanding drawing as communication, whilst drawing for individual generative purposes may well involve a mental dialogue between the two types of representation[26] .

Goodman (1976) makes the important point that representation should not be confused with resemblance, or more specifically that representation should not necessarily involve resemblance. This is in accord with the more recent work of many others, for example, Suwa, Purcell and Gero (1998)[27].

Since drawing is communication requiring some level of shared understanding, conventions[28] are established. These conventions are established by individuals and by collectives: for example, in professions like architecture[29] or engineering. Within these professions, further

[25] Later in the design process, other symbol systems become more important, for example the three dimensional computer model is wholly appropriate once some design direction has been gained.

[26] See Cognitive Attributes section later in this chapter.

[27] Suwa, M, Purcell, T A & Gero, J S. (1998a) 'Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. Design Studies, 19 (number 4) pp 455-483.

[28] See Dubery and Willats (1983), and Edgerton (1975):-
Edgerton, S Y. Jr. (1975) The Renaissance Rediscovery of Linear Perspective. New York: Basic Books.

[29] See Robbins (1994) for an excellent discussion of the historical, social and political aspects of architectural drawing including the development of conventions, along with a number of case studies of architects' drawing practices presented as narratives.

drawing conventions may be developed to express schools of thought or approaches to the particular discipline. Certain conventions of viewpoint, picture plane, surface, movement, orientation etc are well established across disciplines, but within generative drawing are kept adequately ambiguous (this is not necessarily a conscious decision), to allow for reinterpretation. This ambiguity is achieved largely through strategic indeterminacy and facilitated by the materiality of drawing.

Goel (1995, p193)[30] suggests that the density and ambiguity of the symbol systems of freehand 'sketching' are what make it useful in the generative, conceptual phases of a design process. He does this by using a theoretical semantic argument in conjunction with evidence from explorations which compare 'paper and pencil' episodes of generative drawing in graphic design with computer based ones.

Goel defines density as the 'reduction in distance between symbols'[31] , implying that if a drawing is dense[32] then it will automatically lead to multiple interpretations and reinterpretations. He makes the connection between the density of generative drawing symbols or referents and the 'transformation of one idea into another', which he terms the lateral transformation of ideas.

In Ehrenzweig's (1968, p38)[33] writings on creativity, in connection with the decision making of the creative thinker, he posits that 'it is necessary to cloud one's consciousness in order to make the right decisions'. The ambiguity of generative mark-making appears to be viewed by many as a major asset for encouraging interpretation and reinterpretation of a drawing. Ambiguity can arise because of the indeterminacies within the drawing (themselves a product

[30] Goel, V. (1995) Sketches of Thought. Cambridge, MA: MIT Press.

[31] Goel (1995) also uses terms like 'fine-grainedness'.

[32] He also makes the point that density and ambiguity (see later) are both binary terms; ie either a symbol system exhibits the attribute or it does not.

[33] Ehrenzweig, A. (1968) The Hidden Order of Art. A study in the psychology of artistic imagination. Worcester & London: The Trinity Press.

of a drawing strategy) or because of the materials used. This purposeful 'clouding' of the 'consciousness' apparently occurs unintentionally or under the aegis of unambiguously externalising a thought or instinct. It is the nature of the medium which leads to the ambiguity.

In their internet discussion paper[34] , which, it appears, resulted in Suwa, Purcell and Gero (1998a), the authors talk about ambiguity and how it helps in the early part of the design process and how 'the ways designers use visual cues for accessing non-visual information are free and flexible without being bound by some fixed ways of interpretation' and also that 'by reinterpreting their own sketches, designers are able to move away from fixations of ideas from a single perspective only and thus explore a greater variety of functional issues or abstract concepts.'

The transformation of ideas

So, reinterpretation appears to be a key phenomenon in the generation of ideas and may be a result of a number of factors, including density and ambiguity, within the symbol system of generative drawing. During the early, generative stages of an industrial design project, such reinterpretations appear to become part of a dialogue which the designer has with his or her drawings and which result directly in the generation of design alternatives. It is for this multiplicity of ideas which industrial designers are employed, whether in-house or as consultants or freelances to industry. The generation of alternatives creates a divergent design process which can be assessed and later synthesized with client input and focused towards a final proposal. During the design process, ideas are transformed from one state to another and new ideas are generated. Goel (1995, p210) offers overall categories for these transformations, which can be used to relate adjacent (and non-adjacent) drawings in a

[34] Suwa, M, Purcell, T A & Gero, J S. (1998b) 'The role of design sketches: visual cues for accessing non-visual information'. Internet discussion paper, URL: http://hawk.aist-nara.ac.jp/CCC/sakigake/position-papers/suwa/suwa.html [August 1998]

design episode:-

> '... a lateral transformation modifies a drawing into another related, but distinctly different, drawing (as opposed to a more detailed version of the same drawing, a totally unrelated drawing, or an identical drawing). A vertical transformation reiterates and reinforces an existing drawing through explication and detailing. A duplication transformation results in movement from a drawing to a type-identical drawing.'

Within his experimental work, Goel uses these three terms to provide a framework and language with which to analyse the transformation of ideas within small drawing episodes. These, and his 'density' and 'ambiguity' terms, have been used extensively to describe the practical work within this research project, see chapter 2.

Goel also takes Goodman's semantic and syntactic terms and applies them to his transformation terms. Hence syntactic transformations 'relate the form of the marks that constitute drawings' and semantic transformations 'relate the associated contents or ideas'. These are all useful terms for the practitioner-researcher who may be at a loss to find succinct descriptions for identifiable drawing characteristics.

The diagram in illustration 2 is taken directly from Goel (1995) as a reasonably broad representation of a design process[35]. It shows clearly a suggestion for the relationship between the type of symbol systems employed during identifiable design phases of a design process. It also shows two overall cognitive processes at work. These are the lateral and vertical transformations of ideas, as discussed above.

The diagram shows that from receiving a design brief, in symbol terms, natural language is used most of all initially to produce a number of possible interpretations which make up the 'problem structuring' phase. It may be that language is chosen because it provides an

[35] The word 'process' is used specifically and should not be confused with 'procedure', as pointed out by Jones (1980):-
Jones, J C. (1980) Design Methods. John Wiley & Sons.

analytical representation of the problem. This phenomenon was observed practically in the exploratory phases of this project.

Once the problem is structured, perhaps in several different ways[36], there comes an often intense period of what could be described as divergent designing. In the diagram, this is labelled the 'preliminary design' phase and it is largely with this stage which this research is concerned. For this stage, lateral transformations of ideas (the generation of alternative ideas) are required, to facilitate divergence. Goel's (1995) analysis maintains that freehand drawing utilises a symbol system which is both ambiguous and dense and so readily allows lateral transformations to occur. This was supported in the 'reflective practical' work of the project.

In search of a surprise[37]

Schön and Wiggins (1992) suggest that the 'unexpected discovery' is a likely outcome of using generative drawing, since the externalisation of mental imagery as marks on a surface encourages 'reinterpretation' (as explained by Goel (1995) in terms of density and ambiguity).

The architect, Will Alsop takes a painterly approach to the early idea generation phase of his practice's projects. These paintings are used as private exploration and are essentially conversations through mark making. The canvases he uses are of an architectural scale which has an obvious appropriateness. The texture and the paint cannot be totally controlled such that Alsop is always 'in search of a surprise'; ie he is consciously setting the conditions for serendipity[38] . See illustration 3.

[36] Schön (1983) talks about 'framing' the problem and if the original framing doesn't help, then, 'reframing'.
[37] This title comes from the title of a talk given by the architect, Will Alsop as part of the 'First Thoughts: Preliminary sketches by Artists and designers' at the Victoria and Albert museum, London, on 26th January 1996.
[38] Ehrenzweig (1968, pp46-63) used the expression 'The Fertile Motif and the Happy Accident'.

Alsop says that the authority of the majority of architectural drawings mean less participation by the viewer - the concept of closure[39] . However, the fine artist encourages participation and private drawings are actively turned into public works (as expressions of the private explorations). In the more commercial situation of an industrial design studio, this distinction between private and public drawings is just as important, particularly in setting the conditions for serendipity.

At present, in most design studios, the transformation of the private idea into the public presentation very much involves the use of computers. Using a semiotic description, the computer is proven as a tool, and also medium[40], when it comes to resolving the early ambiguities and providing explicit notational representations of ideas. The question is; does it have anything to contribute in promoting early ambiguities?

Chance and reflective practice

One of the central concepts of reflective practice is that of repertoire, or what Schön called 'seeing as'[41] (Schön (1983, pp139-140)). Pasteur's observation that 'chance favours the prepared mind'[42] appears to be in support of reflective practice. Thus a reflective practice approach was considered a wholly appropriate one, where the serendipitous is sought both within the research and within any resulting generative drawing strategies.

Materiality and mark making

The actual action of drawing; making marks on a surface in a reflective 'conversation with materials' (see Schön and Wiggins (1992)) appears to be central to the importance of

[39] The 'law of closure' which results in the 'rounding off' of the image as suggested by Gestalt theory, see Ehrenzweig (1968, p39). This is subtly different from the concept of closure in relation to the generation of ideas.
[40] See the work of Marshall McLuhan (1964), Ranulph Glanville (1994).
[41] This should be compared to Goldschmidt's 'seeing-as', see later.
[42] 'le hasard favorse Iesprit prepare'. The 'prepared mind' relates to the acquisition of skills, knowledge and understanding in an area, not some innate cerebral structure.

generative drawing. Fish and Scrivener (1990), identify 'the vagaries of conventional media' as being the mechanism by which the serendipitous may be encouraged and the advantage which traditional media have over computer based drawing as a site for generative work.

Graves (1977, pp384-394)[43] has written about the idea that the medium within which drawing is made may affect the final artifact being designed.

> 'It has been said that the modern architect has made but one contribution to the techniques involved in the conceptualisation of the building: the use of transparent paper. This medium, capable of being overlaid with successive workings of basic themes, may be in part responsible for the conceptual transparencies expressed in some modern building.'

This idea of aspects of design process media or materiality fundamentally affecting the design process is also evident more recently. Informally, products which have been designed as a series of elevations on two dimensional CAD[44] systems are identifiable as such as are those which have been designed as 3D computer models - the complexity of some of the forms are near impossible to create by other means. So the medium or site in which the externalisation of conceptual design takes place appears to have an effect on the artifact: the difficulty, in research terms, lies in isolating the effects of any particular one when there is commonly reflection-in-action based on many different representational systems employed in any conceptual design process.

Drawing strategies

If drawing is to be truly generative, it appears that a cycle of reflection needs to be established with the drawing process, such that the subject (the draughtsman/woman), the object and the depiction or the act of drawing itself, work together to generate or inspire the

[43] Graves, M. (1977) 'The Necessity for Drawing: Tangible Speculation'. Architectural Design, 6 (77 1977) pp384-394.

[44] Computer Aided Design or Computer Aided Draughting; these terms are now interchangeable and represent a description of computer software used for the notational representation of an object, before manufacture. CAD systems have long since replaced the parallel motion drawing boards in most design and engineering drawing offices.

new. This therefore involves the application of a drawing strategy which may or may not be consciously selected.

The ill-structured or ill-defined nature of most design problems means that prescriptive approaches to the selection of drawing strategies are unlikely to be useful. Heuristic strategies, as outlined by Lawson (1997) in the broader context of design thinking, may be employed which draw on the designer's repertoire (see 'seeing-as', later). In this case, drawings of solutions[45] are made (or a synthesis of part solutions is made) in an attempt to rationalise the core design problems. This relates also to reflective practice as discussed by Schön (1983).

It can be useful to disrupt thought processes by consciously reflecting or acting on a drawing in a particular way[46] . In teaching drawing to children, teachers often emphasize the creative play elements of drawing and this connection between creativity and play is a valuable one in general. Rosenberg (1996b)[47] uses another analogy, that of the sentence structure, describing the student's relationship with their work in terms of 'subject-predicate-object' and telling them to 'interrogate' the drawing, particularly the subject part, that is the 'act of drawing; and the world represented'. To this end, Schön (1983, p141) talks about 'reframing' when reflecting on the design problem and constantly testing the problem 'setting'. It should be noted that apart from its relevance to design process, this is also, of course, the primary mechanism used practically in this research - ie the essence of reflective practice.

In generative drawing, the introduction of a non sequitur, which has no apparent connection

[45] Equally, drawings of problems can be made.

[46] See:-
McKim, R H. (1980) Experiences in Visual Thinking. California: Wadsworth Inc, 2nd Ed.

[47] Rosenberg, T. (1996b) Drawing Workshop: Interrogation and Reflection on Worlds of Objects. Royal College of Art. Internal Project Brief. 1996. See appendix 1.

with the subject of the drawing, is a disruptive drawing strategy which can lead to new and unexpected connections. In one of Rosenberg's (1996a)[48] drawing courses his instruction to students was to 'test the relevant with what appears to be irrelevant'. In connection with creativity, de Bono (1973, p106)[49] talks about his version of the non sequitur, 'random juxtaposition', as a strategy:-

> 'The second basic principle of creativity involves opening yourself up to influences which have no connection with what you are doing. New experiences create new ideas. Instead of waiting for the rare new experiences to happen we create them deliberately in our minds'

Within a more technological framework, Glanville (1994)[50] talks about context and 'surprising proximities' arising from intentional ways of using the storage and retrieval aspects of computers. He talks about the organisation of information and how, in any filing system within a computer, accidental connections can be made through unexpected neighbours. He concludes that these are general features of computer databases and HyperMedia[51] . Setting the conditions for, or actively searching for, the serendipitous is a theme which is important to this work and one which will be revisited.

Clearly, there is a very important relationship between the drawing strategies used and the transformations of ideas and/or mental images which they facilitate.

Managing complexity

Most industrial design conceptualisation problems are complex and ill-structured (see Goel

[48] Rosenberg, T. (1996a) Drawing and Modelling Workshop: Getting Real. . Royal College of Art. Internal Project Brief. 1996. See appendix 1.

[49] De Bono, E. (1973) Po: Beyond Yes & No. Pelican Books.

[50] Glanville, R. (1994) 'Variety in Design'.Systems Research. Vol. 11, No 3, pp. 95-103.

[51] One definition of hypermedia is 'a communications medium created by the convergence of computer and video technologies. The term was originally coined by Ted Nelson to describe hypertext systems that include multiple media - text, image, sound, animation and video.'
see URL: http://www.mediamanagement.org/netacademy/glossary.nsf/kw_id_all/291 [December 1999]

(1995), Schön (1983) and Archer (1996)[52]). Drawing strategies can facilitate the exploration of partial problems and solutions whilst suspending other parts. Simon (1969)[53] pointed out how the limited amount of information the brain can process means that designers are unable to assess all of the implications and potential opportunities produced by a single design decision in advance of making that decision. Schön and Wiggins (1992) refer to this as a 'limited ability to manage complexity'. This is where the representation becomes useful in crystallizing the idea or decision and allowing it to be evaluated. It is also where the serendipitous can act.

As with many of the other generative drawing attributes discussed here, the individual experience of the designer and his/her ability to access tacit knowledge, have an effect on the selection and success of drawing strategy in any situation.

Cognitive attributes: visual thought and perception

If generative drawing is a 'reflective conversation' (Schön and Wiggins, 1992) with the drawing, then perception, cognition[54] and visual imagery must be central to an understanding of the processes which are brought to bear during generative drawing. A good, if brief, overview of the relationship between seeing and knowing is provided by Berger (1972)[55] .

In the field of cognitive psychology, much has been posited about drawing and perception from the analysis of those with brain damage or impaired brain function (see Kosslyn,

[52] Archer, L B. (1996) 'The Science tradition of research'. Course in Research Methods. Royal College of Art. London. Archer defines the ill-structured problem with three statements; '(i) The problem cannot be resolved by transforming the given information alone; and/or (ii) there is no given way of testing the adequacy of any solution; and/or (iii) a procedure for resolving the problem is not known.'

[53] Simon, H. (1969) 'The Sciences of the Artificial'. MIT Press.

[54] In the Italian Renaissance, the generative drawings of artists were known as 'primi pensieri', that is, first thoughts, so the understanding of a connection between drawing and cognition is a long established one. See Petherbridge (1991, p12).

[55] Berger, J. (1972)
Ways of Seeing. London: BBC Books.

1994)[56]. The development of drawing skills in children is also well documented[57] and has produced useful insights into cognitive processes, memory and perception.

Fish and Scrivener's paper (1990)[58] represents more or less the start of a renaissance of interest in the examination of thinking through drawing. They entered into the description-depiction debate (see also Goodman (1976)) and emerged with the idea that, with regard to generative drawing and mental imagery, there is a 'continuum of visual representation' (Fish and Scrivener (1990)) embracing description and depiction. Elsewhere, this is widely held in one form or another[59,60] . Goldschmidt (1991) also talks of a dialogue between the two types of representation.

Subsequently, Fish's Ph.D thesis (1996)[61] is based around producing a model for the cognitive processes used when drawing and is a detailed and rigorous account. This is covered, briefly, below. Suwa, Purcell and Gero (1998) have also made an attempt at coding cognitive actions used in generative drawing, with the aim of assisting in the analysis of drawing protocol studies.

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[56] For a general discussion with particular emphasis on vision, see:-
Kosslyn, S M. (1994) Image & Brain: The resolution of the imagery debate. Cambridge, MA: MIT Press.
For a specific example of the effects of certain left and right hemisphere brain damage on drawing function, see:-
Carter, R (1998) Mapping the Mind. , London: Weidenfeld and Nicolson, p37.

[57] see Thistlewood (1992) for papers representing a good variety of research into this area:-
Thistlewood, D (ed). (1992) Drawing Research and Development. Longman in association with the National Society fro Education in Art and Design.
These include John Willats' 'What is the Matter with Mary Jane's Drawing?'. Elsewhere, Willats has done much in this area, see also:-
Willats, J (1984) 'Getting the drawing to look right as well as to be right : the interaction between production and perception as a mechanism of development' in Crozier WR & Chapman AJ (Eds). 'Cognitive Processes in the Perception of Art'. North-Holland. Amsterdam- New York- Oxford.

[58] Fish and Scrivener draw on the work of Negroponte, N (1977), 'On being creative with computer Aided Design'. Information Processing 77, pp695-704, which compares the attributes of computer systems at the time with the requirements of visual invention through drawing.

[59] This is in accord with the well respected work of Fodor:-
Fodor, J. A. (1975) The language of thought. New York: Thomas Y. Crowell.

[60] Larkin, J. & Simon, H. (1987)
'Why a diagram is (sometimes Worth Ten Thousand Words'. Cognitive Science Journal, Vol 11 (1987) pp65-99.

[61] Fish, J C. (1996) How Sketches Work: A Cognitive Theory for Improved System Design. Ph.D Thesis. Loughborough University.

The concept of different left and right brain cognitive function is long established and has modified by degrees in recent years, see Kosslyn (1994). See Edwards (1979) for an account in relation to observational drawing and Pinker (1998)[62] or Carter (1998) for a general discussion.

The third dimension

Since drawing for industrial design involves the representation of objects and relationships between objects, it is important to try to understand how the mind builds a three dimensional representation from a two dimensional drawing. Apart from an overview, it is beyond the scope of this text to do justice to this subject. For a comprehensive account of how the cognitive processes may work in perceiving form from an image see Marr (1982, pp99-267), particularly his chapter entitled 'From Images to Surfaces'.

The recognition of the third dimension in a drawing practically appears to come from depth cues such as foreshortening, convergence, occlusion, shape contours, changing scale or pattern, light and shadow etc. This is probably why perspective drawing is used quite extensively when dealing with overall concerns such as form or scale, since it can employ a number of these mechanisms which cue depth. Ultimately, depth cues serve to stimulate the mind's predilection for shape, form and pattern seeking and perception of the whole. Industrial designers are virtually unique in their ability to simultaneously visualise the front and rear of an object, a skill which develops out of the necessity to consider the whole when dealing with the implications of partial design solutions.

For an excellent discussion of the 'ambiguities of the third dimension' with particular

[62] Pinker, S. (1998) How the mind works. London: Penguin Books.

reference to art, see Gombrich (1977, p204)[63] .

The visual field

The visual field is, by Poincaré's[64] reasoning, two dimensionalsince it can be divided by a line[65] . Embellishing this concept somewhat, Marr (1982) has proposed a model for the visual field which he called the 2 1/2D sketch because, he argues, it can be reduced to an organisational array which responds to the two-dimensional information whilst labelling it with other information such as an indication of surface boundaries or slant plus an indication of depth. This separation of three dimensions into two dimensions plus depth is explained in terms of memory economy, since one move of the head requires a new set of information. The rods and cones within the eyes receive the two-dimensional information, whereas the depth information has to be extracted from the perception of depth cues such as occlusion and changes in light levels. This makes depth the logical choice for memory economy and hence may go some way to explaining the usefulness of the two dimensional drawing.

Pinker (1998) suggests that one essential element of the perception of vision is the provision of a mental reference frame. Pinker (1998, pp261-263) states that 'the key to using visual information is not to remold it but to *access* it properly, and that calls for a useful reference frame or coordinate system' (his emphasis). Pinker explains how the brain has to move the reference frame to compensate for any movements of the head or viewed object and this is why our perception of the world is a fairly stable cohesive one. This has implications for the provision of reference frames relative to drawings and the practical exploration of these will be encountered in chapter 2.

[63] Gombrich, E H. (1977) Art and Illusion: A Study in the Psychology of Pictorial Representation. 5th Edition. London: Phaidon.
[64] See Pinker (1998).
[65] which is one-dimensional and by Poincaré's mathematics the number of dimensions of an entity is determined by the number of dimensions of an object that can divide the entity plus one

The dialogue with the drawing

There was much agreement in the literature regarding the existence of a dialogue with the drawing during generative drawing work. This consensus provided an abstract framework to support the development of the practical ideas through reflective practice from an early stage and it also became something of which I became conscious in my own drawing practice.

Gabriela Goldschmidt (1991, 1992, 1994, 1995) has published a number of papers detailing her analytical approach to generative drawing studies within the field of architecture, basing her studies on the comparison of experienced and inexperienced practitioners. She places the generative drawing process into the context of cognitive psychology, which appears to provide an analytical framework within which to base experiments and perhaps more importantly, discuss results. Goldschmidt presents some very useful concepts and terms and an almost hierarchical structure of the design process, which deconstructs the reasoning during a conceptual phase of a design project into 'moves', within which are contained 'arguments' which themselves consist of a dialogue between what she calls 'seeing as'[66] and 'seeing that' modalities.

In her own words, 'Moves are the basic coherent operations detectable in designing, and arguments are the smallest sensible statements which go into the making of moves'. She makes the point that both of the terms, 'moves' and 'arguments', can be idiosyncratic because of their use elsewhere and so further clarification is given, 'a design move is defined as an act of reasoning which presents a coherent proposition pertaining to an entity that is being designed' and 'argument stands for a rational utterance made by a designer, and bears on the designed entity or on an aspect thereof'.

[66] Schön also talks about 'seeing as' and describes it in terms of repertoire; the designer develops a certain repertoire with experience on which he/she can draw (sic) and is to some extent linked with precedent. See Schön (1983, pp139-140).

Goldschmidt's idea of arguments are practically observed and analysed to be usually made up of an oscillation of 'seeing as' and 'seeing that' arguments which define the conceptual reasoning occurring during the act of generative drawing and result in the title of her 1991 paper, 'The Dialectics of Sketching'.[67]

Goldschmidt broadly describes 'seeing as' to be associated with the figural or gestalt processes of conceptualisation and perception and consequently the more pictorial aspect of the reasoning. This is in accord with what Schön and Wiggins (1992) have subsequently described as the 'apprehension of spatial gestalts'. Other researchers in the field describe this 'seeing as' phenomena as 'reinterpretation' . For example, Goel (1995)[68] relates levels of 'reinterpretation', observed experimentally, to the ambiguity of the symbol system used (see earlier). There is a general consensus that the encouragement of reinterpretation of an external representation during generative drawing is one of the attributes which makes it so useful for creative, divergent design thinking.

Purcell and Gero (1998) outline three types of reinterpretation that can happen when inspecting a depiction[69] ; reconstruals (change of meaning), reference frame reversals and figure/ground reversals, all of which were used in describing the practical work (see chapter

[67] The definition of the word 'dialectic' is dependent on ones philosophical predilection. One Socratic definition might be that 'dialectic is the process of eliciting the truth by means of questions aimed at opening out what is already implicitly known':-
Blackburn, S. (1996) Oxford Dictionary of Philosophy. Oxford: Oxford University Press, p104.
Whereas, one dictionary definition is 'the development through the stages of thesis, antithesis and synthesis in accordance with systems derived from Hegel's logic ':-
Longman New Universal Dictionary. England: Longman, p267.
This may offer further meaning to Goldschmidt's work.

[68] Ultimately and largely subconsciously, I chose to use mainly Goel's terms in the description of the 'reflective practical' work, but have included Goldschmidt's to maintain a wider context; some alternatives.

[69] See:-
Chambers, D and Reisberg, D (1985)
'Can mental images be ambiguous?' Journal of experimental psychology: Human perception and performance. Vol 11, pp317-328.
Chambers, D and Reisberg, D (1991)
'Neither pictures nor propositions. What can we learn from a mental image?' Canadian journal of psychology. Vol 45, pp288-302.

2).

Returning to Goldschmidt (1991): in contrast to her 'seeing as' modality, she suggest that the 'seeing that' modality tends to be routed in the propositional and therefore more descriptive aspect of the reasoning. Goldschmidt is essentially practically identifying a relationship between both elements in the long running description-depiction debate. That is to say that designers bring both types of representation into play in a constant dialogue. This fits well with the work of Fish and Scrivener (1990) who talk of a 'continuum of visual representation'.[70]

Subsequently, Fish (1996) acknowledges this correspondence, with the reservations that Goldschmidt's 'seeing as' element 'does not necessarily exclude mental descriptions of visual structure and it is not clear that mentally depictive reasoning is excluded from her 'conceptual' ' (the 'seeing that' element).

Although Goldschmidt indicates that the dialectic is between what she calls the 'seeing as' and 'seeing that' modalities[71] , Arnheim (1995), in a subsequent article, makes another interpretation. He feels that the dialogue 'does not take place between the drawing and the mental image but rather between the goal image and its realization, at both levels - the mental percept and the optical percept, the imagination and the sketch.' The goal image to which he refers should be considered as a conceptual notion; one which is used as a measure

[70] Fish and Scrivener explain that classes of objects or properties of objects are described with a descriptive system (eg language) 'which must have arbitrary, learned rules of interpretation linking the sign system to the represented objects'. These systems are often called 'propositional' as they can be represented as propositions, which are more basic than verbal statements (and can be either true or false) - their example is 'a cat is on the mat','on the mat there is a cat','un chat est sur la natte' and 'on(cat, mat)' - these are all the same proposition, expressed in different ways. The advantage of this type of representation is that it is possible to separate what is important from what is not. Descriptions are; amodal - (not specific to one single sense organ); extrinsic - information only exists by being interpreted through externally defined rules of interpretation. Conversely, depictions are commonly; modal - normally specific to one single sense organ, or mode of perception; intrinsic - meaning not that information is explicit, but rather that it can be extracted without reference to externally defined ruled of interpretation (eg direction, relative size). Depictions have the advantage that they can often be used to discover novel visual relationships which would not be easy to identify by descriptive means.

[71] In subsequent papers, Goldschmidt substitutes 'figural' for 'seeing as' and 'conceptual' for 'seeing that'.

of success in the design process, or more accurately as a comparator to assess coherence[72] . This influenced the 'reflective practical' work by being reinterpreted as a real image (see later).

Fish's Ph.D thesis (1996), mentioned briefly earlier, differentiates between the type of cognitive processes used in 'visual invention' from those used in 'visualising a nearly complete object'. Ultimately, Fish presents five hypothetical proposals for cognitive functions used in generative drawing and attempts to integrate them into a 'unified theory', with the overall aim of identifying the features which would be required in any emergent technological system of support for generative drawing[73] . The cognitive functions identified by Fish correspond well with those identified so far in this work. Using the terms used and works referenced within this project, along with some of Fish's which do not have equivalents in this work, his five functions can be summarised thus (in the order in which he presents them):-

1. That generative drawing facilitates a dialogue between descriptive and depictive reasoning or representational systems used in visual thinking. This relates well to Goldschmidt's (1991) 'dialectics of sketching'.
2. The attributes of generative drawing exploit processes of perception and perceptual recognition.
3. Generative drawings are 'percept-image hybrids'; that is, there is a dialogue or comparison between the physicality of the generative drawing and the mental 'goal' image. Emergence is said to be achieved once the mental image has become coherent. This is in accord with the analysis of the work of Goldschmidt (1991) by Arnheim (1995) and the commentary of Temple (1994) later in this chapter.

[72] See Goldschmidt (1991) and Arnheim (1995).

[73] These were discovered relatively late in the research. Otherwise, they may have provided good starting points for practical phases of work.

4. Drawing strategies facilitate the exploration of partial problems and solutions whilst suspending other parts. Fish attributes this to economy with working memory, in agreement with Purcell and Gero (1998).

5. Generative drawings act as support for 'short term episodic memory' as proposed by Simon (1969)

Bringing the image to the drawing

Arnheim (1995, p71) points out that 'because all abstract thinking relies on some perceptual referent, even the most abstract theme is tied from the beginning to concrete images. These images supply the designer with the primary nucleus from which the actual structure develops'. Arnheim (1995) further clarifies this by saying that the 'concrete image' may be a notion or partial requirement of the design.[74]

Arnheim is talking, of course, about mental images. But in the cycle of reflective practice another interpretation was made - could there be potential for technology to allow physical external images to be brought to the drawing, in various levels of concreteness? When the image starts to disintegrate it could be argued that it becomes more like a drawing, more abstract and more likely to deliver perceptual processes with symbols and ambiguity to the drawing site. So, this idea of the goal-image could be viewed as an opportunity to enrich the drawing site with images, as long as they are not invasive or strongly prescriptive, or if their quality approaches that of drawing itself in terms of density, ambiguity and potential symbolism. This was attempted practically within the research.

[74] This should not be confused with the experimental observations of Suwa, M, Purcell, T A & Gero, J S. (1998b). Their comparative study tested the effect of exposing students in several disciplines to images relating to one of their disciplines at the start of a design task. For example, when the starting image related to a mechanical engineering principle, they observed a 'fixation effect' produced in student mechanical engineers which was not observed in student industrial designers. They concluded that a process was operating involving discipline-specific visual cues generating and being used to access non-visual information. It could also be that different disciplines have different ways of reacting to any possible 'design fixation'. Indeed it could be argued that many industrial designers would go out of their way not to be influenced by an example image at the start of their creative process.

As Hockney (1999, p46) postulates, 'The period of chemical photography is over - the camera is returning to the hand (where it started) with the aid of the computer.' There is no doubt that the way of working with the external image is changing through its means of production and its physicality. This became central to phases 3 and 4 of the practical work.

The persistence of Gestalt psychology: figure/ground reversals

It could be argued that the capacity of the human brain to recognise and work with shapes as opposed to just geometry is precisely what makes the freehand drawing more useful than other constrained symbol systems, in generative design work. Arnheim (1984)[75] draws on the work of the Gestalt psychologists and their experimental sensory perception, whilst Marr (1982) makes reference to it as do Schön and Wiggins (1992).

Edgar Rubin (1886-1951) is credited with originally elucidating the figure-ground phenomenon in perception whereby the image of an object (most simply and obviously, in black and white) can be seen alternately to reverse. The classic example is that of the pair of faces which alternates with a vase or goblet (see illustration 4a). The phenomenon occurs whether the vase is black on a white background or vice versa. The mind tries to assign surfaces to the image and decide which surface is in front of the other: the fact that the image appears to alternate between vase and faces is evidence of this perception struggle occurring. Another example of note is the Kanisza[76] triangle, whereby the mind generates a white triangle in the foreground of three circles and another rotated triangle in the background (see illustration 4b). In this case there is no struggle of perception, but rather the generation of a shape which rationally it could be said is absent. Both of these phenomenon work equally with other shapes and are not considered to be unique curiosities.

[75] Arnheim, R. (1984) Art & Visual Perception. A psychology of the creative eye. London: University of California Press. Revised edition.
[76] See: Kanisza, G (1976) 'Subjective Contours'. Scientific American, 234,pp48-52.
also: Kanisza, G (1979) Organisation in vision. New York: Praeger.

They are both examples of the importance of depth and occlusion to human vision and perception and both examples of the revealing nature of graphic illusions.

As Arnheim (1984, pp227-253)[77] explains, we tend to see surfaces and boundaries, and any ambiguity forces decisions which affect the meaning of the perceived image. See also Pinker (1998, p257). So returning to the generative drawing process, figure and ground are probably routinely assigned when making or reflecting on drawings and there is a potential to play to these mechanisms of perception which allow for instant and quite dramatic changes of meaning within a drawing. These were explored in the practical work (see chapter 2). Experimental research by a number of researchers[78] has established a possible link between the perceptual processes which act during figure/ground 'reversals' and the mechanisms which drawing provide in terms of mental imagery and reinterpretation in the design process.

Drawing on Memory

The use of precedents or 'repertoire' (Schön (1983)) in generative drawing link cognition with long term memory, see Purcell and Gero (1998, p403). Simon (1969) proposed that generative drawings function as external aids to memory, by externalising a mental image at a particular instant. Kavakli, Scrivener and Ball (1998, pp485-517)[79] have practically explored drawing from memory - their paper outlines experiments involving the exposure of their participants to different objects (chairs) for a particular time. Once the objects were removed, the participants were taken to a drawing area, where they were asked to draw them from memory. The results were analysed and evidence of structuring in the generative drawings was

[77] For the original work, see:-
Rubin, Edgar (1921) Visuell wahrgenommene Figuren. Copenhagen.

[78] See, for example, the work of Brandimonte and Gerbino (1993):-
Brandimonte, M and Gerbino, W. (1993) 'Mental image reversal and verbal recoding: When ducks become rabbits'. Memory and Cognition. Vol 21, pp23-33.

[79] Kavakli, M, Scrivener, S.A.R. and Ball, L.J. (1998) 'Structure in idea sketching behaviour'. Design Studies, 19 (number 4) pp 485-517.

explained to largely relate to either 'volumetrical or functional cognitive models of the recalled or designed objects'. The 'volumetrical' cognitive models refer to the work of Biederman (1987)[80] who proposed a cognitive representation system of 'geons' or geometrical primitives (developed from some ideas from Marr) which could be combined in different ways to produce representations of three dimensional objects. This produces a model which, although cognitive, is perhaps analogous to solid computer modelling software.

The effects of naming objects (or their depictions) and longer term memory are well established, starting with the study by Carmichael, Hogan and Walter (1932)[81] . They established that, given a language description and a visual depiction to remember, participants in their experiments would remember the language description most readily and it would either stimulate them to remember the depiction, or even override it, in the case that the two original representations were at odds. Whilst this is an example of the relationship between memory and representations, it also sheds some light on the description-depiction debate, by indicating, that for longer term memory cognitive activities, description may aid memory retrieval over depiction. It also helped to make sense of observations in phase 1 of the practical work, see chapter 2.

Coherence/emergence in generative drawing

Temple (1994)[82] says that 'sketching facilitates a visual search, combining all of the available possibilities, until a plausible representation of the entity - or a meaningful aspect of it - is crystallised'. This concept of drawing (sic) towards a coherent or emergent outcome or

[80] Biederman, I (1987) 'Recognition-by-components: a theory of human image understanding'. Psychological Review. Vol 94, pp115-147.
[81] Carmichael, L, Hogan, H. P. and Walter, A. A. (1932) 'An experimental study of the effect of language on the reproduction of visually perceived form'. Journal of experimental psychology 15, 73 1932 in Vernon, M. D. (1962) The psychology of perception. Harmondsworth, Penguin.
[82] Temple, S. (1994) 'Thought made visible: the value of sketching'. Co-Design. Issue 1, 4th quarter 1994, pp16-25.

closure is dealt with by a number of other studies (Goldschmidt (1991), Arnheim (1995)[83] and Schön(1983)) and knowing when sufficient coherence has been achieved is a crucial skill for the practitioner as well as the practitioner-researcher (see later).

Drawing into technology

It is not the intention of this work to start from the position of reviewing the current state of the art with respect to drawing with computers. This can be found elsewhere, particularly in journals and magazines. For an up to date review of computer input devices such as drawing tablets and pen-based computing, there is an excellent website[84] which covers most of the commercially available products.

> 'The real question then is not the (moral or political) question of the use of the technological instrumentum, but the question of the essence of technology, that is, the recognition of the new qualities of our entirely artificial world where nature has become an available "fund" and technology is no longer the result of human effort, but the horizon within which human effort exists.'[85]

When considering drawing and technology, it is easy to forget that paper and pencils[86] are themselves technology. In Europe, paper became readily available towards the end of the 15th century and the first mass-produced pencils came from Nuremburg in 1662[87] . Therefore, the current palette of tools used for generative drawing has been around for some time.

For some time also, artists have sought to exploit technology in producing drawings and paintings. Drawing 'machines'[88] were developed by Dürerand others. The development of Camera Lucida, Camera Obscura, and more recently, Harold Cohen's AARON[89] computer

[83] Arnheim, R. (1995) 'Sketching and the Psychology of Design' in Margolin, V & Buchanan, R (eds). The Idea of Design. London: MIT Press, pp 70-74.

[84] Buxton, Bill (1998) A directory of sources for input technologies. URL: http://www.dgp.toronto.edu/people/BillBuxton/InputSources.html [August 1998]

[85] Barbacetto, G (ed). (1987) Design Interface. Arcadia, p99.

[86] and their predecessors, vellum and charcoal, papyrus and stylus etc.

[87] See Internet web site: URL: http://www.pencilsici@aol.com

[88] See Dubery & Willats (1983, pp68-79).

[89] See Fish and Scrivener (1990).

composition and drawing program (see Fish and Scrivener (1990)) are all relevant examples, well described elsewhere.

With regard to technology and perception, it is still possible to find relevance in the work of McLuhan (1964)[90] :-

> 'The effects of technology do not occur at the level of opinions or concepts, but alter sense ratios or patterns of perception steadily and without any resistance. The serious artist is the only person able to encounter technology with impunity, just because he is an expert aware of the changes in sense perception.'

The application of technology to culture and the culture of technology[91] itself are both areas of continued and heated philosophical debate. Talbott[92] , who builds on the work of McLuhan and Postman, says, in connection with technological artifacts, that 'the artifact is decisively an expression of human consciousness' and this has a certain resonance to anyone who has tried to reflectively explore their practice, via 'artifacts', ie technology. The question concerning whether the computer is a medium or tool is one which runs parallel to this work, but not one to which a definitive answer is actively sought.

Rudolf Arnheim observes that 'Computers combine the concreteness of drawings with a lightfootedness letting them run through any number of variations, but computers can also be accused of a seductive irresponsibility, that allows them to ignore the tangible conditions of materials as well as perceptual experience' (Arnheim, 1995, p71). This reflects a healthy scepticism shared by many design practitioners. The 'tangible conditions of materials' are particularly pertinent to the industrial designer, who ultimately operates directly with the material execution of ideas. This also supports the idea of maintaining the materiality of

[90] McLuhan, M. (1964) Understanding Media: The Extensions of Man. Routledge & K. Paul, p18.

[91] Postman, N. (1993) Technopoly - The Surrender of Culture to Technology. New York: Vintage Books.

[92] Talbott, S. Media Ecology: Taking Account of the Knower. URL: http://pfaff.newton.cam.ac.uk/mirrors/netfuture/www.oreilly.com/people/staff/stevet/papers/knower.html [April 1998]

drawing implicit in the practical approach of this research project.

Computer Supported Cooperative Working

The computer supported cooperative working (CSCW) of interest in relation to this research involves the communication of collaborating individuals in different locations, working together through drawing and natural language. As Hunt (1998) points out, within the field of CSCW, 'there is a focus on supporting person-to-person activities, a shift from the man-machine approach in other computer-related disciplines.' This must be seen as an important shift which refocuses attention on human communication whilst exploring the issues of the computer as a medium for this communication.

Garner et al (1991)[93] , Ishii and Kobashi (1991)[94] and others have done much exploratory work in the area of CSCW. Garner et al's work is particularly relevant since it is based around the analysis of product designers working cooperatively, but remotely through drawings made within networked computers. Verbal and non-verbal communication was analysed during hour long design episodes and a number of observations were made in relation to the requirements of CSCW systems. Access to various types of drawing space and a large number of drawings at any one time were considered essential to encourage successful cooperative working. These included shared and individual drawing spaces.

Garner et al talk about 'shared prototype solutions (SPS)' which are the models (drawn, verbal etc) which are developed as part of team work on a creative activity. Regular occurrences of SPS were noted as part of the analysis work. Working towards a concluding or emerging SPS

[93] Garner, S W et al. (1991) The Use of Design Activity for Research into Computer Supported Co-operative Working (CSCW). URL: http://info.lut.ac.uk/departments/cd/Docs_DandT/staff/Garner/SWG.html[1st February 1996]

[94] See the work of Ishii and Kobashi (1991), which tests a technologically mediated site for shared drawing in the form of a transparent drawing surface, 'clearboard', either side of which participants can draw and be able to see one another in order to improve communication.

was taken as an indication of 'goal-directed behaviour', itself an indication of successful cooperative working. This ties in well with the idea of coherence or emergence outlined earlier.

In a separate paper, Glanville (1994) makes a fundamental observation relating to any cooperative working:-

> 'if I use material originated by you and somehow transform it, making changes available to you, what I do with your material will (probably) surprise you, going outside your expectations....Thus, the lack of ownership can lead to an increase in creativity through shared work.'

Whilst this is concerned with linking creativity and cooperative working, it is also concerned with serendipity. Glanville summarised one particular case of setting the conditions for serendipity (ie a proactive strategy) by the intervention of others and the 'abuse of computer software'. This process is serendipitous, he determined, because 'if the unexpected is not always the new, the new is always unanticipated'. This issue of searching for the serendipitous is important to the practical explorations within this project.

A further, more recent and informal example of Computer Supported Cooperative working is embodied in several simple bit map and vector drawing programs generally referred to as 'whiteboards' and posted on the Internet[95] . These programs are used on the host's website to draw remotely and cooperatively with others who have the equivalent program installed on their computer. They take their name from the commercial contemporary development of the blackboard, which uses erasable multi-coloured felt-tipped pens.

Hunts paper (1998)[96] outlines work by Whittaker et al which analyses the use of the whiteboard for remote CSCW and eventually concludes that a speech channel for the natural

[95] See, for example, http://www.groupboard.com for one of the most well known links.

[96] Hunt, W T. (1998) Shared Understanding: Implications for Computer Supported Cooperative Work. URL: http://www.dgp.utoronto.ca/people/WilliamHunt/qualifier.html [6th October 1998]

language communication is far more useful than a text channel and that the provision of public and private whiteboard work spaces results in much of the shared understanding being constructed in the individual's own private work space as opposed to the public, shared space. This ties in well with the 'practical reflective' work of phase 1 and phase 2, in chapter 2.

Smartboard is a commercially available, technology based version of the blackboard (or more recent whiteboard) which uses a very large back-projected screen as a computer screen. This screen has a digitiser behind it which senses the position and switching state of a number of different coloured pens which can be used to point, write and draw 'on' the screen. The product is fairly expensive and consequently used only by large corporate users, who tend to use it as a boardroom presentation tool - as an alternative to a multi-media projector to make computer based presentations. However, I briefly experimented with a Smartboard around the time of the phase 3 practical work and this experience contributed to the reflection-in-practice.

Computational recognition of drawings

Generative drawing as an ill-structured problem solving activity is at odds with the computational theory of mind, according to Goel (1995). He suggests that this may be where the cognitive science community have been going wrong with their quest for machine 'intelligence' in relation to design. It is not the aim of this exploratory, reflective research to step into this artificial intelligence arena. The firm belief that generative drawing accesses and enables cognitive processes which develop creativity within the design process, means that the project is focused around the designer's skills rather than the machine's 'skills'.

However, the quest for a computer mediated replacement for paper and pencil still appears to be actively pursued. The 'electronic cocktail napkin', Gross (1996), lays some ground work for

the recognition of drawings by computer, with the aim of attempting to key databases of architectural images from drawings. It is described as a 'computational drawing environment' and whilst the organisation of the interface is very interesting for future systems, it appears to be prescriptive in terms of the drawing symbolism it requires from the designer. This is an area which I encountered several times on searching for literature during the project, but not one which I felt able or compelled to engage with on a practical level.

Relationship between the literature and reflective practice

This chapter has attempted to relate the practice of drawing in industrial design to a broad selection of the relevant practical and theoretical works and to use recent research to illuminate the reasons for the usefulness of drawing for conceptualisation. Some cognitive and practical aspects of generative drawing have been juxtaposed with descriptions of some of the spectrum of relatively recent forays into drawing using technology. Hopefully, this has served to contextualize the whole research area and provide language and concepts which can be used to describe the practical work.

The nature of this project as reflective practice meant that the discovery of the published research in and around the field was an ongoing process. The discovered material was found to be useful for three, often connected or overlapping, purposes:

Firstly, certain concepts discovered significantly influenced the practical moves made as the project progressed and therefore acted as an external input to the reflective practice process. This is best summarised diagrammatically through both illustrations 1 and 1a, which show abstractions of the relationship between all of the elements within the research. This process will hopefully become apparent, in more detail, in the practical narrative of chapter 2.

Secondly, the literature search discovered variance in the terminology often describing the same or similar concepts. This was seen as crucial: an important practical obstacle encountered in this research was the lack of language to describe ideas about drawing, without using drawing itself; that is, the problem of describing tacit knowledge. See Ashwin (1989) for further comment on this phenomenon. This led to a pragmatic solution in that language could be borrowed from certain works in the literature. Goel (1995) was particularly useful in this regard, as was Schön (1983) for the general methodological language of reflective practice.

Thirdly, certain literature connected concepts or completed a view of a particular aspect of the field and was therefore instrumental in contextualizing the research as a whole. This type of information may also have had an indirect or subconscious influence on the reflective practice.

An attempt has been made to connect these first two classes of material to the relevant practical phases of project work. The third class of material obviously contains the other two and accounts for the rest of the literature outlined in this chapter.

1. Direct Stimulus For Reflective Practical Phases

This is the literature which served to provide or identify certain concepts which went on to stimulate the reflective practice; as starting points as opposed to as means to analysing observations. A summary of the most notable of these concepts is (in no particular order):

> (1) Figure and ground reversals/ basic recognition/Gestalt Theory. Marr (1982), Arnheim (1984), Purcell and Gero (1998), Schön and Wiggins (1992). Stimulated phase 4 'pen as activator' work in an attempt to purposely encourage reinterpretations. In the literature (particularly Goel, 1995) this has been seen as an indicator that a tool or process can assist in the lateral transformations of ideas.

(2) Chance and reflective practice. Schön (1983), Schön and Wiggins (1992). Influenced all phases of exploratory work - reflective practice set the conditions 'in search of a surprise' (Alsop).

(3) Materiality and mark-making. Graves (1977), Fish and Scrivener (1990), Petherbridge (1991). The materiality of traditional drawing techniques was identified in several sources in the literature as one particular feature which may encourage ambiguity and serendipity. This issue stimulated the initial reflective approaches and became central to the idea of 'taking the technology to the drawing'.

(4) Dialogue between mental images and the drawing. Goldschmidt (1991), Arnheim (1995), Fish (1996). Led to the question: what if one brings an image to the actual drawing? which stimulated phases 3 and 4 of the practical work.

(5) Reinterpretation (Goel) or 'reframing' (Schön, 1983). The idea of encouraging reinterpretation stimulated the development of the phase 4 CCTV camera objects.

(6) Non sequitur. de Bono (1973) talks about his version of the non sequitur, 'random juxtaposition'. Glanville (1994) talks about context and 'surprising proximities'. This concept stimulated the provision of cameras, particularly and ultimately in phase 4, in order to bring random, as well as intentional, images to the drawing site.

(7) Changing nature/role of photography. Hockney (1999, p46), 'The period of chemical photography is over - the camera is returning to the hand (where it started) with the aid of the computer.' This became influential to phases 3 and 4 of the practical work.

(8) Drawing 'machines' particularly Camera Lucida & Camera Obscura. Dubery & Willats (1983). Stimulated the development of the back projection drawing table in Phase 3, which itself led to the CCTV cameras in phase 4.

(9) Computer Supported Cooperative Working. The description of precedent helped in formulating shared drawing spaces from phase 2 onwards largely as a methodological measure. Garner et al (1991) , Ishii and Kobashi (1991), Glanville (1994), Hunt (1998)

2. Concepts and Terms Used to Describe the Reflective Practical Phases

These form the basis of the language and ideas with which I have attempted to describe and assess the practical phases of the research in chapter 2. The overall objective was, through reflective practice, to generate ideas for technological intervention with the generative drawing process and/or work space and to attempt to assess, through practical exploration,

the effects of such intervention on the generation of ideas within a design process. A summary of the concepts and terms which were useful for describing phenomena observed in the reflective practicals is (in no particular order):

(1) Density and ambiguity. Ehrenzweig (1968), Goel (1995). Terms used in an attempt to assess the use of the symbolic review objects in phase 2; also used to explain the use of the shared drawing spaces in phase 3.

(2) Lateral and vertical transformations of ideas. Goel (1995). Terms used as evidence of divergent thinking and convergent thinking respectively; used extensively in the practical phases.

(3) Reinterpretation. Goel (1995). Term used for describing observations in relation to density and ambiguity terms.

(4) Managing complexity - evidence of partial problems/ solutions observed in all phases of practical work; that managing the complexity of even the simplest design task can benefit from the partition of mental attention to focus on partial problems or solutions. Linked to the limitations of memory as pointed out by Simon (1969), Fish (1996), Purcell and Gero (1998).

(5) 'Seeing as'. Goldschmidt (1991) and Schön (1983) both describe the phenomenon of 'seeing as', perhaps most easily understood in terms of ideas of repertoire and linked to long term memory. Phrase used in evaluating phase 1 sound devices.

(6) 'Reframing'. Schön (1983). Term mainly used in relation to reflective practice, to make a distinction with reinterpretation (Goel, 1995) used in relation to drawings.

(7) The effects of naming objects (or their depictions) and longer term memory. Carmichael, Hogan and Walter (1932). These were brought to bear briefly and generally in the analysis of the phase 1 drawings.

(8) Goel's (1995) description of design process was reinforced by practical observations, particularly problem structuring element and the link with natural language . Phases 1 and 4.

(9) The term node from Ehrenzweig (1968) in this context was intended to refer to a turning point within the design process; ie a point at which an apparently important idea is generated. This term was used to describe one of the symbolic review objects in phase 2.

(10) Mental/perceptual reference frame. Pinker (1998), in relation to perception of vision and 'reference frame reversals', Purcell and Gero (1998). Both helped to describe phase 3 explorations where the appropriation of frames of reference of the back projected image was observed.

(11) Computer Supported Cooperative Working. The description of collaborative working was helpful from a methodological point of view from phase 2 onwards. Particularly Garner et al (1991). Also Ishii and Kobashi (1991), Glanville (1994), Hunt (1998).

Whilst these two preceding lists have been produced to guide the reader through the practical work and relate it to the relevant literature, they should not be viewed in isolation: all of the areas outlined in this chapter have had some direct and practical manifestation in the practical work. This should become clear in chapter 2 wherein further connections are made throughout the narrative.

Summary of Research Approach

The overall approach to the practical work was based, very early on, around assessing the potential of taking the technology to the drawing[97] , in contrast to the drawing being conducted within the technology. The aim was to purposely seek a hybridized approach, juxtaposing and combining the identified attributes and techniques of generative drawing with some practical technological ones, in a cycle of reflection-in-practice. Also important was the idea that the technology became a 'handmaiden[98] to the generative drawing process, ie turning concepts of master and servant, or agent and instrument (see Jennings (1991)[99]), on their head and attempting to directly address the motivating contradiction as outlined in the introduction to this thesis.

[97] As a reaction to the motivating contradiction described at the start of this thesis.

[98] This term was suggested by the project supervisor, Prue Bramwell-Davis, during a discussion about suitable titles. The term 'handmaiden' is chosen purposely, to conjure an unexpected and feminine side to technology. For those who may take offence, it could equally have been 'footman' or the like, but the connotations of drawing by hand, as well as the unexpected gender description, would then have been lost.

[99] Jennings, D. (1991) Subjectivity and Intersubjectivity in Human-Computer Interaction. Communication and Information Research Group. PAVICS Publications.

To this end practical phases of reflective practice were established and these were stimulated and illuminated by the literature outlined in this chapter. As previously mentioned, the whole process was necessarily discursive. Furthermore, the process has been decidedly non-linear and new information has been sought as a result of reflection on particular research moves, experiences or other literature.

Chapter 2

Drawing As Data

Practical manifestations in taking the technology to the drawing

This chapter describes the practical work carried out during the project. The chapter starts with a brief discussion about research methodologies, focusing on reflective practice, the main mechanism by which the research was conducted. The 'borrowing' of other small elements from Social Science methodologies is also identified. The majority of the chapter is taken up with the narrative description of the 'reflective practical' work. An attempt is made to clearly identify the connections between adjacent phases of practical work and also to offer an explanation of how the literature discovered was influential[100] within the overall process of reflective practice.

Reflective Practice

The primary research methodology which was used in this project was reflective practice as described in the introduction to this thesis. Regular reframing of the research occurred stimulated by my own on-going research action, my own design practice, a search for new literature, the evaluation of new equipment or practices and the contributions of other practitioners. This constant reflection and reframing led to the generation and exploration of previously unexpected areas of practical interest. Once again, see illustration 1 for an overall representation of the project and illustration 1a for a representation of the intricacies of taking the practical work forward through reflection-in-practice.

Within the overall reflective practice approach to the project, pragmatic approaches to pursuing the practical exploratory work have been focused around the notion of taking the technology to the drawing. This has itself been viewed as speculative and opportunist rather

[100] This was also covered briefly at the end of chapter 1.

than as a dogmatic philosophy.

I argued earlier that one of the problems with research through reflective practice is that of identifying satisfactory closure. This is analogous to closure in an industrial design project (itself reflective practice, of course), which tends to be a function of the skill and experience of the designer. I would acknowledge that the analogous skill and experience within the research project had to develop in parallel with the research itself and was, in fact, a personal objective of the research project.

Practical sub-methodologies

As outlined in chapter 1, there is much precedence in the published work of researchers in the field of generative drawing in the relatively recent past, but very few appear to utilise the methodology of reflective practice. They tend to operate within a Social Science tradition, using case studies as a basis for illuminating the subject matter. Within these, the use of protocol analysis is common, whereby drawing episodes are deconstructed and analysed after the event. This is often with the benefit of either audio-taped or video-taped interviews, review discussions (see Kavakli, Scrivener and Ball (1998), for example) or even running commentaries mediated by the researcher (see Goldschmidt (1991), for example). Indeed, much of the analysis in this field involves an attempt at the coding of cognitive actions. For example, the paper by McGown, Green and Rodgers (1998)[101] is a good example of the application of some of the idea transformation theory illuminated by Goel (1995) and also the application of the 'participant-as-observer' social sciences model of research[102].

Practically, these works lent some of their language and descriptive elements, as well as some common practical concerns, to the research project, but without Social Science's rigorous

[101] McGown, A, Green, G and Rodgers, P. (1998) 'Visible ideas: Information Patterns of Conceptual Sketch Activity'. Design Studies 19 (number 4) pp 431-453.
[102] Robson, C. (1993) Real World Research. Oxford: Blackwell.

approach to analysis. This was felt to be at odds with the inherently subjective approach of reflective practice.

There was one particularly relevant reservation[103] with the experimental methodology used by many of the Social Science protocol studies in the field and that was the problem of affecting the design and/or drawing process by instructing the subjects to verbalise their design reasoning as they proceed. This is a difficult area within which to propose any helpful improvements and it is one which is common to most researchers in this field: viz how does one find out about a cognitive process as it is happening, without affecting it? Some possibilities have been investigated within this research (with varying degrees of success) and these are outlined below:

1. Video surveillance of shared designing/drawing activity to actively produce a dialogue and commentary. Whilst the interest in shared drawing spaces eventually became purely methodological, it originally began as a focus for potential research action. This was found to be an effective way to encourage the primary researcher to externalise design/drawing thinking, perhaps overcoming any articulation and post-rationalisation problems (see below). Practically, this was perhaps the most successful of the three approaches.

2. Unstructured (informal) interview of participant with reference to the drawing as artifact. Useful for externalising design/drawing thinking of those other than the primary researcher.

3. Video surveillance of designing/drawing activity combined with video taped review

[103] Fish (1996) makes the same reservation and refers to the following work which deals directly with this issue:- Evans, J. B. T. (1980) 'Thinking: experiential and information processing approach', in Claxton, G (ed) Cognitive psychology: new directions. Routledge & Kegan Paul.

of drawing artifact and structured interview of participant.

Reflective practice itself does also help to address this methodological problem, but probably also introduces its own intrinsic problems: namely, the problems of articulation and potentially, post rationalisation. These were considered to be part of the territory of using reflective practice in research.

As previously mentioned, the nature of this project as reflective practice meant that the discovery of the published research in and around the field was an ongoing process. This process of discovery significantly influenced the practical moves made as the project progressed and therefore acted as an external input to the reflective practice process. Above all else, the literature discovered has lent a language, structure and context to the 'reflective practical' work. All of the areas outlined in the first chapter have some direct and practical manifestation in the practical work.

Exploratory 'vehicles'

The essence of the original research proposal was that the work must be relevant to and informed by professional practice. The practical work was based on three types of design project as vehicles for the research:-

(1) Professional, commissioned work. To use reflective practice research on real practice commissioned work obviously lends a credibility to any resulting observations. This can be done if the client is not party to the early generative work (see illustration 5 for a diagram showing extremes of professional interaction). But this obviously requires the consent of the client; the obvious limitation with this type of project being one of confidentiality. Certain projects which were considered ideal as subjects within this research could not be disclosed to a third party. However, some

of the drawings used in this thesis are from client work, but the details of the clients and the actual nature of the projects are purposely omitted to preserve confidentiality.

(2) Speculative, generative work. These projects were generated in the design studio and developed prior to any significant interaction with a client, backer or manufacturer. These projects lent themselves well to the more exploratory and conceptual type of research endeavours. The only drawback may be the lack of interaction with other professionals outside of the design team in this case.

(3) Specified design exercises. These were small self contained projects which had a short given time scale and entailed the observation and interview of the participants. The single most significant reservation in this case was that the tasks were not actually real design tasks.

The Actual 'Reflective Practical' Project Phases

Whilst there were many areas of practical interest[104] during the course of the project, ultimately the processes of reflective practice resulted in four main inter-related phases of work, broadly summarised in an approximately chronological[105] order as follows:-

Phase 1: The 'Grafting' of Sound onto Drawings

Phase 2: The Observation and Cataloguing of Continuous Roll Drawings

Phase 3: The Back Projection Drawing Table

Phase 4: The LCD Drawing Interface Table, With CCTV Image Capture

From a methodological point of view it is important to note the mechanisms of reflective

[104] See illustration 6, which shows four collections of stimulus material very early on in the project. It should be noted that these areas are different from the subsequent 4 practical phases described in this thesis (although there is plenty of cross-over). This illustrates the result of reflective practice in generating a body of practical work.
[105] there was some cross-over as subsequent reflection/reframing often led to revisits to earlier phases

practice which occurred and an attempt has been made to indicate the links between phases as the narrative unfolds. Illustration 1a describes a typical reflective link between adjacent practical phases of work, also indicating the role played by the discovery of new literature.

The following four part narrative should be read in association with the appendices, illustrations and accompanying CD-ROM. The CD-ROM contains brief edited video footage from each of the four phases of work, to give an insight into the types of drawing exploration and equipment used.

Phase 1. The 'Grafting' of Sound onto Drawings

The storage of sound 'within' a drawing

This exploratory avenue originally came from an area of earlier project focus, that of process cataloguing and selective disclosure[106], indicating its link also to phase 2. Later it became linked to ideas of reflection on the drawing and a cognitive shift from the visual to the verbal as and when they were discovered in the literature.

From anecdotal evidence, it appears that designers who are not precious about their sketch books will positively encourage aging and signs of history to enter their drawings. One example is coffee cup stains - they have a quality which somehow enhances and enlivens the drawing, perhaps also triggering memory of the circumstances of its making. Another example is the rubber stamp which, in an instant, enriches the paper surface with information and a sense of time or action in time - the imperfect quality of the inking is essential to this (and it is ironic that such an imperfection can be cause for celebration in itself).

These observations led me to question whether sound could, in some way, be appended to the surface of the traditional sketch sheet or book. If so, then presumably technology would allow non-invasive, integrated, recording and playback of sound from the drawing. This was considered of practical interest for two reasons:-

(i) To allow the incorporation of audio notes, made by the designer, as an aide memoire[107] when returning to the drawing at a later date and possibly for presentation to a second or third party. The premise at the time was that speaking the notes may have less of an interrupting effect on the drawing and creative process than writing.

[106] See illustration 6.

[107] Purcell and Gero (1998, p419) talk about the possibility that, in the context of cognition, verbal activity whether spoken or written, may act to 'free working memory' to allow concentration to be focused on moving from the mental, conceptual to the externalised, physical in the design/drawing process.

Subsequently, literature research into the cognitive science aspects of generative drawing raised questions about whether this process was indeed more invasive to the act of drawing than writing, since it may represent a shift in thinking from right to left brain[108] or depictive to descriptive reasoning. However, this is not conclusive since, as outlined in chapter 1, there is some consensus amongst researchers in the field, that generative drawing engages a dialogue between the two types of representation. Therefore, tools which encourage a cognitive shift must be of at least academic interest.

(ii) To allow the incorporation of audio sounds as cues for the context and even function of an object eg. using a series of sounds as stimuli to generative drawing.

Mock up[109] functioning objects were constructed to explore their relevance and limitations in the process of generative drawing.

Practical Usage:-

The concept was developed from the idea of sampling something on the drawing surface and containing it (see illustration 7). Clearly, there is a spatial relationship between the drawing surface and anything which resides upon it, as well as a temporal one within the process of placing anything on the surface. In addition, I hoped that it may reveal some of the types of non sequiturs that occurred during the drawing/thinking process, as outlined in earlier chapters.

[108] See chapter 1 for a brief discussion about the continuing research into so-called left and right brain function.

[109] Whilst the exploratory objects were extremely ad hoc in their design and construction, a more finished object was proposed and is discussed briefly here as an aside (see illustration 8 and appendix 7). The object contains power, microphone and speaker with connections at either end and has two distinct ends and is oriented depending upon whether recording or playback is required. Semantics of the object are supposed to suggest a horn facing upwards for playback and also a compression/expansion through the 'hourglass' shape. This configuration allows privacy in the recovery of the sound associated with a particular drawing, through the possibility that the record/playback unit is unique to a set of chips or flash cards.

See illustration 9. The mock up objects were made from modified 'memo pens' and were fairly crude. The sound storage system was separated into two components - a marker which was attached to the drawing surface during drawing as required and a record/playback unit which was attached to the marker, thereby utilising the spatial and temporal relationships mentioned above. A total of six units were constructed. If there was a requirement to use more than six devices in an episode of drawing then reuse of previously used devices was considered acceptable, providing that the stored sound contents were first recorded either onto video tape or by written means.

Illustration 10 shows the drawing and 'notes' of sound resulting from one short episode of designing[110] as presented in the CD-ROM video footage. The 'notes' of sound which were originally recorded into the discrete sound devices were subsequently transcribed onto the drawing as type written notes.

Phase 1: Summary of Practical Observations

1. The recording of verbal activity during generative drawing and its storage 'within' the drawing is a feasible concept. It could be that it acts to 'free working memory' in order to develop ideas or generate new ones, as pointed out by Purcell and Gero (1998, p419). Practically, this was observed and there appeared to be a pause in design process when making the 'notes' such that reflection could occur. The 'notes' could therefore be said to encourage reflection-in-action or reflection-on-action. This, however, probably happens whether the notes are spoken or written.

2. The grafting of sound onto drawings was observed to increase ambiguity (see chapter 1)

[110] The subject of this particular episode was a speculative, generative type of object as outlined in the introduction to this chapter.

when the sound is not played back, by effectively hiding the descriptive notes on a drawing and allowing for a multiplicity of interpretation and reinterpretation in their absence.

3. The nature of the recorded sound 'appended to' the drawing was concerned with a variety of types of information including specific design details, design strategies and deixis[111] . Therefore, they appeared to be functioning not only to remind their creator of an issue on reflection, but also to potentially focus an ambiguous issue in an instant: the sound recordings could be said to be assisting in creative decision making in their own right.

4. In relation to handwritten notes, it is difficult to state definitively how the stored sound would compare in terms of promoting reinterpretation of the drawing. This is because handwriting involves symbols which are themselves open to reinterpretation (in terms of decreasing ambiguity - writing, speaking, typing) and this is not directly comparable to the 'covert' storage of the sound which is only accessible by pressing a button.

5. Whilst recording sound 'within' the drawing is possibly an acceptable process for lone drawing, inhibitions come into play particularly when the sound is replayed to (or created in the presence of) others. The slightly unstructured nature of the contents of the recordings dispelled early fears of the process being too invasive to the process of drawing. However, the potential switch in cognitive processes from depictive to descriptive representation could be disruptive, although it was felt that once the novelty of the action of talking instead of writing wears off, there is probably little difference between them with regard to the actual act of drawing.

6. Only one of the five sound recordings indicated in illustration 10 was too long for the

[111] Garner reports on the use of deictic words in the collaborative design process and observed that their use remains 'fairly steady over the design cycle up to the last ten minutes or so...then there is a sudden increase' which he attributed to his subjects hurrying towards closure in their design exercises. See Garner, S W et al. (1991)

memory of the sound device, indicating that six seconds was quite a good first attempt at a suitable capacity. It is estimated that the sound clips recorded were more lengthy than if they had been written: indicating that some editing must be occurring when selecting words for written notes.

7. The inclusion of sound non-sequiturs was not observed in the limited trials.

8. The naming of objects and elements within the speech notes was observed in this practical phase. This may have occurred as a shorthand for omitted drawings or elements; sometimes economy favours descriptions with language rather than drawing. In addition, the function of generative drawing notes (whether by speech or handwriting) may relate to long term memory as discussed in chapter 1. The work of Carmichael, Hogan and Walter (1932) posits that for longer term memory, description may aid memory retrieval over depiction: therefore, the speech notes may have been made sub-consciously as longer term memory aids, in addition to having been made as shorthands for objects or elements not depicted. Goldschmidt (1991) and Schön (1983) both described this phenomenon as 'seeing as', perhaps most easily understood in terms of ideas of repertoire: the naming of objects and elements may be serving to both draw on and contribute to repertoire.

Computer-based system

Another system which was developed to an operational level was one which utilised a drawing tablet and computer to record and replay the sounds. The concept has far reaching consequences in terms of using the drawing to activate information other than just sound - eg animations, video, engineering information, simulations, colour charts, graphics etc etc. The whole area and idea hinges on the drawing as the central place at which activation of other information occurs. However, whilst the idea of sound storage in a drawing was seen to be seductive and interesting, the practical work exposed its limitations in relation to this

project and coincidentally the role of sound capture became a peripheral methodological theme (via video), rather than a central exploratory one. It is interesting to note the importance of the role of the accidental in reflective practice - this may not have happened if the research was conducted via a more structured, less amorphous, methodology. See below.

The Practical Cycle of Reflection: Phase 1

In terms of the connection of this phase with others in the cycle of reflective practice, the reflection-in-action and reframing of the ideas of phase 1 directly generated most of the areas of interest which subsequently became phase 2. Most notably, the idea that technology to record dialogues of natural language might be useful in reflecting on a design process was pursued as a practical concern. However, it should be noted that phase 1 was progressed approximately in parallel with phase 2, since they were both driven by an interest in the function of generative drawings in terms of cataloguing, selective disclosure and the appending of information to the surface.

The actual objects originated in phase 1 became subject to closure quite quickly. It was felt that further exploration of these discrete phase 1 sound objects would result in convergence to a narrow set of tools or practices rather than divergence to more fruitful and related areas as in the case of focusing the research on phase 2 (which, as we will see, ultimately resulted in the origination of the two later phases).

Phase 2: The Observation and Cataloguing of Continuous Roll Drawings

Drawing tables, drawing rolls

Whilst working on phase 1 of the project, it was felt that any practical drawing explorations needed a dedicated, yet flexible, site in order to focus the exploratory activity. Three identical drawing tables were constructed (see illustration 11), to allow the identified exploratory 'vehicles' to be integrated into my design studio practice.

Each table was made with two parallel drawing surfaces to create a storage area for large drawings (see illustration 12) and removable spindles at either end to allow rolls of paper to be attached. A system of G-clamps was used for this to allow the spindles to be removed if a table was not to be used with a paper roll or if the table was put to another use within the studio.

Early explorations involved simple conceptual projects aimed at getting used to using the paper roll. The paper roll was considered an important element within the project for the following reasons:-

1. It is what could be considered to be a traditional drawing surface, ie paper, which is obviously extremely familiar to designers. Therefore, the use of paper from the start was felt to be a pragmatic approach to the search for hybridized ways of working with generative drawing.

2. It is continuous (to a point) - this means that one cannot edit one's conceptual mark-making work. Everything is explicit and present. This was extremely important in being able to reflect on the generation of ideas.

3. Different rolls could be mounted onto the drawing tables for different projects; this resulted in fairly simple management of drawing catalogues which would perhaps normally be very difficult to handle (lots of different formats of paper, in jumbled order, some dated/timed, some not.)

4. The psychological effect of a site or place to generate ideas cannot be underestimated in both positive and negative influences.

Phase 2: Preliminary Observations: a site for ideas generation

In terms of the experience gained from practical use: as one used the drawing table and roll of paper, the initially intimidating effect of the large empty white roll of paper receded and the idea of a specific site or place to generate ideas became increasingly stimulating and useful. Eventually, drawing rolls were used with clients on live design projects with great success and they continue to be integrated into the practice. They have even become a medium of presentation for those projects where the client wants to get actively involved in the creative process and be a party to all of the work which that involves.

After some time and several projects, it became evident that the strength of the drawing tables lay in their use as shared drawing spaces. This may be related to their scale (is it possible that a drawing space can be too large for 1 person's ideas?) or just to the fact that designers would motivate each other to go and use the tables as a way of starting a creative dialogue or of stimulating a stagnant one.[112]

There were considered to be two applications for the shared drawing space within the context of this research project. Firstly, as a means to exploring generative drawing during cooperative working (see chapter 1) and secondly as a methodological approach to the

[112] Later, these anecdotal attributes were exploited to generate some mark-making objects which would act as creative shared generative drawing starters. See appendix 7.

exploration of the cognitive processes at work during episodes of generative drawing, with a view to observing the effects of any technological interventions or objects. The shared drawing space encouraged those working within it to articulate and be explicit whilst still continuing to generate ideas[113].

The most people working on one table (actually two tables placed end to end) was four and although not conclusively proven, it seemed to be limiting to the individuals - this was not due to a lack of space, but rather, the difficulty of focusing a design process and agreeing on a direction between that many people in any creative pursuit. Whilst 3 people drawing worked quite well, overall, 2 people seemed to work particularly well and it was noted that sufficient time needed to be allocated to allow the participants to become comfortable with this site for ideas generation.

It is extremely revealing to observe the different ways in which people related to and engaged with the drawing table. One person, who does not draw very often with his own individual design process (he is a furniture designer and a maker at the craft end of design) tended to use the drawing table to reflect on drawings of other users and to make connections - he tended to write on the roll more than he drew. This may also be connected to his attempts at problem structuring as outlined in chapter 1, with reference to the work of Goel (1995) and others.

Once the usefulness of the drawing tables was established, two aspects of development of the process were addressed:

1. The search for a more sophisticated means of observation and recording of the act of drawing and the accompanying dialogues. It must be emphasised that this was

[113] It is very important to make the distinction between the two uses of the shared drawing space; ie the cooperative working site per se and the methodological tool to encourage the use of natural language during designing.

pursued as a creative tool for the designer, not as an effective research mechanism[114].

2. Associated tools were developed to ensure that the observation and recording of the process would not be invasive to the process itself. The aim was to make tools which would actually enhance the process.

Before outlining these, it may be useful to reiterate the motivation behind this phase of the practical work, namely, why is it of interest to observe and record the shared drawing and dialogue process?

One answer to this question became the dominant basis (reframing) of a new phase of reflection-in-action and was actually the link with the phase 1 work. The observation was that the drawing rolls produced (like any other generative drawing sheets) contained many notes and signs/symbols and gestures which were added to the core generative work as annotations as the process proceeded and that:-

(i) as in phase 1, the replacement of written notes with the recording of the spoken dialogue during the creative process would help to smooth out the process and avoid stilting it[115]. This is the same argument as used for the phase 1 sound grafting experiments, except that the designer was, in that case, expected to use the sound devices instead of writing notes. In this case the designer was expected to understand that the video observation would automatically and without intrusion record any spoken notes and gestures. These would immediately be spatially and temporally oriented within the recording of the drawing, negating the need for written notes at all.

[114] Although it is acknowledged that in hindsight the former generated the latter.
[115] There is a counter argument at this point: that annotation, along with adding colour, hatching, circling, shading, framing, underlining etc. are important periods of unconscious reflection during a fairly intensive cerebral activity.

(ii) more (and different) meaning could be added to the resulting drawings through the use of technological and material tools.

(iii) perhaps, at least the resulting information could become more explicit to those other than the originators, ie perhaps the relatively private generative drawings could be more easily converted into public expressions of the ideas. This was considered to be of peripheral interest.

A more sophisticated means of observation and recording of time-based drawing and dialogues

On reflecting on the action of using the shared drawing space, it was realised that the dialogues occurring were liable to take sudden unexpected turns, the importance of which could only be realised some time after the event, at which time, often, the details of the thought or inspiration may have been lost within the impetus of the process.

Originally, the phase 1 exploratory work had tried to provide a mechanism to capture the spoken essence of these design process nodes[116] for playback at a later occasion, ie once the importance of the comments had been realised.

The limitation of this method of working lay in the fact that quite a significant amount of conscious effort was required to lay down the sound 'bites' whilst the incidence of wanting to replay the sound may, on the whole, be quite low. Also, the process was quite invasive to the design/creative process - it was largely used for an individual working alone; necessitating the individual to speak out loud during creative thought, whereas the shared

[116] The term node in this context is intended to refer to a turning point within the design process, as used by Ehrenzweig, A. (1968, p36); ie a point at which an apparently important idea is generated. See the Symbolic Review Objects and particularly the triangular Node Marker, later.

drawing space has spoken dialogue as an inherent part of the creative process.

Initially, a microphone connected to a computer was used to record the whole of the dialogue. This had the advantage (over tape) of enabling non-linear examination of the resulting sound file to revisit the dialogue. The sound file was linked to the drawing by a manual time code - regularly recording the time from a stopwatch spatially onto the drawing.

It was anticipated that a time stamp should be developed to make time coding of the drawing less invasive to the design process. However, this whole process of recording sound and its associated 'position' on the drawing was rather cumbersome in practice and the next reframing of the situation overtook this idea.

Digital Video (as observer and cataloguer)

It was decided that the observation of the drawing space and the recording of the sound should occur in one integrated medium. The obvious choice was video. After having examined various video cameras (both analogue and digital), a digital video camera (DVC) was selected on the basis of its small size and advanced digital features such as digital playback zoom[117] and excellent quality. This was the JVC GR-DVX.

The camera needed to be mounted above the drawing surface with the ability to be repositioned quickly as required. A sprung arm was constructed.

The camera was used in two ways:-

1. To record the process clips onto digital video tape, which was taken into the computer after the event.

[117] This meant that a limited amount of reframing (as zooming inwards) could occur after footage was taken - a feature which was found to be extremely useful in the subsequent reflection on drawing episodes.

2. To record the process clips directly onto the hard disk of the computer.

Both of these methods resulted in the same outcome - a non-linear accessible process file stored on the computer. Recording to digital tape saved on disk space and therefore expense; however, during the timescale of the project, this was becoming less of an issue as the cost to capacity ratio of computer data storage was constantly reducing.

Essentially, the resulting file was an image of the drawing space plus a soundtrack of the dialogue plus a time code to orient it all. Therefore, when reviewing the video file, the time code and/or recognisable parts or events in the drawing were used to identify the part of the process of interest - as an aid to reflection-on-action, to use one of the terms from Schön (1983). However, when exploratory use of the system was made it was felt that additional visual (or aural) signs were needed to assist in review: that is, to speed up the identification of moments of interest[118] .

Two options were investigated:-

1. Audio Identifier

A whistle was blown when the design process was at a potential node. This was then used on the computer during review - looking for the spike of sound which is present when the whistle is blown. This was tried using Adobe Premiere[119] to analyse the video file which was split into video, sound and time code. However, the second option (the symbolic review objects) appeared to be the more successful, probably because it was slightly less codified

[118] Some inspiration was taken from the Franco-Italian film, Cinema Paradiso, 1988 (written and directed by Giuseppe Tornatore) wherein part of the narrative involves the removal of 'love' scenes from the distributed films to be shown at the local cinema. An interesting piece of marking occurs when the film censor, on watching the latest release, has the local projectionist put pieces of paper into the rotating film spool, to mark later edits. See illustrations 16 (a) & (b).

[119] Adobe Premiere is a commercially available, relatively inexpensive software package used to edit video and audio.

and more accessible, relying on direct visual identification, rather than visual identification of a sound waveform alongside the drawing, not to mention the noise of the whistle!

2. Symbolic Review Objects

A set of symbolic objects were developed, to be placed 'in camera' at appropriate points in any process dialogue (see illustrations 13, 14, 15(a) & (b)). Although the idea could be extended to a greater number of objects, there were initially four as follows:-

(a) Projection Dice

The projection dice is a cube with six colour coded letters, each one representing one of the six types of orthogonal view used in a drawing.

The letters used were selected as follows:-

T - TOP	U - UNDERSIDE
L - LEFT	R - RIGHT
F - FRONT	B - BACK

So, for example, if a process involved drawing the plan view of an object, the cube would be placed with 'T' uppermost next to the drawing. Essentially, this object helped to remove some of the ambiguity[120] from the video footage of the drawing during review. It resided within the drawing space and was placed next to a drawing to communicate the projection.

(b) Node Marker

The node marker is a red, triangular marker with a yellow spot. This marker was

[120] It is acknowledged that, according to many research sources, not least Goel (1995), ambiguity is one of the key attributes of generative drawing. In practice, these mechanisms for resolving ambiguity were observed to have a tendency to focus discussion on the subject of the ambiguity, without necessarily eliminating the ambiguity, as exemplified by appendix 2.

intended to be used to indicate a key, or potential key, node during the design process. The triangle is an easily recognisable shape which generally stands out from the rest of the drawing space when reviewed at speed on the computer screen or drawing table. Furthermore, the triangle was chosen because it is not sensitive to viewing orientation - it always looks like a triangle[121].

(c) Orientation Marker

The orientation marker is a semicircular symbol which indicates horizon and/or the vertical. This symbol was considered necessary because often the shared drawing space was used to draw from many different directions, eg two drawings next to each other may differ by 180° in terms of orientation. Practically, this object was not used extensively.

(d) Tangential Marker

The tangential marker is a circular symbol with a red centre, a green outer and a white tangent path indicated. This symbol was used to indicate that the design process or idea generated was at a tangent to the original objective or brief. The symbol indicated that the idea marked was still of interest, whilst tangential to the task at hand, and may provide a useful starting point for another idea or brief.

Frame Rate

Early experimentation was performed with the video being captured and stored in the computer at full frame rates, ie 25-30 frames per second (resolution 640 X 480 pixels). This is the universally acknowledged optimum frame rate for smooth motion to be perceived by the viewer.

[121] Arnheim (1984) refers to work by Louis Gellermann in which this recognition phenomenon was determined experimentally with children and chimpanzees.

However, such full frame rate clips are very large when stored digitally and the video signal of mark-making is not always a particularly dynamic visual event - hence the smoothness of playback can be reduced in order that the resulting file is considerably reduced in size. The sound file is not altered in this case such that the resulting file is effectively a soundtrack plus a series of still images of the drawing space.

Whilst many different frame rates were tried, 5 frames per second appears to be adequate for most drawn events. The overall result was that of 'talking hands which draw' and it is interesting to notice the amount of gestural communication which occurs over the drawing space.

Phase 2: Practical Usage

The symbolic review objects were a bare minimum of notational symbols which, when used with the dense and ambiguous symbolism of the generative drawing, overlaid points of reference which themselves could become focal points of meaning and possibly reinterpretation. Therefore, the resulting footage, reviewed as a largely non-linear record on the computer, became a layering of at least three separate symbol systems - generative drawing, natural language and the symbolic review objects. This in itself could be considered to constitute a density of symbol systems and it was seen experimentally to facilitate different interpretations from the same information - itself a requirement for density.

A dialogue from one particular episode of designing where the dice came into use is transcribed in appendix 2. In this particular case the dice was initially used to clarify the drawing projection under discussion. That is, the notational symbolism of the dice was being overlaid onto the ambiguous symbolism of the drawing in order to clarify the design move (using the term of both Goldschmidt (1991) and Schön (1983), as outlined in chapter 1). However, it is evident from the video footage, that the dice itself became instrumental as part

of the discussion by interacting with the natural language to identify the route of the ambiguity under discussion.

Methodological Note

From a methodological point of view, the recording of a shared drawing episode on video, with the accompanying verbalisations as they occur, may well be a less invasive technique to reveal the cognitive processes at work during generative drawing[122] than, say, prompting a verbalisation from an individual subject. There can be no doubt that the latter, as mentioned earlier in Goldschmidt's (1991) work and others, must have some effect on the design thinking - for a designer to be asked to constantly verbalise during generative drawing must have some invasive effect on the actual thoughts and imagery used, even if it serves to focus the process.[123] From a methodological point of view it is also important to notice that the means of recording drawing episodes were also bound up with the ideas for taking the technology to the drawing site. Initially, this was cause for concern over making sense of the research, however, it was realised that this is typical of a reflective practice situation whereby reframing and reflection can be triggered by any input - literature, experience, the methodology itself.

Phase 2: Summary of Practical Observations

This phase of the research was involved with the development of a site for ideas generation, in the form of a series of bespoke drawing tables. After some familiarisation, most designers who used the tables found that they were helpful in assisting the generative drawing process. Preliminary cataloguing of the drawing/design process was attempted using a digital video camera and playback via a computer file.

[122] despite the fact that the context is one of cooperative working.

[123] Particularly if one subscribes to the separation of analytical, language functions and visual, imagery functions within the brain, although the latest evidence doesn't produce such a clear distinction between left and right brain, say. See Kosslyn (1994) and Pinker (1998).

The use of the computer to review the drawing/design process necessitated the development of some symbolic objects for use 'in camera'. It was observed that it is possible to introduce objects which have a useful, if momentary, role to play in generative drawing, at least in a cooperative working situation. In this situation, the object becomes a communication 'prop'[124] and serves to focus and externalise natural language discussions, by introducing another level of symbolism.

The Practical Cycle of Reflection: Phase 2

As mentioned at the end of the phase 1 narrative, in terms of the connection of this phase with others in the cycle of reflective practice, phase 2 occurred approximately in parallel with phase 1, since they were both driven by the initial consideration of the drawing site and the implementation of ideas for taking the technology to that site and more specifically ideas based around the function of generative drawings in terms of cataloguing and selective disclosure of information. Reflection on the observations of phase 2, along with certain literature discovered (particularly involving the relationship between the image and the drawing) generated the basis of phase 3.

[124] In the sense of a theatrical prop (property).

Phase 3: The Back Projection Drawing Table

Bringing the image to the drawing

Having produced a fairly sophisticated and workable system for cataloguing and reflecting on the shared drawing process (phase 2) and with some experience of developing design process objects (phase 1), attention was turned to actually affecting the drawing process, ie the production of tools for drawing in the design process.

Earlier in the project, a lot of effort was expended on finding a technology to bring images to the drawing space. All efforts were concentrated on permanently embedding the image into the drawing and conceptual proposals for ink jet and dye sublimation printers which move across the paper (rather than the paper moving relative to them, in the conventional sense). These were exceptionally difficult to implement within the remit and timescale of this research - indeed I was advised that the development of one-off machines of this complexity would probably occupy the entire project without regard for any other activities. They were also considered of peripheral interest.

However, with this idea in suspension, and with the idea of the cataloguing digital video camera, a new possibility serendipitously presented itself. Namely, that the DVC could be used to capture and replay images on and off-line with regard to the drawing. The problem was how could the image be taken to the drawing?[125] The answer lay in using simple projection - paper (which, from the outset, was defined as an essential element for the drawing used in this research) is an excellent projection screen. However, forward projection would mean that the activities of those drawing would interfere with the projected images in terms of shadow casting. The obvious solution was to use back projection.

[125] The relevance of bringing the image to the drawing was covered in chapter 1 and relates to depth perception, reference frames, drawing in context etc.

A glass top drawing table was constructed, allowing captured images to be projected from underneath and allowing a paper roll to be used on its upper surface, as the drawing space.

In this situation, the video camera takes on another role. In addition to the role of observer and cataloguer as outlined above, the video camera presents the possibility of feeding back a composite image from the drawing plus the projected image beneath it. That is, it effectively produces the same result perceptually as a printer would have, except that the result is digitally stored and also can be changed 'on the fly' (see illustrations 17 and 18 (a) & (b)).

Projection System

Many different means and configurations of projection were attempted with a variety of interesting and useful results:-

1. OHP & LCD and large parallel mirror. Image is almost as large as table top.
2. OHP & LCD and small, close parallel mirror. Image is smaller. Edges are slightly ill-defined.
3. Option 2. above developed into OHP & LCD with periscope replacing OHP mirror. Image framed well at approximately A4 (4 X 3 proportion)
4. OHP & LCD and no mirrors - direct projection. Projector is directly beneath table.
5. LCD alone beneath table with back light and fresnel lens.

There are many possibilities for back projection onto the drawing surface and much time and effort was expended in trying to explore different options. A projection test pattern was constructed in an attempt to understand and reflect on the optical characteristics of each configuration, see illustration 19. One significant issue which was crucial to the development of the projection system was the size of the projected image. Initially, it was felt that the largest possible projected image would be the most useful. However, as the practical

exploration proceeded it became clear that a smaller image may be more useful. It was observed that people drew over the image and into the space around it and that the dialogue drifts away to the periphery of the image and beyond.

This blank frame around the temporary image was found to be very important. Also, the scale of the image at approximately A4 (but different proportion, ie 4 X 3) appeared to be a good scale if the object image was a full projection - it was an appropriate size for the wrist/elbow movements used in generative drawing. This approximate A4 size was arrived at by trial and error and in consultation with others who tried the back projection drawing table.

Phase 3: Practical Usage

Bringing an image to the drawing surface allowed the creation of composite images constructed from drawings plus other sources, see illustration 20. The DVC image projected onto the drawing surface allowed non sequiturs to be offered up to the generative drawing, in the search for unexpected connections.

The use of the drawing space for cooperative working enabled a dialogue to occur beyond the self. Practically, this was seen to encourage an improved cooperative working relationship between designers. It also allowed the research to examine the design process in detail, by producing a natural commentary.

The cataloguing and retrieval attributes of information technology were used successfully for review and editing of drawing/design process material. The need for other objects to assist in the review of any catalogued material quickly became apparent. Some phase 2 objects were further incorporated into the phase 3 work, most notably the symbolic review objects (projection dice etc).

Whilst much effort was expended in bringing an image to the drawing, through back projection, the potential for bringing the object to the drawing was also explored. The digital video camera provided an opportunity to capture images of a variety of scales of object and bring them almost immediately to the drawing site. These images were seen to be useful in terms of freeing working memory which may otherwise be engaged in the recall of peripheral or contextual details.

The interplay between the drawing and the projected image influenced perceived depth and allowed basic layering to take place. It also allowed structuring of the drawing to take place, whereby the frames of reference evident in an image could be appropriated for the drawing. This appropriation sometimes took the form of a corruption of the original frames of reference (see illustration 21 (a) & (b)) and could therefore be said to initiate reinterpretation. This was considered to be, at times, a serendipitous process.

The density and ambiguity of symbolism in the shared drawing space with the contextual image present, was seen to be very high. This was only apparent when the image was removed and the drawing viewed alone (see illustrations 22 and 23).

Drawing tends to be monocular since depth is cued in the conventions selected, for example, perspective cues depth with foreshortening and convergence. However, much of the video evidence produced shows an interesting variation in viewpoint between the draughtsperson and the drawing - the head is rarely in the optimal viewpoint, even during the actual act of drawing. This reinforces the idea of the descriptive function of generative drawing as an inaccurate external representation as opposed to an accurate depiction.

Phase 3: Summary of Practical Observations

Bringing a temporary image to the drawing surface appears to have a number of

consequences:

1. Restructuring of the drawing. The image can be used to structure or restructure a drawing in an unexpected way. Appropriation of the image's frames of reference by the drawing may initiate an instant change of state, for example, scale, which could be seen as a reinterpretation instigated by the image, not the drawing.

2. The density and ambiguity of the symbols used only became apparent when the image was removed and the drawing viewed alone. This may be a positive aspect in that the drawing is operating as an assemblage of partial problem areas, however, there is a possibility that the structuring (frames of reference) brought about by the presence of the image may be inhibiting reinterpretations, in conflict with point 1 above.

3. The bringing of a contextual image to the generative drawing may fixate the design team and create problem boundaries which are incidental and misleading. Choice of image and the duration of use in the generative cycle is thought to be crucial.

The Practical Cycle of Reflection: Phase 3

In terms of the onward connection of this phase with the next in the cycle of reflective practice, the main issue of phase 3, namely, bringing an image from elsewhere to the drawing site, seemed enduring. Therefore, it was retained, but practically the situation was reframed in the light of the serendipitous discovery[126] of some other drawing interface equipment as outlined in the next section.

[126] during a search for literature

Phase 4: The LCD Drawing Interface Table, With CCTV Image Capture

The informal hybridized drawing space

The struggle to develop a non-invasive and reliable back projection drawing table (central to phase 3) was met with an important and serendipitous discovery in searching for equipment and other research literature. That was the discovery of the commercially available Visionmaker Sketch 14[127] (see illustrations 24 (a) & (b)) drawing interface. Subsequent to this discovery, experiments with a hybridized drawing approach based around a commercially available product were possible - allowing the emerging interest in the CCTV camera[128] to be practically developed, whilst maintaining the aim of bringing the image to the drawing surface (as originally introduced in phase 3).

Phase 4 of the practical work has been purposely split into two parts. Firstly, my observations on my own reflective practice using the equipment, as before. Secondly, several colleagues performed very short episodes of focused designing using the same equipment and their observations and their own actions and reflections are used for comparison, to assist in drawing the project to a conclusion.

Phase 4: Observations, Part One

The first (observational) drawings made with the Sketch 14 are shown in illustrations 25 and 26. These were drawn directly using the drawing interface which is evident from the quality of line, itself a function of the software.

[127] The Visionmaker Sketch 14 is a commercially available product made by Input Technologies Inc of Toronto, Canada. This A4 sized drawing interface product is effectively a combination of an LCD monitor and a drawing tablet (a digitiser plus induction coil pen) which is configured in such a way as to enable different surface angles, like a traditional drawing board. It is used in a number of industries including animation and automotive design. For more information see the Input Technologies Inc website (URL: http://www.iti-world.com/ [April 1998]). Wacom also make a comparable product, represented on their website (URL: http://www.wacom.com/ [November 1998]).

[128] This came from successful use of the digital Video Camera (DVC). The idea was to employ lots of cheap and simple, yet specialised, CCTV camera 'tools' in place of the one, expensive and complex DVC.

The limitation of the brightness of the LCD screen on the Sketch 14 (drawing interface) meant that the only paper which could practically be used as an overlay was tracing paper or draughting film. This tended to have the effect that the drawing interface would be used alongside the paper as opposed to beneath it, as with the original back projection drawing table. Consequently, the role of the hybridized drawing space became more informal and perhaps more fragmented. In this work, the Sketch 14 was used almost exclusively with bit-map based 'painting' software[129] , which was considered the most suitable for generative drawing, as outlined by Fish (1996). In order to facilitate the use of the tracing paper overlays, the Sketch 14 was rationalised into its own drawing table, with a series of selectable CCTV cameras enabling images to be fed back around the loop of being projected under the drawing surface. See illustrations 27 and 28.

1. CCTV as instantaneous image bringer

A number of configurations of CCTV cameras and lenses were explored, with the aim of producing not one definitive image bringer, but a number of flexible possibilities at the disposal of those using the drawing table. They were to act as instantaneous scanners of information at a resolution intended for the eye not the print process.

The majority of the CCTV cameras used were monochrome, partly for economy but also because there is a similarity between them and the monochrome drawing[130] , which, I supposed, would result in the encouragement of ambiguity in the hybridized drawing/image. The type of image which became available at the drawing surface ranged quite dramatically from the silhouette to the detail (macroscopic, more than the eye can see) and from the sample (from the current,

[129] Particularly Adobe Photoshop (version 4.0) and to a lesser extent, Fractal Design Painter (version 5.0.3).

[130] The majority of 'traditionally' produced generative drawings encountered within this work were largely monochromatic. However, the digitally produced generative drawings were likely to contain multiple colours which were used to codify product components or elements of the drawing, probably because of the speed and immediacy of selecting or changing colour in the digital domain.

or another, drawing) to the context or site of the potential object.

It was hoped that such diversity would allow the naturally useful cameras to emerge from the exploratory work. And indeed, there were three types of CCTV camera which emerged from this cycle of reflection-in-action:-

(i) The CCTV lupe

See illustrations 29 and 30.

This was an optical lupe with a CCTV receiving a relatively undistorted image of any surface beneath the lupe, eg the drawing surface. Magnification was approximately 800%. It could be used to capture relatively small drawings or details of drawings.

(ii) The aerial CCTV

See illustration 31 & 32.

This was a CCTV camera mounted magnetically from an articulated lamp, with its own telescopic stem, so as to be adjustable for height above a surface or object. This camera could be used to capture relatively large drawings or the whole drawing area.

(iii) The surface CCTV

See illustrations 33 (a) and (b).

This was a CCTV camera mounted inside the surface of the table focused to capture an image on the surface. The image was reversed by a mirror to allow a direct mapping from a drawing to its resultant video image on the LCD screen. Unlike the CCTV lupe , this one was magnified so much as to capture the grain of the drawn line.

2. Change of scale

Taking the CCTV lupe to the drawing surface was seen to instantly produce a reinterpretation

of the marks through a change of scale, reframing or selective viewing and the observance of the material structure of the mechanism of mark making, ie an increasingly detailed view of, for example, pencil and paper. Of course, the totally digitally based approach can yield analogous effects. A high resolution file can be magnified almost immediately and by many times. Therefore, a hybridized system of pencil, paper, camera and interface was seen to effectively borrow some of the benefits of the purely digital domain to the traditional domain.

3. Pen as activator

In addition to mark-making, the Sketch 14 pen could also be set to be used as a spatially sensitive switch. Like other pen based computing pens, a button on the barrel of the Sketch 14 pen activates a switch. This switch was set through the interface, to activate a number of functions including a scrolling window at the tip of the pen. This function was found to be useful for at least the following purposes:

(a) Photoshop protocols for reducing information: 'stamping' - the raw video signal tends to be visually noisy. If the source image is a drawing on paper, then the video image produced will tend to merge the drawing with the background noise. The 'stamping' filter within Photoshop produces a black and white image where the drawing becomes the more defined information, not dissimilar to a low grade photocopy, whereas the background noise is all but eradicated. See illustrations 34 (a) and (b). for an example.

(b) figure-ground reversals (see chapter 1 and below) were possible instantaneously, setting the pen button to 'invert' within Photoshop.

4. Digital paper roll

The idea of the unedited paper roll which was developed in the phase 2 experiments was reinterpreted within the digital domain as a scrolling window. See illustration 35 for an example. In a sense, whilst the materiality may have been compromised, the scrolling drawing became a truly hybridized record of the drawing activity in that it could also contain CCTV images and images of paper drawings, even sound, in one continuous medium. It was felt that this 'digital paper roll' offered closure to a much earlier idea and in effect the research had gone full circle.

5. Depth Perception

Exploiting depth perception, a number of non- blank, non-white backgrounds were developed and explored. See illustration 38 for an example. Erasure was used to make the marks; this is an advantage which a digital medium can have over paper and pencil. Some interesting depth effects were observed and the backgrounds were observed to intrinsically increase ambiguity within the resultant drawing, thereby potentially assisting in producing reinterpretations and consequently the lateral transformation of ideas. See Goel (1995). These drawing backgrounds would have merited further investigation had the research continued past this phase.

6. Figure/ground reversals

Figure/ground reversals were found to be extremely simple to arrange in the digital domain. Within the hybridized domain, the use of the CCTV camera capture was seen as an advantage so that paper drawings could also benefit from image manipulation in the simplest possible way. This provision is significant for the reasons outlined in chapter 1[131] . Once again, the encouragement of reinterpretations is seen as an indicator that a tool or process can assist in

[131] Particularly the work of Brandimonte and Gerbino (1993), who have established the link between the perceptual processes which act during figure/ground reversals and the mechanisms which drawing provides in terms of mental imagery and reinterpretation in the design process.

the lateral transformations of ideas (see also Goel (1995)), ie divergent idea generation.

Phase 4: Observations, Part Two

The second part of the phase 4 'reflective practical' work was involved with the observation of colleagues using the equipment and introducing their own reflections on their own actions, for some different perspectives. See illustrations 36 & 37. Colleagues were given the design briefs shown in appendices 3 and 5. Representations of two example sets of drawings produced are collated in appendices 3a and 5a.

Part Two Design Exercise

A specification for drawing exercises, for colleagues to perform, was formulated as set out in the following: A suitable task product needed to be reasonably simple both formally and conceptually and needed to be suited to being drawn - ie not something of such proportion or material or use as to be impossible to develop through drawing, or for which another modelling technique may be preferred, eg model making. A smallish scale was also considered desirable to enable the three main CCTV drawing cameras to be useful.

It was considered that for the relatively short time scales involved in the proposed generative drawing tasks, the provision of a focal component or object would be of benefit. This was intended to give the problem structure and boundaries, making it less ill-defined than the design of say a pure form or subjective object. Additionally, it was felt that if the task object had to be based around another object or component, then the participant was likely to need to represent that given component, thereby introducing an element of observational drawing to be considered in relation to the focal generative drawing. Also, good contextual and precedent possibilities for both image stimulus and analysis/comparison of outcome were required, ie something which could easily be assessed.

Finally, objects or situations which would be moderately familiar to the participants were required, to dispense with steep familiarisation curves. Although it is acknowledged that practically up to this point in the project familiarisation has been observed to be one of the purposes of generative drawing - the drawing out of the imagined or remembered object produces something tangible which in turn produces a percept which then goes round the cycle again.

A format was developed for the drawing exercises. This took the form of individuals being observed and video-taped drawing alone, with the following sequence of events: (i) introduction to equipment/preliminary familiarisation; (ii) briefing; (iii) video taped exercise; (iv) video taped review and (v) structured interview (based on questionnaire).

A rigorous Social Science analysis of these exercises was considered beyond the scope of this research project and also potentially at odds with the reflective practice approach taken thus far. Therefore, the collated information is presented informally and as a narrative as previously throughout the project and later synthesised and compared with my own reflective assessment of the hybridized work space.

Part Two Observations

The drawings were 'individuated'[132] by the participants[133] and myself, using the video taped review, to enable the deconstruction of the drawing sequence. The observations made are set out below, in no particular order:-

1. One of the participants spent considerable time trying to capture an image of some woven

[132] The participant was asked to number each discrete drawing and also each discrete idea just after having performed the design task, as described by Goel (1995). See appendices 3a and 5a.

[133] These particular participants were of similar ages, experience and educational backgrounds. They undertook two different briefs.

material. He then realised that it was easier to just draw the material from observation/memory. This was thought to be an anomaly which probably came from the novelty of the work space more than anything else.

2. Anecdotally, the participants found the immediate access to different colour (digital) mark-makers[134] to be a useful attribute for indicating hierarchies or different components or materials.

3. Comparison of the two generative drawings of the participants represented in appendices 3a and 5a, reveal that participant B appears to have accessed more densely ordered symbolism and perhaps approached the design task with a strategy involving more detail, having segregated problems and/or solutions into partial ones[135] . However, both participants managed to make at least several lateral transformations of their ideas, in the limited time allotted.

4. There was some concern that participant B was making drawings in the knowledge that they were to become public. However, when asked directly whether he had modified the type of generative drawing he would normally make, he indicated that he had not. The drawings appeared to be more illustrative than cognitive.

5. Both participants tried to annotate their drawings through handwriting and both appeared to express some concern over the relative difficulty in using the drawing interface for the writing. However, both eventually managed to write moderate amounts of notes. This appeared to be a function which was important to their design processes and one which helped them structure their ideas[136] .

[134] A software issue: colour palettes

[135] See chapter 1 for the literature regarding density, symbolism and managing complexity.

[136] This is in accordance with what we saw in the literature of Goel (1995) and others in chapter 1.

6. Further to their practical manifestation as outlined above, the use of different symbol systems for different phases of the design process as outlined in chapter 1, was acknowledged by the designers in the structured interview part of the phase 4 exercise. This was noticed particularly in response to the question '...which of the following are you likely to use most to generate ideas at the start of a design project?' where 'writing' and 'talking', ie language, were the most common answers. I took this as evidence that the designers are quite aware of the tacit knowledge that they bring to bear in designing.

Phase 4: Summary of Practical Observations: Parts One & Two

1. Further 'reflective practical' work in attempting to develop a non-invasive and reliable back projection drawing table, central to phase 3, was met with the serendipitous discovery of a commercially available drawing interface, generating the basis for phase 4.

2. A consequence of the discovery of the drawing interface was that the emerging interest in the CCTV camera as an instantaneous image bringer could be practically developed. This was originally introduced through the use of the Digital Video Camera in phase 3.

3. The drawing interface was successfully rationalised into its own drawing table, with a series of selectable CCTV cameras enabling images to be fed back around the loop of being displayed under the drawing surface (on the LCD screen). This was practically observed to result in a very flexible and functional work space for generative drawing. However, one observed limitation to this was one of orientation - the graphical user interface used on the drawing interface unit tended to have a top and bottom or up and down. This could be modified or eliminated in any software re-design.

4. Practically, the CCTV camera objects allowed a variety of image types to become available at

the drawing surface including silhouette (accidentally discovered in poor lighting conditions), macroscopic view, instantaneous drawing 'scan' and images of objects or large scale sites. In particular, taking the CCTV lupe to the drawing surface was seen to instantly produce a reinterpretation of the marks through a change of scale, reframing or selective viewing.

5. The Aerial CCTV camera object appeared to be the most useful in capturing images from a variety of different sources. The Lupe CCTV camera was also practically very useful particularly for the fact that it resided on the drawing surface and could be brought into play with the minimum of thought or effort.

6. In a way which was analogous to a drawing produced as a high resolution digital file which can then be magnified almost immediately and by many times, the hybridized system of pencil, paper, camera and interface was seen to effectively borrow some of these benefits and bring them to the disposal of 'traditional' drawing materials. Practically, this was relatively invasive to the act of drawing itself, but refinement of the system would no doubt eliminate this.

7. In using the informal hybridized work space, one practical problem which quickly became apparent was that of switching between digital stylus and traditional pencil or pen. This was addressed in the speculative design of some hybrid pen/pencils for the Royal College of Art show (see appendix 7).

8. In this phase of practical work, the drawing interface was used almost exclusively with bit-map based 'painting' software and this appeared to be appropriate in accordance with Fish (1996). The quality of line or image, was of course largely a function of the software. Reflection on this suggested another possible exploratory avenue - namely, the investigation

of ways in which to introduce material and feedback qualities into the digital domain. Unfortunately, it was not possible to pursue these within the timescale.

9. In addition to mark-making, the drawing interface stylus could also be set to be used as a spatially sensitive switch. Practically, this switch was set, through the interface, to activate a number of functions including a 'stamping' function; whereby the noise of a video image could be reduced to enable edges to emerge and 'figure-ground reversals' (see chapter 1) to be available instantaneously, setting the pen button to 'invert' within the software. Whilst 'figure-ground reversals' were found to be extremely simple to arrange in the digital domain, within the hybridised domain, the use of the CCTV camera capture was seen as an advantage so that paper drawings could also benefit from image manipulation in the simplest possible way. This provision is significant for the reasons outlined in Brandimonte and Gerbino (1993), who propose the link between the perceptual processes which act during 'figure-ground reversals' and the mechanisms which drawing provides in terms of mental imagery and reinterpretation in the design process. As in other areas of the practical exploration, the encouragement of reinterpretations was seen as an indicator that a tool or process could assist in the lateral transformations of ideas (see also Goel (1995)), ie divergent idea generation.

10. Exploiting depth perception, a number of non-blank, non-white digital drawing backgrounds were developed and explored using erasure as the mark producing mechanism. Some interesting depth effects were observed and the backgrounds were observed to intrinsically increase ambiguity within the resultant drawing, thereby potentially assisting in producing reinterpretations and potentially the lateral transformation of ideas. These drawing backgrounds would have merited further investigation had the research continued past this final phase.

11. The assistance of some colleagues was used more formally in this phase of practical work. The colleagues, who tried the phase 4 equipment for set design exercises, were observed to mainly draw directly using the drawing interface. On reflection, it was believed that they were basically responding to the novelty of the situation, and were perhaps not as patient as I was in trying to use the assemblage of equipment. This behaviour was also possibly a reaction to the addition of Petherbridge's 'technical considerations' and evidence of them indeed having an interrupting effect on the 'initial formulation of visual ideas'.

12. The brightness of the LCD screen of the drawing interface was limited. It was felt that this may also be a possible explanation for the discouragement of the hybridization of digital and traditional drawings by the colleagues. This meant that the only paper which could practically be used as an overlay was tracing paper or draughting film. This tended to have the effect that the drawing interface would be used alongside the paper as opposed to beneath it, as with the original phase 3 drawing table. Consequently, the role of the hybridized drawing space became more informal and perhaps more fragmented.

13. The accidental was seen to play a part in the digital domain drawing, with accidental fills, captures and non sequiturs all observed during the practical experiments. For example, the magenta fill in the drawing in appendix 3a was accidental.

14. One of the participating colleagues spent considerable time trying using the CCTV camera objects to capture an image of some woven material. He then realised that it was easier to just draw the material from observation/memory. This was thought to be an anomaly which probably came from the novelty of the work space more than anything else.

15. Anecdotally, the participating colleagues found the immediate access to different colour (digital) mark-makers to be a useful attribute for indicating hierarchies or different

components or materials.

16. Comparison of the two generative drawings of the colleagues represented in appendices 3a and 5a, reveal that participant B appears to have accessed more densely ordered symbolism and perhaps approached the design task with a strategy involving more detail, having segregated problems and/or solutions into partial ones. See chapter 1 for the literature regarding density, symbolism and managing complexity. However, both participants managed to make at least several lateral transformations of their ideas, in the limited time allotted.

17. There was some concern that participant B was making drawings in the knowledge that they were to become public. However, when asked directly whether he had modified the type of generative drawing he would normally make, he indicated that he had not. The drawings appeared to be more illustrative than cognitive.

18. Both participating colleagues tried to annotate their drawings through handwriting and both appeared to express some concern over the relative difficulty in using the drawing interface for writing. However, both eventually managed to write moderate amounts of notes. This appeared to be a function which was important to their design processes and one which helped them structure their ideas. This is in accordance with what we saw in the literature of Goel (1995) and others in chapter 1.

19. Further to their practical manifestation as outlined above, the use of different symbol systems for different phases of the design process as outlined in chapter 1, was acknowledged by the participating colleagues in the structured interview part of the phase 4 exercise. I took this as evidence that the designers are quite aware of the tacit knowledge that they bring to bear in designing.

20. The idea of the unedited paper roll which was developed in the phase 2 experiments was reconsidered within the digital domain as a scrolling window. In a sense, whilst the materiality may have been compromised, the scrolling drawing became a truly hybridized record of the drawing activity in that it could also contain CCTV images and images of paper drawings, even sound, in one continuous medium. It was felt that this 'digital paper roll' offered closure to a much earlier idea and in effect the research had gone full circle.

Chapter 3

Drawing Conclusions

In this project, attempts have been made to explore the potential of taking technology to the generative drawing, through reflective practice. This chapter attempts to evaluate this potential by summarising and discussing the practical phases of work and reiterating their relationship with the literature in order to draw conclusions.

The earlier argument about paper and pencils being themselves new technology hundreds of years ago could be logically extended to current information technology. Even over the timescale of this project (almost 5 years) computing power has increased by several times[137] and miniaturisation and the diversification of the form and typology of technological products continues at an almost incomprehensible rate.

This speed of technological development, when coupled with the relatively fluid state of understanding in the fields of perception and cognition, has meant that this project has operated in an exciting and stimulating area.

Phase 1: The 'Grafting' of Sound onto Drawings

Phase 1 of the practical work was involved with the recording of verbal activity during generative drawing and its storage 'within' the drawing; by appending discrete devices to the surface of the drawing. This appears to be a feasible concept and may, as indicated by the literature, act to 'free working memory' in order to develop ideas or generate new ones. Practically, this was observed as a significant pause in design process when making the 'notes' such that reflection could occur. The 'notes' could therefore be said to be encouraging

[137] At the time of writing, the speed and complexity of computers is thought to be doubling every 18 months. This is attributed to Gordon Moore of the computer processor manufacturer, Intel:-
Margolis, J (1999) '...But what about year 3000?', Financial Times. How to Spend It Magazine, 4th December,1999, p8.

reflection-on-action. However, this is probably the case whether the notes are spoken or written.

There were theoretical concerns about the possibility of disrupting cognitive processes by encouraging these verbalisations during generative drawing. The theory suggested that the devices may be forcing a switch in depictive to descriptive thinking. However, this was not proven practically one way or the other. The fact that the stored sound was less accessible than writing may actually have assisted in increasing momentary ambiguity and may therefore have potentially encouraged reinterpretation of the associated drawings.

The sound 'appended' to the drawing was seen to be concerned with a variety of different types of information including specific design details, design strategies and deixis. Therefore, it appeared to be functioning not only to remind the practitioner of an issue on reflection, but also to potentially focus an ambiguous issue in an instant: the sound recordings could be said to be assisting in creative decision making in their own right. The naming of objects and elements within the speech notes was also observed practically. This may have occurred as a shorthand for omitted drawings or elements; sometimes economy favours descriptions with language rather than drawing. In addition, the function of generative drawing notes (whether by speech or handwriting) may relate to long term memory as discussed in chapter 1. If this was the case, then the speech notes may have been made sub-consciously as longer term memory aids, in addition to having been made as shorthands for objects or elements not depicted. This may well relate to the descriptive work of Goldschmidt (1991) and Schön (1983) who talk about the phenomenon of 'seeing as', perhaps most easily understood in terms of ideas of repertoire.

In relation to handwritten notes, it is difficult to state definitively how the stored sound would compare in terms of promoting reinterpretation of the drawing. This is because

handwriting involves symbols which are themselves open to reinterpretation (in terms of decreasing ambiguity - writing, speaking, typing) and this is not directly comparable to the 'covert' storage of the sound which is only accessible by pressing a button. A rigorous comparative study would need to be undertaken to establish this.

Whilst recording sound 'within' the drawing was observed to be an acceptable process for lone drawing, inhibitions come into play particularly when the sound is replayed to (or created in the presence of) others. The limitation of 6 seconds for the capacity of the sound devices was practically observed to be adequate for the majority of sound recordings. The slightly unstructured nature of the contents of the recordings dispelled early fears of the process being too invasive to the process of drawing, but raised further questions of comparison with handwriting; most specifically, relating to the similarities and differences between the editing which takes place in writing notes and in speaking them. This was not addressed practically or theoretically, but could itself form the basis of a comparative study.

The inclusion of sound non-sequiturs was not observed in the limited practical trials.

In terms of reflective practice, reframing of the ideas of phase 1 directly generated most of the areas of interest which subsequently became phase 2. Most notably, the idea that technology to record dialogues of natural language might be useful in reflecting on a design process was pursued as a practical concern. Both phases were driven by an interest in the function of generative drawings in terms of cataloguing, selective disclosure and the appending of information to the drawing surface.

Phase 2: The Observation and Cataloguing of Continuous Roll Drawings

Phase 2 of the practical work was involved with the development of a site for ideas generation, in the form of a series of drawing tables. After some time and several projects, it

became evident that the strength of the drawing tables lay in their use as shared drawing spaces. This may be related to their scale or just to the fact that designers would motivate each other to go and use the tables as a way of starting a creative dialogue or of stimulating a stagnant one. Tangentially, these anecdotal attributes were exploited to generate some mark-making objects which would act as creative shared generative drawing starters (see appendix 7).

On reflecting on the action of using the shared drawing space, it was realised that the dialogues occurring were liable to take sudden unexpected turns, the importance of which could only be realised some time after the event, at which time, often, the details of the thought or inspiration may have been lost within the impetus of the process. Originally, the phase 1 exploratory work had tried to provide a mechanism to capture the spoken essence of these design process nodes (Ehrenzweig, 1968) for playback at a later occasion, ie once the importance of the comments had been realised. The limitation of this method of working lay in the fact that quite a significant amount of conscious effort was required to lay down the sound 'bites' whilst the incidence of wanting to replay the sound may, on the whole, be quite low. Also, the process was quite invasive to the design/creative process - it was largely used for an individual working alone; necessitating the individual to speak out loud during creative thought, whereas the shared drawing space had spoken dialogue as an inherent part of the creative process.

Consequently, preliminary cataloguing of the whole drawing/design process was attempted using a digital video camera and playback via a computer file. This was explored in this phase as a tool for the practitioner, but later in the process of reflective practice it was also reinterpreted as a research tool. This happened largely because the shared drawing space encouraged those working within it to articulate and be explicit whilst still continuing to generate ideas; ie, it became a non-invasive way of stimulating a design episode commentary.

Since mark-making is not always a particularly dynamic visual event, the smoothness of playback was reduced in order that the resulting digital file was considerably reduced in size. The sound file was not altered in this case such that the resulting file was effectively a soundtrack plus a series of still images of the drawing space. 5 frames per second appeared to be adequate for most drawn events. The overall result was that of 'talking hands which draw' and it was interesting to notice the amount of gestural communication which occurred over the drawing space. The possibility of digitally cataloguing the drawing process, including any cooperative working, is becoming increasingly feasible and was demonstrated on a small scale, as part of this study.

Reflection on this gestural communication in the context of the use of the computer as a process tool to review the drawing/design process suggested the development of some symbolic objects for use 'in camera'. The use of a projection dice, node marker, orientation marker and tangential marker was explored practically and is described in chapter 2. The symbolic review objects were a bare minimum of notational symbols which, when used with the dense and ambiguous symbolism of the generative drawing, overlaid points of reference which themselves could become focal points of meaning and possibly reinterpretation. Therefore, the resulting footage, reviewed as a largely non-linear record on the computer, became a layering of at least three separate symbol systems - generative drawing, natural language and the symbolic review objects. This in itself could be considered to constitute a density of symbol systems and it was seen practically to facilitate different interpretations from the same information - itself a requirement for density.

A dialogue from one particular episode of designing where the dice came into use is transcribed in appendix 2. In this particular case the dice was initially used to clarify the drawing projection under discussion. That is, the notational symbolism of the dice was being overlaid onto the ambiguous symbolism of the drawing in order to clarify the design move

(using the term of both Goldschmidt (1991) and Schön (1983)), as outlined in chapter 2. However, it was evident from the video footage, that the dice itself became instrumental as part of the discussion by interacting with the natural language to identify the route of the ambiguity under discussion.

Overall, it was observed that it is possible to introduce symbolic objects which have a useful, if momentary, role to play in generative drawing, at least in a cooperative working situation. In this situation, the object can become a communication 'prop' and can serve to focus and externalise natural language discussions, by introducing another level of symbolism.

Drawing on a paper roll was found to produce an unedited stream of generative drawing which was useful for the researcher and practitioner alike. The initially intimidating effect of the large empty white roll of paper was observed to recede and the idea of a specific site or place to generate ideas appeared to become increasingly stimulating and useful. Drawing rolls were used with clients on live design projects with great success and they continue to be integrated into the practice. They have even become a medium of presentation for those projects where the client wants to get actively involved in the creative process and be a party to all of the work.

Reflection on the observations of phase 2, along with certain literature discovered (particularly involving the relationship between the image and the drawing) generated the basis of phase 3.

Phase 3: The Back Projection Drawing Table

Having produced a fairly sophisticated and workable system for cataloguing and reflecting on the shared drawing process (phase 2) and with some experience of developing design process objects (phase 1), attention was turned to actually affecting the drawing process, ie the

production of tools for drawing in the design process.

Reflection on the concepts of goal image and image-percept hybrids in the literature (particularly Arnheim 1995, but also Goldschmidt (1991), Fish (1996) and Hockney (1999)) resulted in the idea of evaluating the use of a temporary image brought to the drawing surface for use in the generative drawing process. The relevance of bringing the image to the drawing was thought to relate to a number of issues including depth perception, reference frames and drawing in context as covered in chapter 1.

Practically, the complexity of bringing a permanent image to the drawing surface (say, through a print process), made it difficult to pursue these ideas until phase 2 and the use of the cataloguing digital video camera (DVC), when a new possibility serendipitously presented itself. This was, that the DVC could be used to capture and replay images on and off-line with regard to the drawing. The problem was finding a mechanism by which the image could be taken to the drawing. One solution lay in using simple projection - paper (which, from the outset, was defined as an essential element for the drawing used in this research) is an excellent projection screen. The obvious solution was to use back projection to avoid the problems of shadow casting.

A glass top drawing table was constructed, allowing captured images to be projected from underneath and allowing a paper roll (from phase 2) to be used on its upper surface, as the drawing space. Practically, it was observed that people drew over the projected image and into the space around it. This blank frame around the temporary image was found to be very important in order that any design directions stimulated by the presence of the image, could be pursued into the 'open space' . Also, the scale of the image at approximately A4 appeared to be about right - it was an appropriate size for the wrist/elbow movements used in generative drawing. This size was arrived at by trial and error and in consultation with others

who tried the back projection drawing table.

Bringing an image to the drawing surface allowed the creation of composite images constructed from drawings plus other sources. The DVC image projected onto the drawing surface allowed non sequiturs to be offered up to the generative drawing, in the search for unexpected connections.

The cataloguing and retrieval methods developed in phase 2 were used successfully for review and editing of drawing/design process material in phase 3. The need for other objects to assist in the review of any catalogued material quickly became apparent. Some phase 2 objects were further incorporated into the phase 3 work, most notably the symbolic review objects (projection dice etc).

Whilst much effort was expended in bringing an image to the drawing, through back projection, the potential for bringing the object to the drawing was also explored. The digital video camera provided an opportunity to capture images of a variety of scales of object and bring them almost immediately to the drawing site. It is thought that these images were useful in terms of 'freeing working memory', to allow focus on partial problems or solutions as suggested by the literature of Simon (1969), Fish (1996) and Purcell and Gero (1998).

Practically, the interplay between the drawing and the projected image appeared to influence perceived depth and allowed basic layering to take place. It also allowed structuring of the drawing to take place, whereby the frames of reference evident in an image could be appropriated for the drawing. This appropriation sometimes took the form of a corruption of the original frames of reference and could therefore be said to initiate reinterpretation, instigated by the image, not the drawing. This was considered to be, at times, a serendipitous process and was assumed to be analogous to the 'reference frame reversals'

described by Purcell and Gero (1998).

Using the descriptive terms of Goel (1995), the density and ambiguity of the symbols used only became apparent when the image was removed and the drawing viewed alone. This may be a positive aspect in that the drawing is operating as an assemblage of partial problem areas, however, there is a possibility that the structuring (frames of reference) brought about by the presence of the image may be inhibiting reinterpretations, in conflict with the previous conclusion.

The bringing of a contextual image to the generative drawing may fixate the design team and create problem boundaries which are incidental and misleading. Choice of image and the duration of use in the generative cycle is thought to be crucial. This observation concurred with the experimental work of Suwa, Purcell, & Gero (1998b).

Drawing tends to be monocular since depth is cued in the conventions selected, for example, perspective cues depth with foreshortening and convergence. However, much of the video evidence produced shows an interesting variation in viewpoint between the draughtsperson and the drawing - the head is rarely in the optimal viewpoint, even during the actual act of drawing. This reinforces the idea of the descriptive function of generative drawing as an inaccurate external representation as opposed to an accurate depiction as discussed in the works of Goodman (1976), Fish and Scrivener (1990), Goldschmidt (1991) and Suwa, Purcell & Gero (1998a).

In terms of the onward connection of this phase with the next in the cycle of reflective practice, the main issue of phase 3, namely, bringing an image from elsewhere to the drawing site, was considered to be enduring. Therefore, it was retained, but practically the situation was reframed when, during a search for literature, the serendipitous discovery of some other

drawing interface equipment occurred.

Phase 4: The LCD Drawing Interface Table, With CCTV Image Capture

Further literature searching in attempting to develop a non-invasive and reliable back projection drawing table, central to phase 3, resulted in the serendipitous discovery of a commercially available drawing interface, generating the basis for phase 4. The idea of bringing the image to the drawing was continued in this new phase once again informed by the concepts of goal image and image-percept hybrids in the literature (particularly Arnheim 1995, but also Goldschmidt (1991), Fish (1996) and Hockney (1999)). A consequence of the discovery of the drawing interface was that the emerging interest in the CCTV camera as an instantaneous image bringer could be practically developed. The drawing interface was successfully integrated into its own drawing table, with a series of selectable CCTV cameras enabling images to be fed back around the loop of being displayed under the drawing surface (on the LCD screen). This was practically observed to result in a very flexible and functional work space for generative drawing. However, one observed limitation to this was one of orientation - the graphical user interface used on the drawing interface unit tended to have a top and bottom or up and down. This could be modified or eliminated in any software re-design or physical table re-design.

The CCTV camera 'tools' were produced as three physical variants. Practically, they allowed a variety of image types to become available at the drawing surface including silhouette, macroscopic view, instantaneous drawing 'scan' and images of objects or large scale sites. In particular, taking the CCTV lupe to the drawing surface was seen to instantly produce a reinterpretation[138] of the marks through a change of scale and reframing. This reinterpretation

[138] This happened in a way which was analogous to a digital drawing produced as a high resolution file which can then be magnified almost immediately and by many times; the hybridized system of pencil, paper, camera and interface was seen to effectively borrow some of these benefits and bring them to the disposal of 'traditional' drawing materials. Practically, this was relatively invasive to the act of drawing itself, but refinement of the system would no doubt eliminate this.

was taken to be a desirable attribute in relation to the work of Goel (1995), who linked it with the lateral transformation of ideas; ie the CCTV camera 'tools' appeared to have the potential to encourage divergent thinking through reinterpretation. The Aerial CCTV camera object appeared to be the most useful in capturing images from a variety of different sources, if one definitive 'tool' was required. The Lupe CCTV camera was also practically very useful particularly for the fact that it resided on the drawing surface and could be brought into play with the minimum of thought or effort.

One specific practical problem which quickly became apparent was that of switching between digital stylus and traditional pencil or pen. This was addressed in the speculative design of some hybrid pen/pencils for the Royal College of Art show (see appendix 7).

In this phase of practical work, the drawing interface element was used almost exclusively with bit-map based 'painting' software and this appeared to be appropriate in accordance with Fish (1996). The quality of line or image, was of course largely a function of the software. Reflection on this aspect suggested another possible exploratory avenue - namely, the investigation of ways in which to introduce material and feedback qualities into the digital domain. Unfortunately, it was not possible to pursue these within the timescale. In addition to mark-making, the drawing interface stylus could also be set to be used as a spatially sensitive switch. Practically, this switch was set, through the interface, to activate a number of functions including a 'stamping' function; whereby the noise of a video image could be reduced to enable edges to emerge and 'figure-ground reversals' to be available instantaneously, setting the pen button to 'invert' within the software. Whilst 'figure-ground reversals' were found to be extremely simple to arrange in the digital domain, within the hybridised domain, the use of the CCTV camera capture was seen as an advantage so that paper drawings could also benefit from image manipulation in the simplest possible way. This provision is significant for the reasons outlined in Brandimonte and Gerbino (1993), who

propose the link between the perceptual processes which act during 'figure-ground reversals' and the mechanisms which drawing provides in terms of mental imagery and reinterpretation in the design process. As in other areas of the practical exploration, ultimately the encouragement of reinterpretations was seen as an indicator that a tool or process could assist in the lateral transformations of ideas (see also Goel (1995)), ie divergent idea generation.

Exploiting depth perception, a number of non-blank, non-white digital drawing backgrounds were developed and explored using erasure as the mark producing mechanism. Some interesting depth effects were observed and the backgrounds were observed to intrinsically increase ambiguity within the resultant drawing, thereby potentially assisting in producing reinterpretations and potentially the lateral transformation of ideas. These drawing backgrounds would have merited further investigation had the research continued past this final phase.

In order to draw the project to a close in the most rounded way, the assistance of some colleagues was used more formally in this, the final phase of the practical work. The colleagues, who tried the phase 4 equipment for set design exercises, were observed to choose mainly to draw directly using the drawing interface. On reflection, it was believed that they were basically responding to the novelty of the situation, and were perhaps not as patient as I was in trying to use the assemblage of equipment. In addition, the brightness of the LCD screen of the drawing interface was limited. This meant that the only paper which could practically be used as an overlay was tracing paper or draughting film. This tended to have the effect that the drawing interface would be used alongside the paper as opposed to beneath it, as with the original phase 3 drawing table. Consequently, the role of the hybridized drawing space became more informal and perhaps more fragmented. This was a disappointing limitation which, in hindsight, would have been technically relatively simple

to improve if timescales had not been constrained.

The accidental was seen to play a part in the digital domain drawing, with accidental fills, captures and non sequiturs all observed during the practical explorations carried out by myself and the colleagues. This was quite a significant observation, in the context of the paper by Fish and Scrivener (1990), who identified 'the vagaries of conventional media' as being the mechanism by which the serendipitous may be encouraged and the advantage which traditional media have over computer based drawing as a site for generative work.

One of the participating colleagues spent considerable time trying using the CCTV camera objects to capture an image of some woven material. He then realised that it was easier to just draw the material from observation/memory. This was thought to be an anomaly which probably came from the novelty of the work space more than anything else, but may well have been symptomatic of the crudity of the system. This latter one is an important general point to make; that exploratory systems for drawing have to be developed to a good level of sophistication in order to stand a chance of being selected by the practitioner, given the alternative of, say pencil and paper.

Comparison of the two generative drawings of the colleagues revealed that one colleague appeared to have accessed more densely ordered symbolism and perhaps approached the design task with a strategy involving more detail, having segregated problems and/or solutions into partial ones; a 'working memory' practice discussed in the works of Simon (1969), Fish (1996), Purcell and Gero (1998). It was unclear whether this was a function of the individual or the task since the equipment was the same for both colleagues. However, this said, both colleagues managed to make at least several lateral transformations of their ideas, in the limited time allotted.

All of the practitioners who tried generative drawing using the drawing interface attempted to annotate their drawings through handwriting and there was some concern over the relative difficulty in using the drawing interface for this function. I took this as evidence that the structuring of design process often occurs in parallel with generative drawing. This suggests a modification to the design process model proposed by Goel (1995) and shown in illustration 2. Furthermore, the need for provision of speech or writing capacity in any digitally mediated drawing system is one which is in accordance with the conclusions of Fish (1996).

Anecdotally, all of the participating practitioners found the immediate access to different colour (digital) mark-makers to be a useful attribute for indicating hierarchies or different components or materials. This speed in changing 'tools' was thought to be a minor advantage which the digital drawing had over the traditional one.

The idea of the unedited paper roll which was developed in the phase 2 experiments was reconsidered within the digital domain as a scrolling window. In a sense, whilst the materiality may have been compromised, the scrolling drawing became a truly hybridized record of the drawing activity in that it could also contain CCTV images and images of paper drawings, even sound, in one continuous medium. It was felt that this 'digital paper roll' offered closure to a much earlier idea and in effect the research had gone full circle.

In summary, the technological tools supplied in the informal hybridized drawing site took time to assimilate. Some forced certain modes of working and possibly led to a less ambiguous environment for generative drawing, perhaps due to their lack of 'materiality'. However, this was by no means conclusive and it is quite possible that computer speed, display and sensing resolution and memory advances can assist in more suitable technology, if it is considered beneficial.

Benefits and Limitations of Reflective Practice.

Within this project reflective practice has been used to generate a number of inter-related practical areas. The initial setting of overall project boundaries was relatively unproblematic since scale, cost, time, technology etc were relatively straightforward to establish and did not allow too much latitude. However, as expected with reflective practice, regular reframing of the research occurred stimulated by my own on-going research action, my own design practice, a search for new literature, the evaluation of new equipment or practices and the contributions of other practitioners. This constant reflection and reframing led to the generation and exploration of previously unexpected areas of practical interest in a broadly systematic way, not dissimilar to a design process.

The problem of exploring cognitive functions which operate within the context of professional practice is one which cannot be underestimated. Reflective Practice itself does help to address this problem, but probably also introduces its own intrinsic problems as identified in this work; namely, the problems of articulation and potentially, post rationalisation. These were considered to be part of the territory of using reflective practice in research.

Another of the problems with research through reflective practice is that of identifying satisfactory closure. This is analogous to closure in an industrial design project (itself reflective practice, of course), which tends to be a function of the skill and experience of the designer. I would acknowledge that the analogous skill and experience within the research project had to develop in parallel with the research itself: A process which, I suppose, was a personal objective of the project.

At the very least, by conducting this project I have personally gained an insight into, and

practical appreciation of, research through reflective practice and am conscious of the great difference between it and Technical Rationality (which still dominates through education and institutionalisation). This is an issue of great importance to anyone attempting to research in the area of Art and Design and one which continues to be debated in many quarters.

The problem of trying to use exploratory practice in a commercial design studio situation cannot be understated. The pressure to fulfil commercial deadlines takes priority over the research and clients are not necessarily interested in the intricacies of design process. Hence the most successful experiments in this situation tend to be the least invasive 'small steps' which can be accommodated with little or no disruption or time penalty. When the use of exploratory techniques on 'live' projects was possible, the results were often not communicable because of the issue of client confidentiality. The only way around this problem was to show drawings and design process which are anonymous, that is, to remove the context when presenting drawings to a third party. An example where this was the case was in the phase 3 work included in this thesis.

Final Conclusions

The rate of change of technological innovation is currently phenomenal and it appears to be accelerating. The emergence of 'electronic paper' - Gyricon[139] , in the last twelve months in a sense contextualizes this research, giving a short term horizon for speculation.

Referring back to Deanna Petherbridge's quote at the start - the effect of purposely introducing 'technical considerations' which is implicit to the original hypothesis has proved interesting, if technically problematic.

[139] A Xerox innovation.

Some attributes of the digital domain were observed to actually assist in encouraging some of the cognitive processes identified (through the literature) as important in generative drawing. Practically, examples of figure/ground reversals, density and ambiguity of symbolism, reinterpretations and the lateral transformation of ideas were all observed when the technology was taken to the generative drawing site. However, the materiality of the technological side of things was felt to be lacking and it was difficult to remove Petherbridge's 'technical considerations' from much of the practical phases. This resulted in equipment which was often difficult to use and certainly not as flexible, economical or spontaneous as paper and pencils.

Furthermore, in response to the original motivating contradiction; in my commercial studio practice, we still use paper and pencils for our generative drawing!

Suggestions for Further Work

(1). The development of a hybrid of the final phase drawing table with the earlier, phase 3, back projection drawing table is suggested. This would have the effect of producing a more strongly back lit table, satisfying the original aim of projecting the drawing interface/CCTV images directly onto overlaid paper, producing a truly hybridized system.

(2). The development of variable feedback pens/styli for use with emerging technology is suggested as a potentially helpful route. The objective of a study could be the exploration of the nature of materiality in drawing as a special case of human computer interaction.

Appendix 1a

Rosenberg, T. Drawing Workshop: Interrogation and Reflection on Worlds of Objects. Royal College of Art. Internal Project Brief. 1996.

DRAWING WORKSHOP
AN INTERROGATION AND REFLECTION ON WORLDS OF OBJECTS

INTRODUCTION

I	See	D	Mind
	Feel	R	Eye
	Imagine	A	A world (of the) heart
	Analyse	W	Senses

SUBJECT	PREDICATE	OBJECT

A drawing inescapably reflects the subject, predicate and object in the sentence above. It is a formula that involves 1. The doer 2. the perception/depiction and 3. a world imagined sensed emoted or seen It is always of and about all three aspects.

This project seeks to draw attention to this through reflective drawing. What we are asking in this project is to interrogate in drawing : drawing itself, examining the 'I' drawing; the act of drawing; and the world represented

An interrogation that expects no answers in the usual sense but one that offers latent significances and pure possibilities (which will help and may develop into designs at a later stage).

So that these investigations are not determined by preconceptions - finding only that which we set out to seek ,we need to find disruptive strategies in drawing and thinking at all levels. The drawing surface is to be thought of as a place to think in action, not, in this instance, to present already determined designs.

"The creative thinker has to make a decision about his route without having the full information needed for his choice. This dilemma belongs to the essence to creativity. It is necessary to cloud one's consciousness in order to make the right decisions"

Ehrenzweig

"I do not seek; I find" Picasso

We need to relinquish our need for stable focussing and rational coherence till much later in the whole procedure.

THE INTERROGATION

1.THE NOUN

Select objects that take your interest - NOUNS in the constructions of language.

Consider them as riddles, as objects shrift of function, never seen before. Try and understand their nature in the duplicity of representation.

2.THE SYLLABLE

Disassemble the objects looking at them in their constituent parts. These components relate to SYLLABLE in language. Take these components and prod, stretch, warp, twist them in drawing.

Break these components down further so they become plane, pivot, line, shape, pure form PHONEMES (pure sounds).

3. THE PHONEME

The Phoneme in the language/object which is realised only in representation. The component is to be seen in its universal/particular and explored in both aspects. Like a child's first attempts to understand the world around him/her the component (Syllable) is to be subjected to a series of play/tests in its representation. Play with its substance, its scale, texture, the aspects of it you are representing and the modes of representation (plan elevation, perspective, fragment, profile). Remember the drawing is our understanding. The drawing as a process should throw up new solutions and suggestions.

There is a fundamental narcissism in this, a reciprocity between us the explorers, the exploration and the territory explored.

Play, therefore with your structures of understanding-
Ie: the drawing itself.

Invent obstacles in methods, materials, and perceptions so that you may explore the world ahew. What you draw at this stage will become the generating axes for new elements, mechanisms and objects.

4. HYBRIDIZATION

Assemble the newly manipulated forms into new configurations building hybrids from the variety of invented forms. Choices at this juncture are purely aesthetic, although we should be directing our attention to possible objects - back to nouns of the future (sic)

5. ADJECTIVES

Adjectives may be conjoined to the object/noun and the drawing of them. Thus we may have, aggressive, soft, fragile etc. structures and drawings. A description divorced from function. These adjectional nouns may begin to suggest possible functions and contexts.

6. VERBS

These functions are the verbs of this language in objects. The newly organised configuration should begin to murmur - hinting at possible new workings and meanings. These too are to be explored but only as possibility in drawing.

7. ADVERBS

Adverbs qualify the verb. Therefore the adverb is the way the thing functions Eg. economically, noisily, softly, cheaply. These are the final consideration of our procedures. In our normal design procedures these may be our starting point.

CONCLUSION

This stripping down of procedures and thoughts may offer up richer veins for exploration - than a rigid and deterministic approach.

I DRAW THINGS

The object of the language formula above has been explored through de and re construction.

The predicate Ie. the action of drawing will have been explored through the materials and the physical and mental activity involved in representation.

The subject will be detected not only through the physical activity involved - manipulation of hand/drawing took, coordination of eye - but also in the choices made at each level of the procedure; by association made and followed.

Extend all of this into a context in the world and one may see a way of defining the design, the designing and the designer culturally, mythically, socially and politically.

Appendix 1b

Rosenberg, T. Drawing and Modelling Workshop: Getting Real. Royal College of Art. Internal Project Brief. 1996.

DRAWING AND MODELLING WORKSHOP -GETTING REAL

Between the project ' abstract' and the intended product is a space which needs to be filled with creative play; play that seeks to inform the generating context with detail and materiality. Invention may lie in drawing (sic) out possibilities through observation of and corrections (formal and conceptual) between physical phenomena. The spirit or noumena of the work that you are seeking and articulating or desire for in presentations to date can be enriched and infer construction and a material manifestations by addressing what already exists.

By making physical representations of (a) your thought processes and (b) the articulated object and its circumstances you will advance your project.

There is clear evidence in Leonardo da Vinci's sketchbooks (for example) that invention is inextricably bound to observation and the recording of observations. In his drawings and writings nature, man and artefacts are tied together in a tissue of observation (and their representations) that offer up understandings and novel uses.

Your task in this project is to get real. Choose to model and represent what is already (not what is projected!).

1. Use **your project** drawings and models to date. Scrutinise and reverse engineer them to see that opportunities have not been lost in the process.

2. Bring them up to **their influences**. By drawing modelling the project with what has influenced it , you may find information to drive the project on.

3. Draw the projects **neighbours**. The physical neighbourhood in which the project is being worked on. Your work top etc. Being conscious of the circumstances in which you are working may be a useful device in concentrating the project.

4. **The non sequitur** - that which you cannot immediately see the relevance of, may also draw your project into fertile albeit unanticipated territories. Test the relevant with what appears to be irrelevant.

Seek what may move your project from thought to matter.

Investigate:

Mechanisms
Forms and shapes
Colours
Texture
Materials
Structures
Play with the representations of your observations in drawings and models.

DRAW -MAKE - DRAW WHAT IS MADE AND DRAWN - MAKE AGAIN

Timetable:

Tuesday 6th February - PROJECT LAUNCH "Is it all in place" DRAW

Wednesday 7th February - "Checking it out" - MAKE

Thursday 8th February - "Getting Sorted"- DRAW

Friday 9th February - "Sorted" - MAKE AGAIN

Tuesday 13th February - "Getting Real" - PRESENTATION

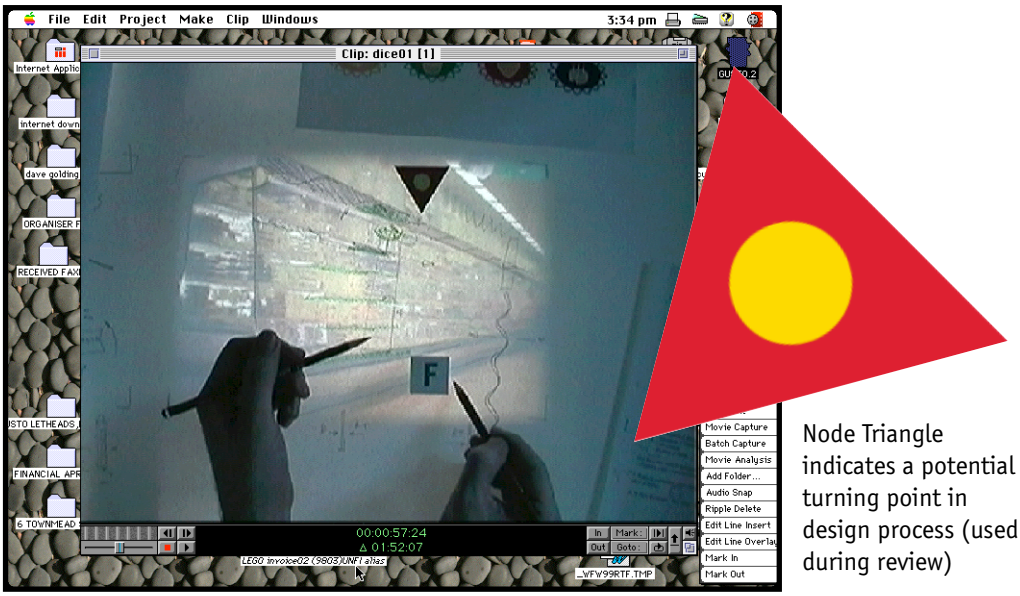
Appendix 2

Transcription of use of 'projection dice' (from DV tape RCA 02)

A: ...maybe they just need to be really subtle, um, actually, another way of doing those to make them less [pause] sudden, is from the front view there [drawing arrow] there, to actually do them like that [drawing undulating line], so it could be like corrugated things
B: Oh yeah
A: so that there's not a sudden...
B: Yeah, which would relate to that there [pointing and drawing]
A: so you've got that hanging down
B: where's the dice?
A: the dice
B: need to put that on there
A: that is..
B: front
A: front view [placing dice with 'F' towards camera]
B: or plan, top
A: it's front view, isn't it? I'm thinking that these things ripple...
B: Ah now, but should it be top?
A: I don't know
B: Cos if you read that as being [placing dice with 'T' towards camera]...top, doesn't that relate more to either direction? Ah, it works both ways, doesn't it? [drawing arrows]
A: no
B: cos if you see it as front view...
A: yeah
B: it's...it is sending it back [gesturing at arrows], you know you look at it... implying that way and that way
A: so you're looking at the plan view of the cabinet?
B: yeah
A: so the products are here? Well I just thought that those were quite big
B: mm
A: so ok, draw it onto here is the best way, if you think about it [starts drawing]
just sort of quite big, almost as big as a product, so from this three quarter view you'd see this wavy...
B: yeah
A: ...thing like that and that would give you the feeling that something ... ended and began but not, kind of, abruptly
B: yeah
A: so, I don't know, it's a thought [laughs]
B: ah, it's nuts
A: It could be quite interesting though, couldn't it? ... unless we put that suggestion in to the structure of it or something?
B: yeah

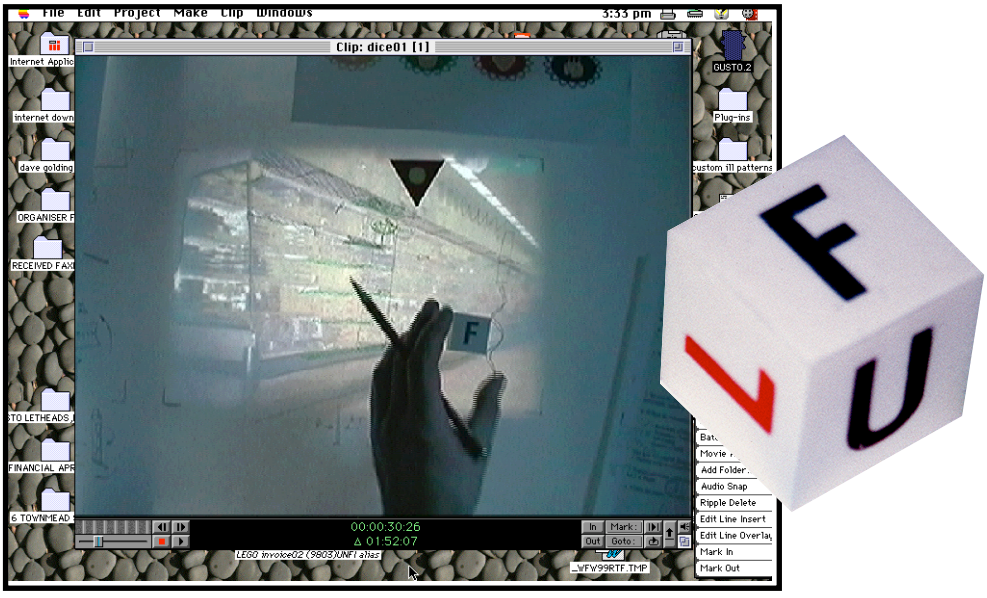
end of episode

(a)



Node Triangle indicates a potential turning point in design process (used during review)

(b)



Projection cube is used to identify views during review

PHASE 3 BACK PROJECTION DRAWING TABLE: REVIEW OF DVC FOOTAGE IN ADOBE PREMIERE

Appendix 3

Phase 4 Experiment: The LCD Drawing Interface Table, With CCTV Image Capture

Date:
Reference: participant B

Introduction

Thank you for agreeing to take part in this experiment which is concerned with an evaluation of the relationship between generative drawing (sketching), cognitive processes brought to bear whilst designing and the potential for some technological mediation or assistance in this process.

Equipment/Experimental Details

You are asked to use the drawing table workspace provided which has a computer monitor built into it and a pen which can be used to draw directly on screen. A selection of different configurations of CCTV cameras are available to capture images and drawings which will then appear on the screen. You are also given tracing paper, cartridge paper and pens/pencils which can also be used. Apart from the use of the computer interface and pen, please work as you would normally on the conceptual phase of a project.

You will be video taped as you work and all of your drawings will be retained for later analysis. Your work will not be used for any commercial gain.

[Demonstration of interface, pen and cameras]

Please feel free to ask if you need help to use the equipment at any time.

Scenario

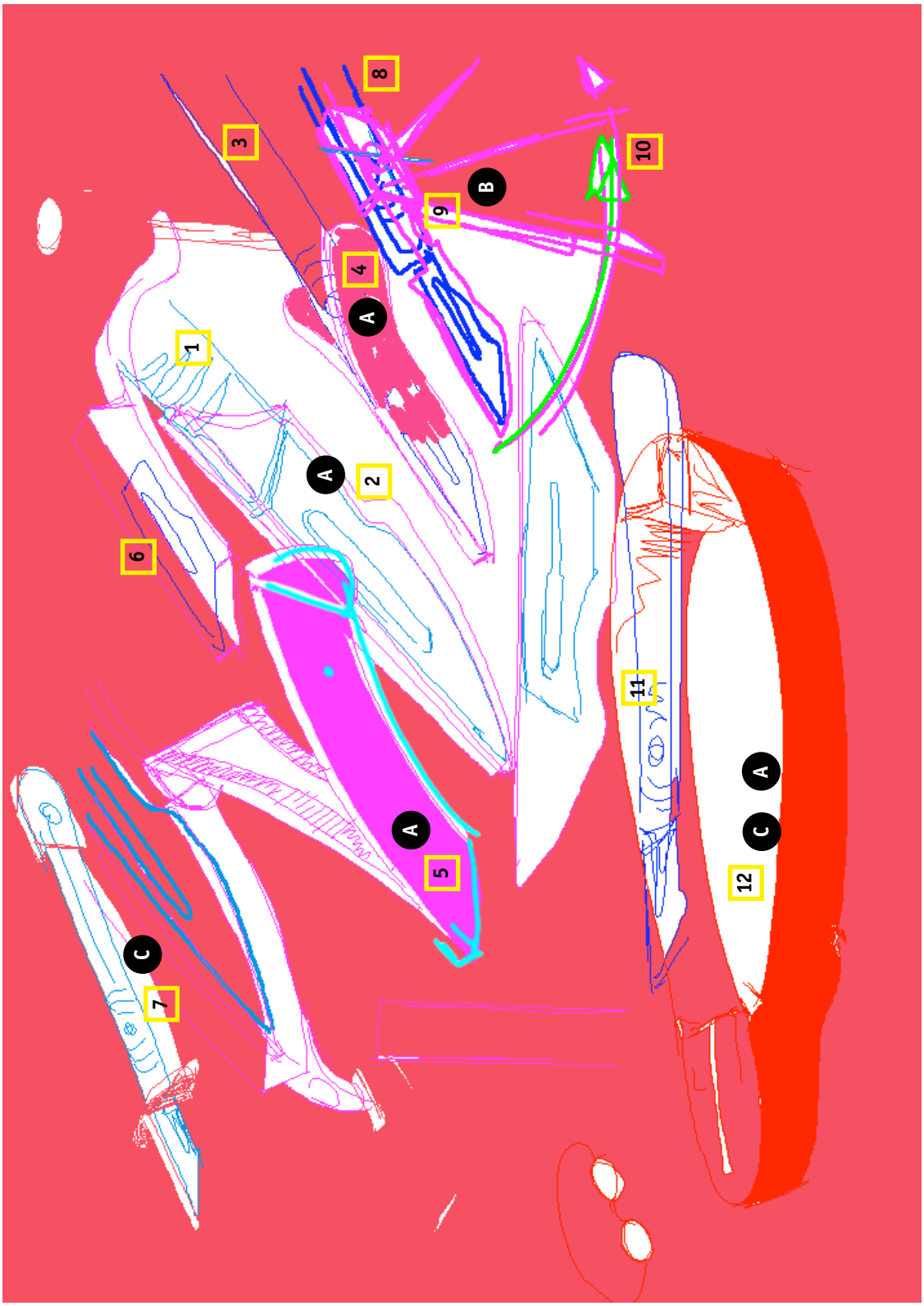
Your client has been manufacturing large quantities of scalpel handles and blades for the last 50 years. Part of their sales are non surgical; ie to the education, art and design sectors.

Brief

1. You are asked to come up with several ideas for a scalpel blade guard or cover which are based around the existing scalpel. The volume of products to be produced is in the 100,000's.

Appendix 3a

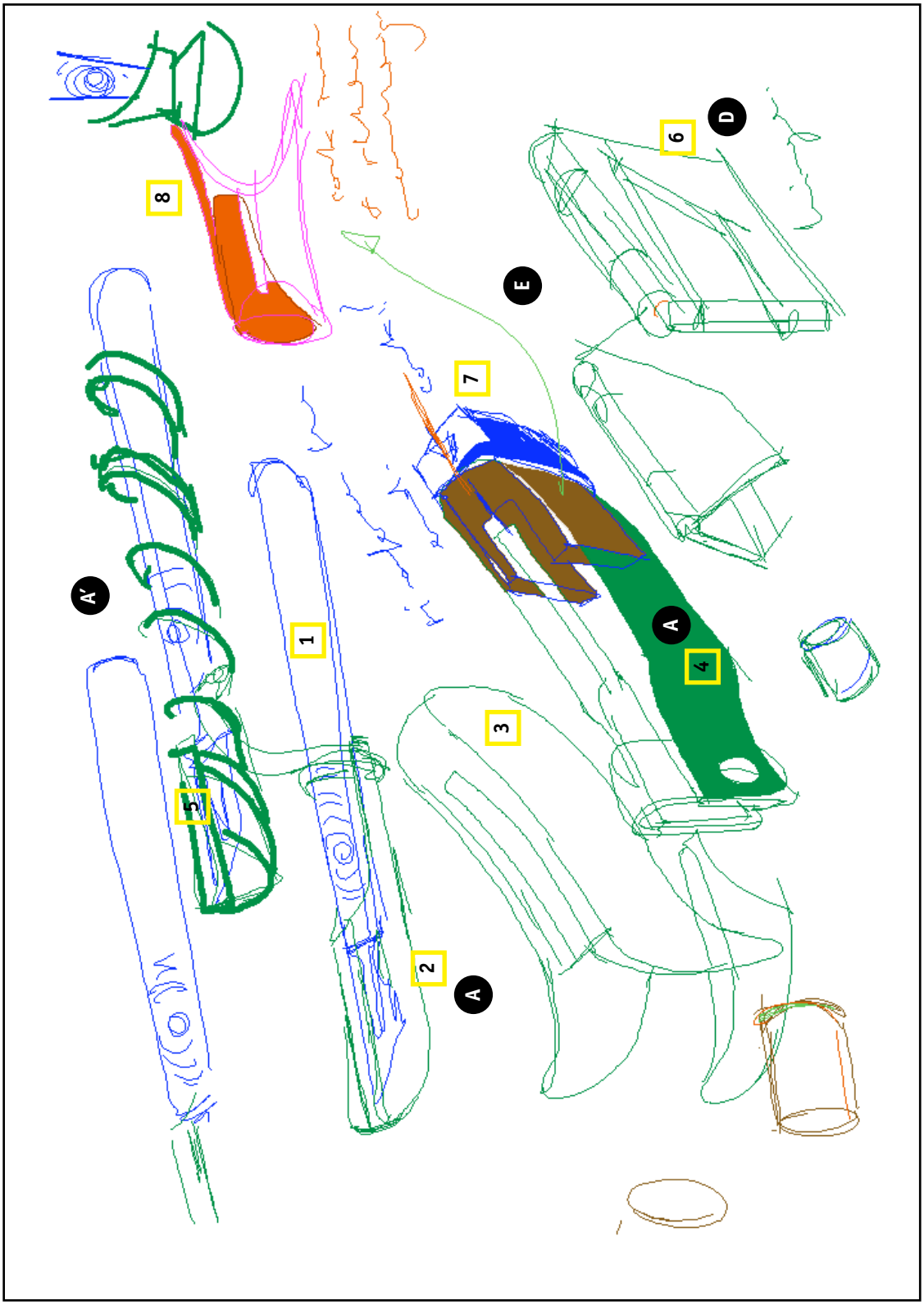
Participant B, scalpel guard brief



Concept/Description

A. Encapsulating Blade: Rubber Moulding **B.** Rotating Head Cover **C.** End Cap & Elastic Band (categorised by participant during review session)

Participant B, scalpel guard brief



Concept/Description

A. Encapsulating Blade: Rubber Moulding **B.** Rotating Head Cover **C.** End Cap & Elastic Band (categorised by participant during review session)

Notes relating to Practical Experimental Methodology:-

Subject:

1. Subject was 'warmed up' after having been drawing (on paper) for most of the day, before participating in the experiment.

2. Video taping took place. However, it was attempted from a tripod with the aim of capturing the subject whilst using the CCTV cameras. The limitations of this technique were immediately realised - during review of the footage it was difficult to clearly see the actual marks being made, although the gestures of the hands were clear. Overhead video taping (as previously used on the back projection drawing table) of the drawing surface plus periphery was considered essential after this particular experiment.

3. 1 Hour tape required per participant for episode plus review.

4. The CCTV cameras and selection switch were not labelled and so there was a brief trial and error period when the participant selected the camera and decided which one had been activated. This is easily addressed.

5. Could ask participant to place something on the drawing surface each time a new idea is generated? might be invasive?

6. When asked to annotate the drawings after having finished the main part of the session, the participant used numbers to indicate the approximate order of mark making and letters to indicate distinct ideas generated.

Notes relating to Analysis of Drawings:-

1. The participant generated two separate drawing 'sheets' (each one 1005 by 712 pixels as supplied).

2. According to the participants subsequent annotation of the drawings; 6 distinct product ideas were generated, with 1 idea resulting in a variation, which could be described as sufficiently distinct , thereby resulting in a probable 7 distinct ideas.

3. The participant identified 20 different drawings or drawing phases in the episode.

Accidental filling of space on Sheet 1 resulted in the magenta background colour

Appendix 4 Participant B, Scalpel Cover Brief

Phase 4 Experiment: The LCD Drawing Interface Table, With CCTV Image Capture

Structured Interview

Thank you for participating in these experiments. I have two further interviewing tasks in which I would like you to participate. It should take no longer than 10 minutes in total.

A. Video Review

I would like you to very briefly take me through your thought and design processes by referring to the drawings you made (response recorded on video).

B. Questionnaire

In order to make sense of the drawing and design exercises you have just performed, I would like to ask you a few confidential questions about yourself, your design process and what you thought of the tasks.

1. In both personal and professional design projects, which of the following are you likely to use most to generate ideas at the start of a design project?

writing talking drawing making computer other

2. For how much of your ideas generation do you draw?

None 1 2 3 4 5 6 7 All

3. How would you rate the practical usefulness of using the computer drawing interface and pen for generative drawing?

Not Useful 1 2 3 4 5 6 7 Useful

4. Did you find the camera tools of any practical help?

Not Useful 1 2 3 4 5 6 7 Very Useful

5. For how long have you been using computers in design?(In Years)

Never 1 2 3 4 5 6 7 8 9

10 10+ Yrs

6. How would you classify your competency in using Adobe Photoshop?

Incompetent 1 2 3 4 5 6 7 Expert

---

7. How long have you been using Adobe Photoshop? (In Years)

Never 1 2 3 4 5 6 7 8 9

10 10+ Yrs

---

8. In the DRAWING INTERFACE DESIGN TASK you just completed, in your opinion, how much of the task was related to each of the following:-

	Low Content									High Content
Form/detailing	0	1	2	3	4	5	6	7	8	9
Communication/ semantics	0	1	2	3	4	5	6	7	8	9
Technology/manufacturing	0	1	2	3	4	5	6	7	8	9

825

---

9. How old are you? 29

Thank you once again for your participation in this experiment.

Appendix 5

Phase 4 Experiment: The LCD Drawing Interface Table, With CCTV Image Capture

Date:
Reference: participant C

Introduction

Thank you for agreeing to take part in this experiment which is concerned with an evaluation of the relationship between generative drawing (sketching), cognitive processes brought to bear whilst designing and the potential for some technological mediation or assistance in this process.

Equipment/Experimental Details

You are asked to use the drawing table workspace provided which has a computer monitor built into it and a pen which can be used to draw directly on screen. A selection of different configurations of CCTV cameras are available to capture images and drawings which will then appear on the screen. You are also given tracing paper, cartridge paper and pens/pencils which can also be used. Apart from the use of the computer interface and pen, please work as you would normally on the conceptual phase of a project.

You will be video taped as you work and all of your drawings will be retained for later analysis. Your work will not be used for any commercial gain.

[Demonstration of interface, pen and cameras]

Please feel free to ask if you need help to use the equipment at any time.

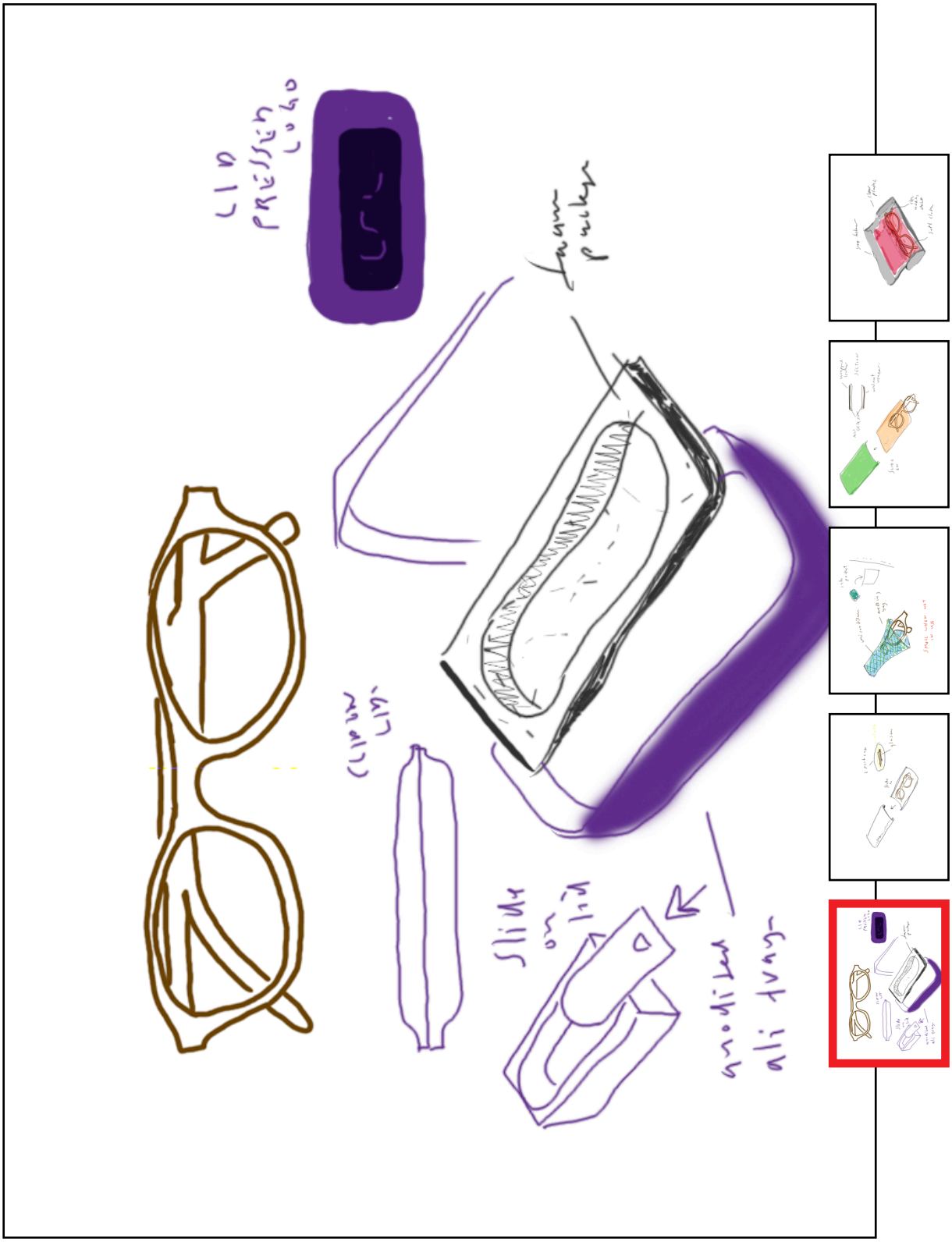
Scenario

Your client has been manufacturing high quality spectacles for some time and is regarded as one of the top brands. However, they 'buy in' spectacles cases, with their own branding applied.

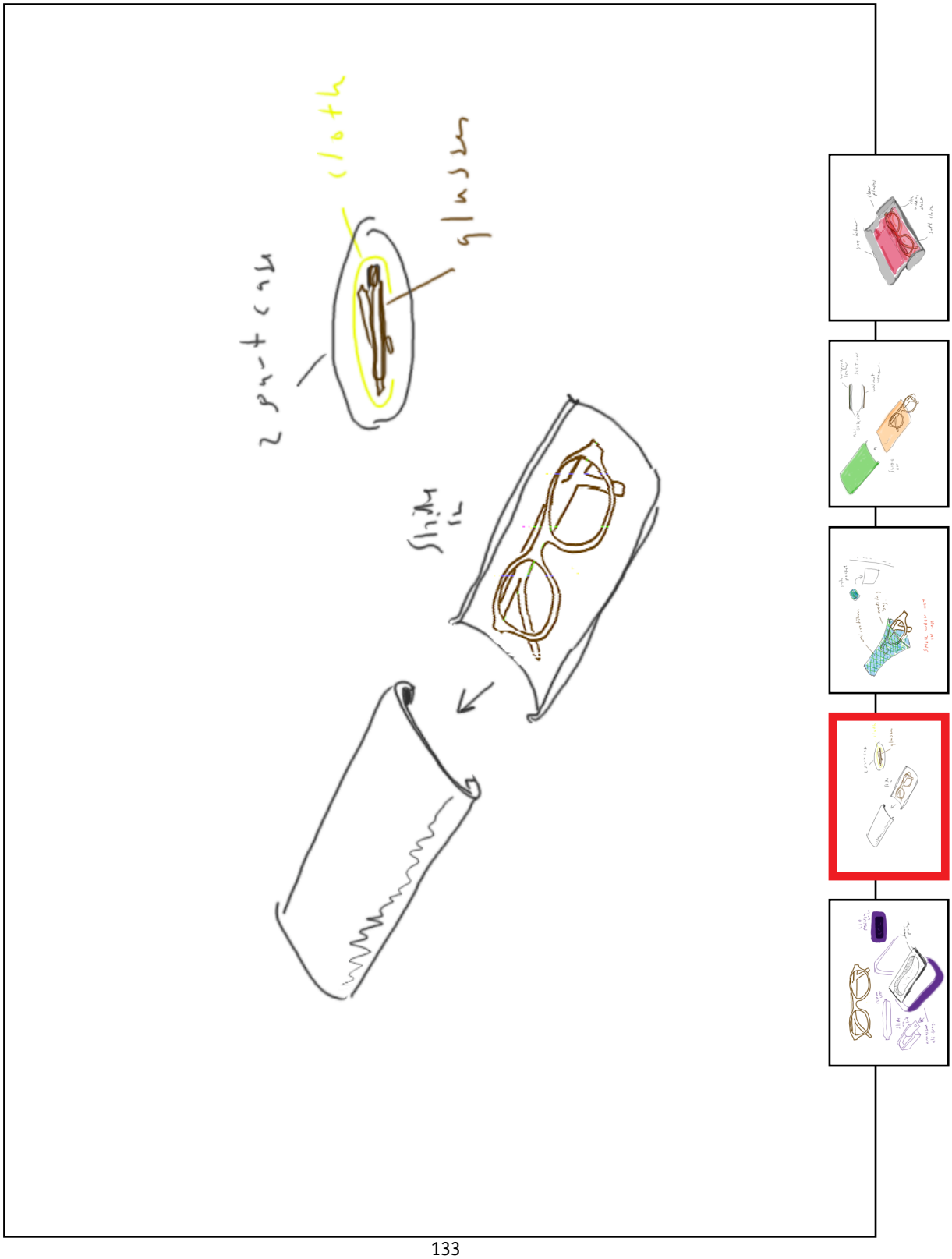
Brief

1. You are asked to come up with several ideas for high quality, 'high' design spectacles cases which will not only protect the spectacle, but also communicate the client's core brand values. The volume of products to be produced is for an initial run of 50,000 units.

Appendix 5a
Participant C, specs case brief

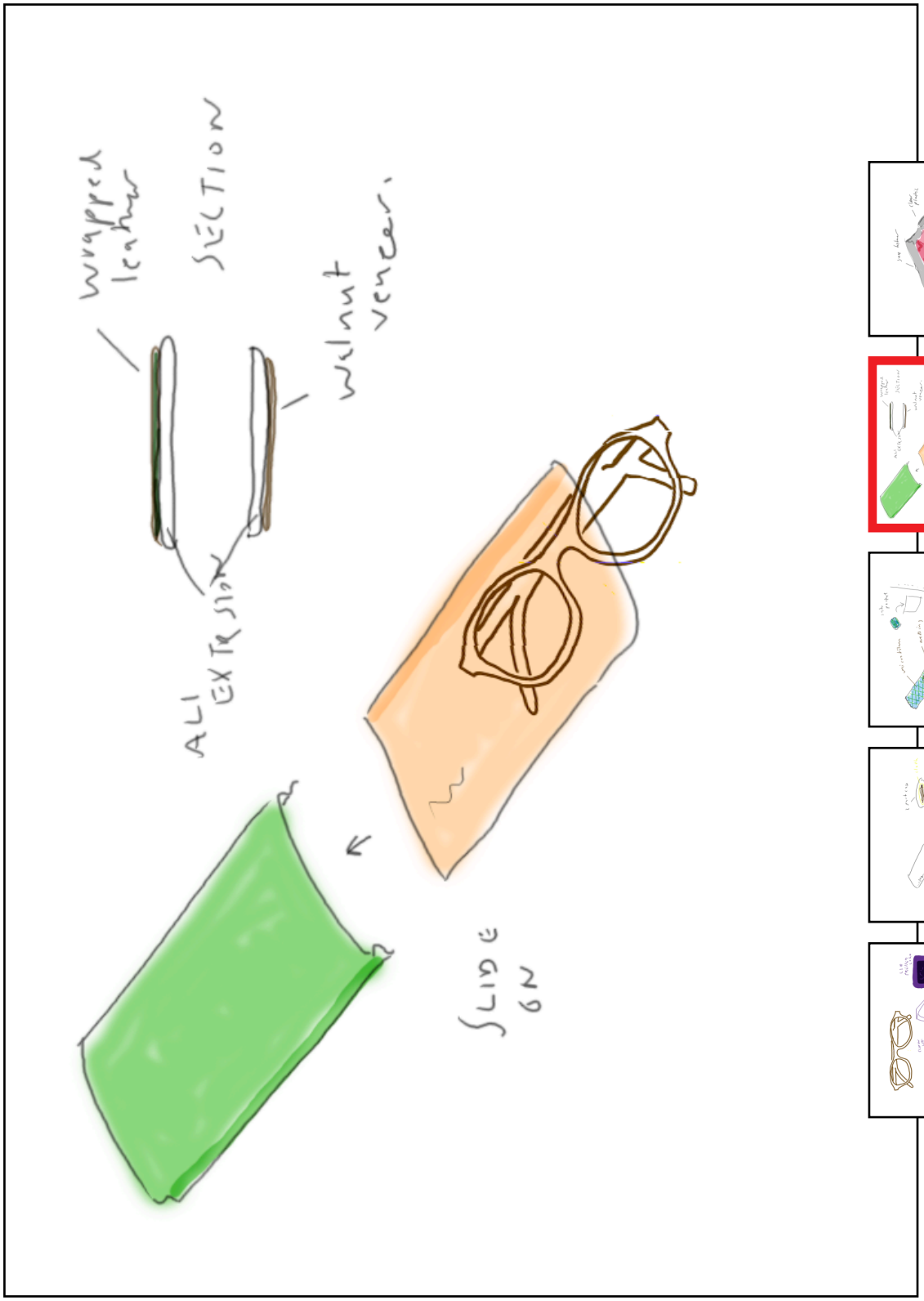


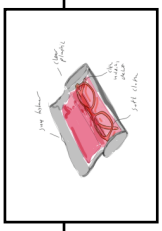
Participant C, specs case brief

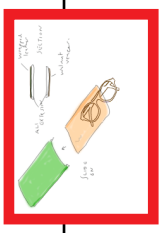


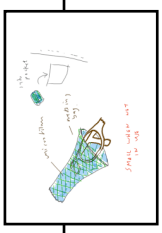
Participant C, specs case brief

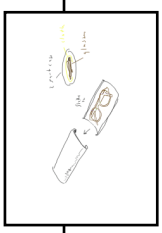
Participant C, specs case brief

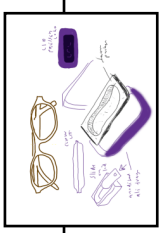




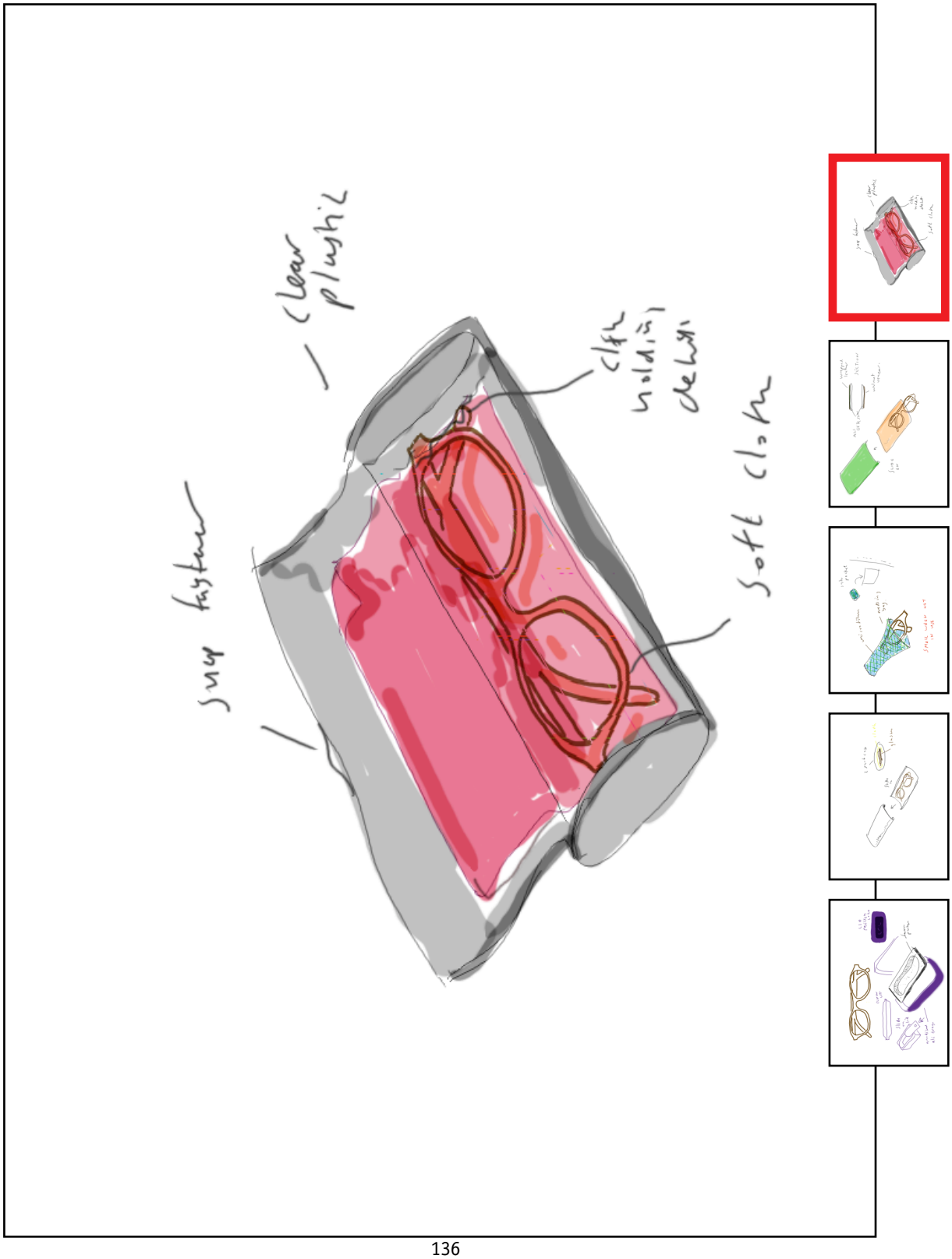








Participant C's process brief



Appendix 6 Participant C, Spectacles Case Brief

Phase 4 Experiment: The LCD Drawing Interface Table, With CCTV Image Capture

Structured Interview

Thank you for participating in these experiments. I have two further interviewing tasks in which I would like you to participate. It should take no longer than 10 minutes in total.

A. Video Review

I would like you to very briefly take me through your thought and design processes by referring to the drawings you made (response recorded on video).

B. Questionnaire

In order to make sense of the drawing and design exercises you have just performed, I would like to ask you a few confidential questions about yourself, your design process and what you thought of the tasks.

1. In both personal and professional design projects, which of the following are you likely to use most to generate ideas at the start of a design project?

writing talking drawing making computer other

2. For how much of your ideas generation do you draw?

None 1 2 3 4 5 6 7 All

3. How would you rate the practical usefulness of using the computer drawing interface and pen for generative drawing?

Not Useful 1 2 3 4 5 6 7 Useful

4. Did you find the camera tools of any practical help?

Not Useful 1 2 3 4 5 6 7 Very Useful

5. For how long have you been using computers in design?(In Years)

Never 1 2 3 4 5 6 7 8 9

10 10+ Yrs

6. How would you classify your competency in using Adobe Photoshop?

Incompetent	1	2	3	4	5	6	7	Expert

---

7. How long have you been using Adobe Photoshop? (In Years)

Never	1	2	3	4	5	6	7	8	9

10 10+ Yrs

---

8. In the DRAWING INTERFACE DESIGN TASK you just completed, in your opinion, how much of the task was related to each of the following:-

	Low Content									High Content
Form/detailing	0	1	2	3	4	5	6	7	8	9
Communication/ semantics	0	1	2	3	4	5	6	7	8	9
Technology/manufacturing	0	1	2	3	4	5	6	7	8	9 735

---

9. How old are you? 29

Thank you once again for your participation in this experiment.

Appendix 7

Proposals for Speculative Commercial Objects

From the completion of the thesis, some of the material ideas and objects were pursued through to a conclusion via an exhibition, for the Royal College of Art year 2000 degree show. A spectrum of objects were exhibited which illustrated the practical and academic aspects of this work and which were perhaps more accessible than a written thesis. Images and brief descriptions of these are included below:

'eKidley' Hybrid Drawing Interface

This is a soft Connolly hide drawing surface which rests on the lap for informal generative drawing. The LCD screen has an overlaid matrix which senses the pen and results in drawing directly on screen unlike conventional computer drawing tablets. The top surface is suitable for paper - encouraging a hybridized approach to drawing as characterised by the concerns of the research project.

Four types of associated objects, intended for use with this drawing interface, are shown on the following page.

CCTV Capture Cameras

The aim of producing a hybridized paper/electronic drawing interface was facilitated by the origination of three types of CCTV camera - the end of the pencil version; the magnetic aerial version and the lupe for magnifying and capturing paper drawings.

Symbolic 'In Camera' Objects

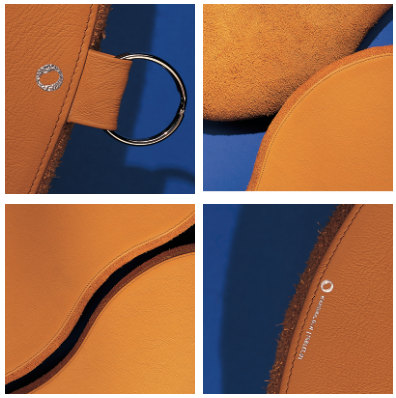
The two examples shown are a projection dice (indicating the orthographic projection used in the drawing) and a design process dice (indicating potential turning points, tangents and points of later interest in the design process).

Speech Recorders

These objects were created to enable the recording of discrete verbal activity during generative drawing and its storage 'within' the drawing (spatially). Practically, this appeared to act to 'free working memory' in order to develop ideas or generate new ones. The sound is recorded and the object is turned upside down to replay the sound 'bite'.

Hybrid Pen/Pencil

One of the frustrations with drawing on both paper and the drawing interface lies in changing between pencil and stylus. These pens address this observation and allow quick switching between graphite and stylus. The removable collar which holds the stylus nib, dictates the digital feedback of the pen - simulating pencil 'softness'. The angled ends of the pens also means that two pens can be connected together to produce more flexibility in terms of multiple pens with multiple settings.



'Kidley' Drawing and Writing Tablets

These tablets came from a simplification and reduction of the 'eKidley' Drawing Interface and, in fact, the removal of the technology element.

They are soft leather drawing surfaces which rest on the lap for informal writing or drawing. The shape results in a good interaction between more than one tablet and therefore encourages group working.

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MPhil, Royal College of Art, 2001

Pencils for Shared Drawing

A slight variation on a familiar object resulted in pencils which help to start the action of shared generative drawing. The pencil is snapped in the centre to generate two new pencils which are re-sharpened ceremoniously. The words on the pencils are aimed at stimulating those drawing and to suggest potentially opposite approaches to the same creative process.The idea was originated in the Phase 2 exploratory work where the shared drawing space was sometimes seen to inhibit the start of the drawing process. It was felt that a gestural object might introduce a small element of ceremony: share the pencil; share the drawing.

Glossary

CCTV

Closed circuit television. Used in the context of the miniature cameras employed in the phase 4 exploratory work in this project.

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Index

Technology as Handmaiden to Generative Drawing
Illustration

Neil Barron
MPhil, Royal College of Art, 2001

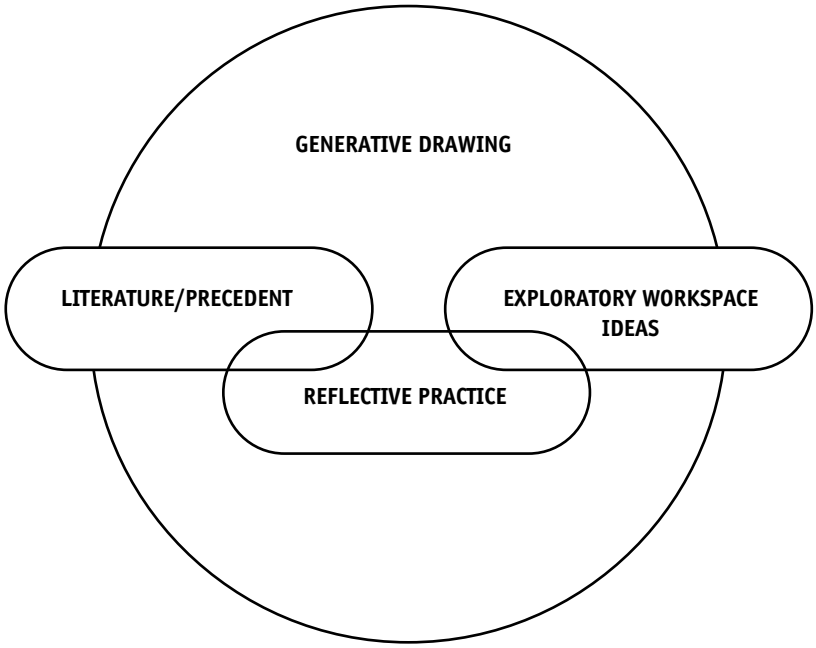

ILLUSTRATION 1

OVERALL PROJECT STRUCTURE
This diagram is an attempt to illustrate the relationship between the main elements of the research. The exploratory workspace ideas and the literature relate though reflective practice to the overall area of generative drawing in industrial design. Not all of the literature or workspace ideas are exclusive to generative drawing.

Technology as Handmaiden to Generative Drawing
Illustration

Neil Barron
MPhil, Royal College of Art, 2001

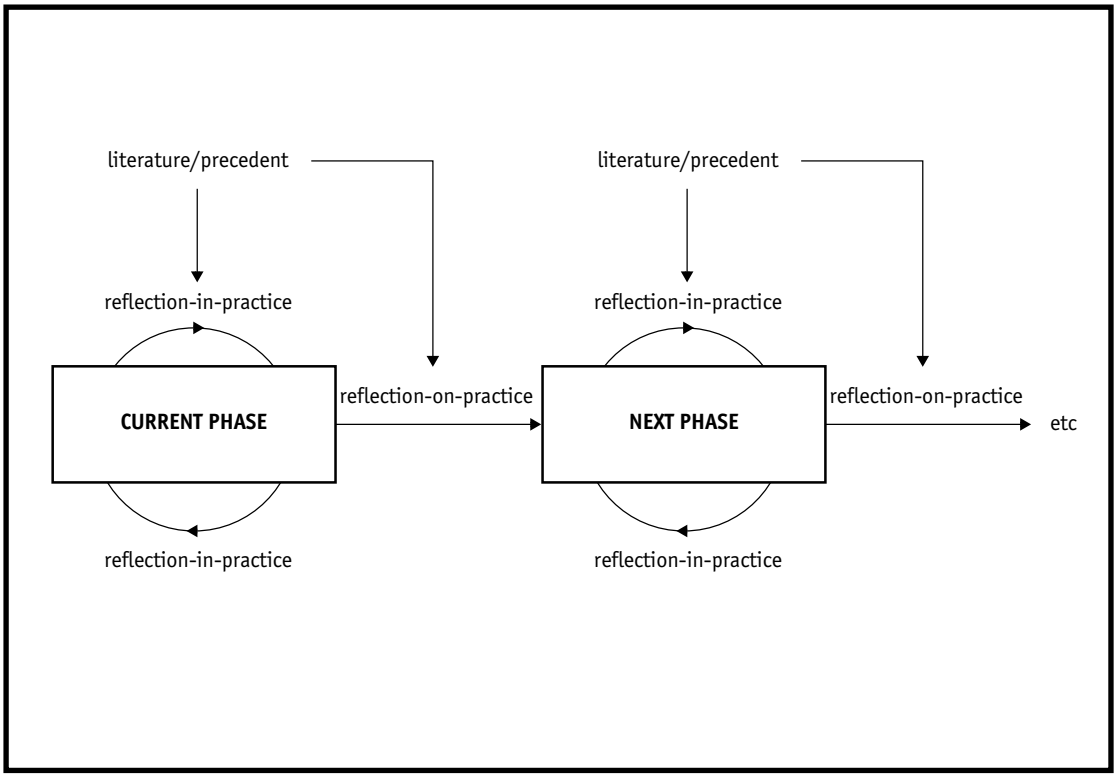

ILLUSTRATION 1a

PRACTICAL PHASE STRUCTURE
This diagram shows the cyclic relationship between adjacent phases of practical, exploratory work under the influences of reflective practice and the search for relevant literature

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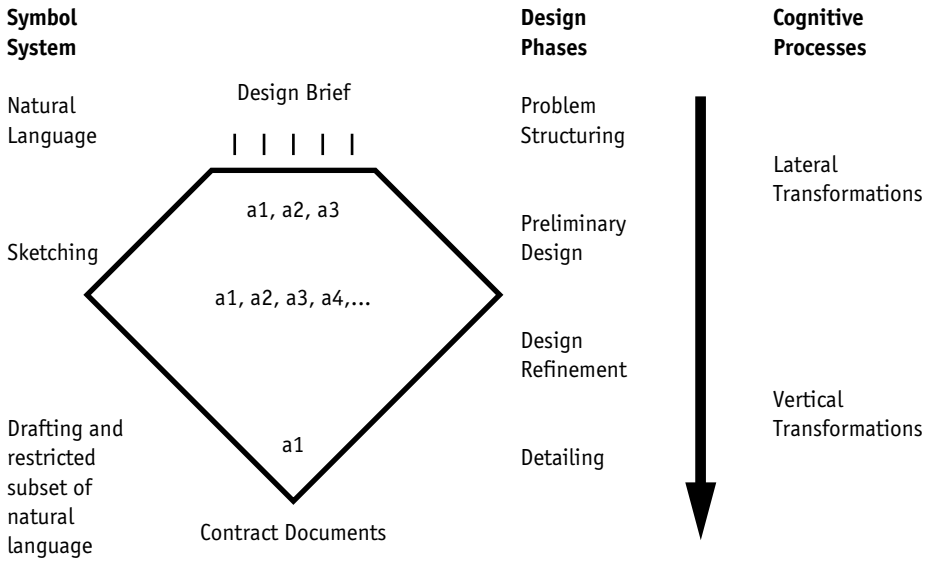

ILLUSTRATION 2

RELATIONSHIP BETWEEN SYMBOL SYSTEM, DESIGN PHASE AND COGNITIVE PROCESSES:
Based on 'Different symbol systems correlate with different cognitive processes' on p 190 of Goel, Vinod. 'Sketches of Thought'. Cambridge, MA: MIT Press. 1994

Technology as Handmaiden to Generative Drawing
Illustration

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ILLUSTRATION 3

ARCHITECT WILL ALSOP AT WORK ON A GENERATIVE DRAWING/PAINTING

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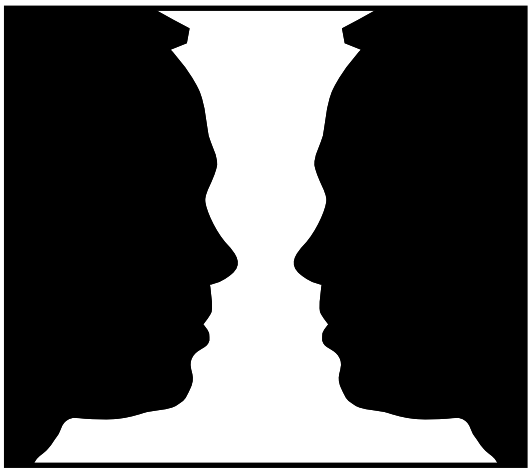

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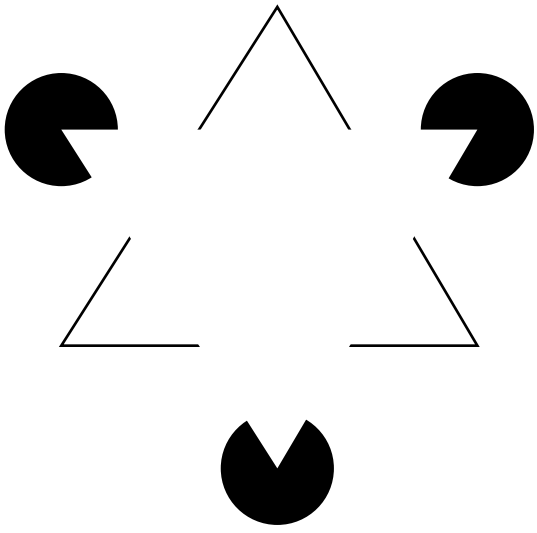

(b)

ILLUSTRATIONS 4(a) & 4(b)

(a) GOBLET
(b) KANISZA TRIANGLE

Technology as Handmaiden to Generative Drawing
Illustration

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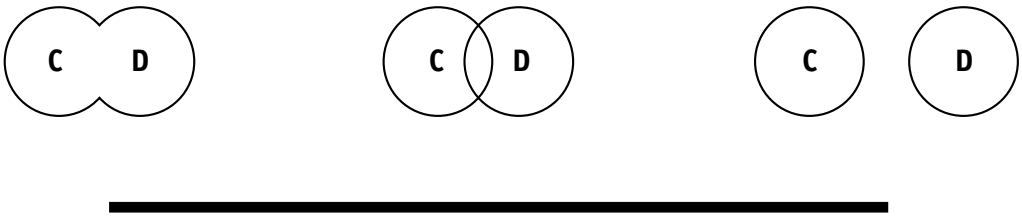

total collaborative working **closure** or **'fait accompli'**

ILLUSTRATION 5

THE SPECTRUM OF INTERACTION BETWEEN DESIGNER AND CLIENT
Clearly, the interaction may change during the course of a project and in practice either extreme is probably quite rare. The total collaborative working end of the spectrum removes the filtering and editing expertise of the designer, whilst the closure end of the spectrum removes the expert input of the client.

Technology as Handmaiden to Generative Drawing
Illustration

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MPhil, Royal College of Art, 2001

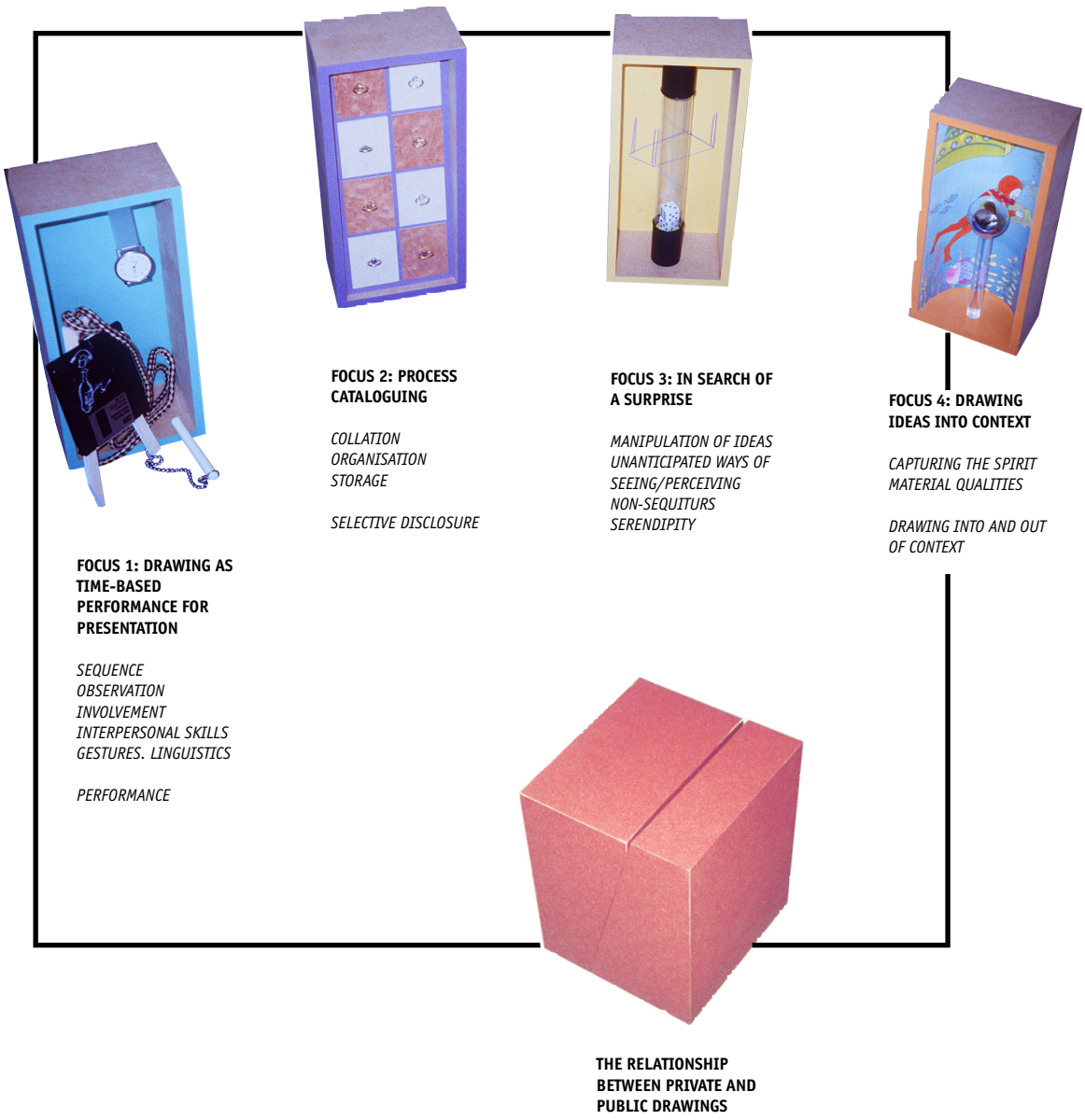

ILLUSTRATION 6

THE DEVELOPMENT OF STIMULUS CATEGORIES EARLY ON IN THE PROJECT
Communicated through expressive objects

Neil Barron
MPhil, Royal College of Art, 2001

ILLUSTRATION 7

STIMULUS IMAGE: THE POTENTIAL OF THE DRAWING SURFACE FOR CAPTURE AND SAMPLING

Neil Barron
MPhil, Royal College of Art, 2001

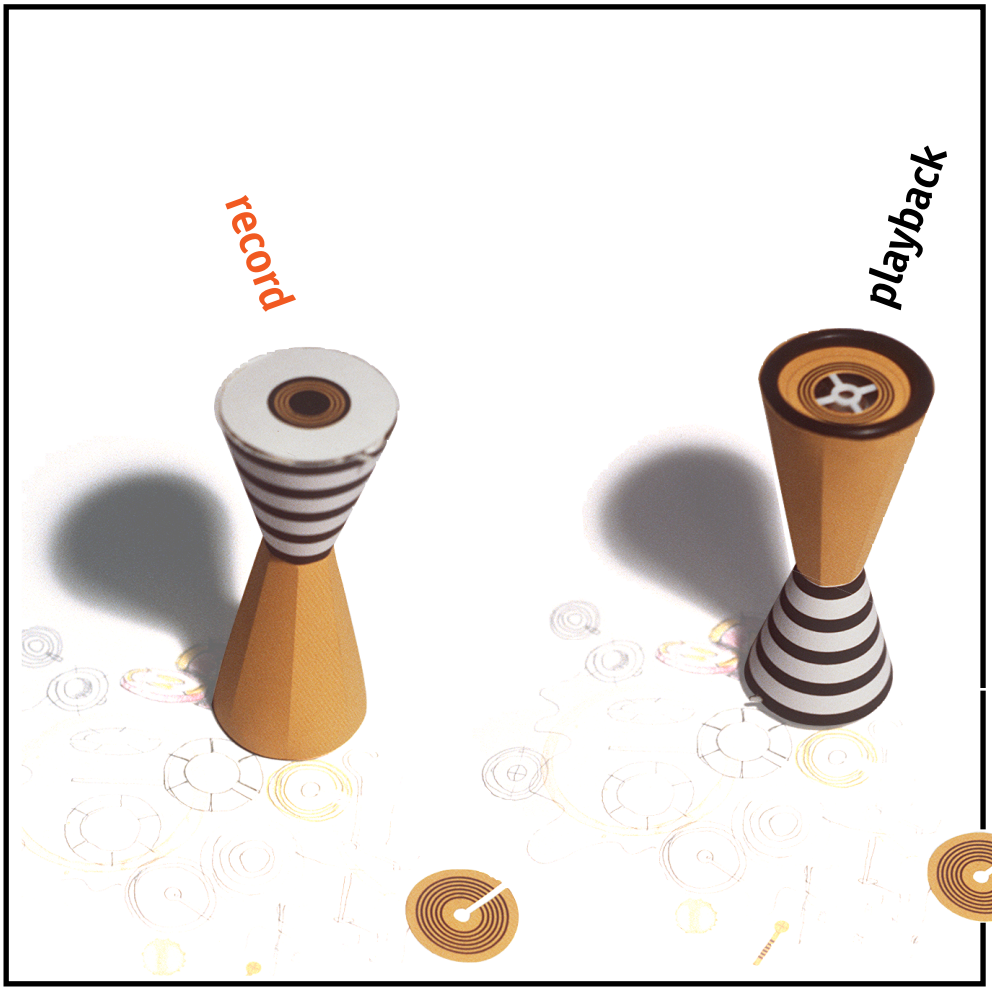

ILLUSTRATION 8

MOCK UP SOUND DEVICE 1

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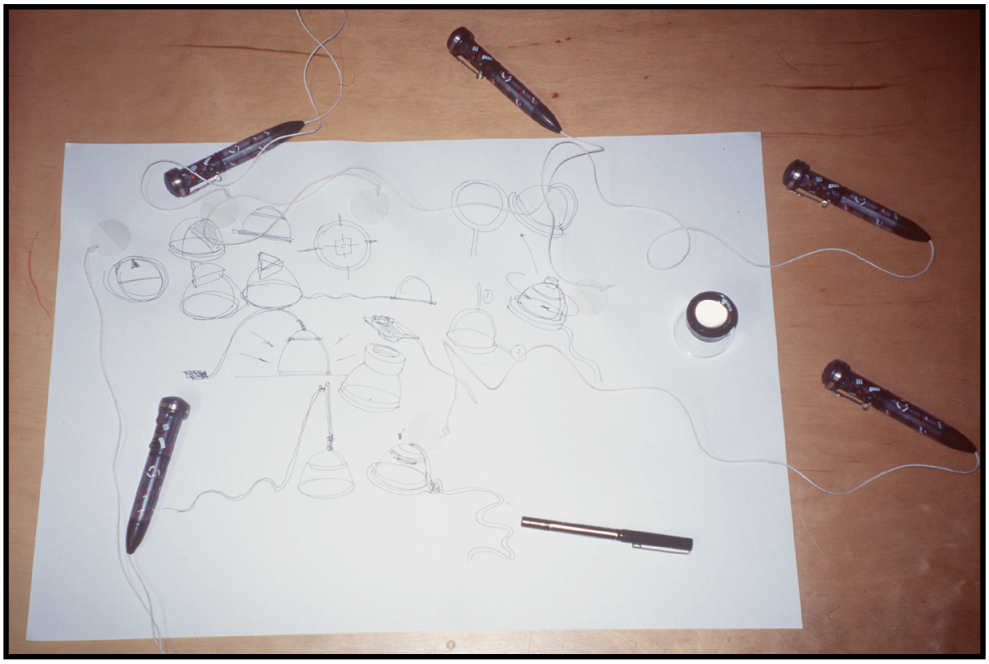

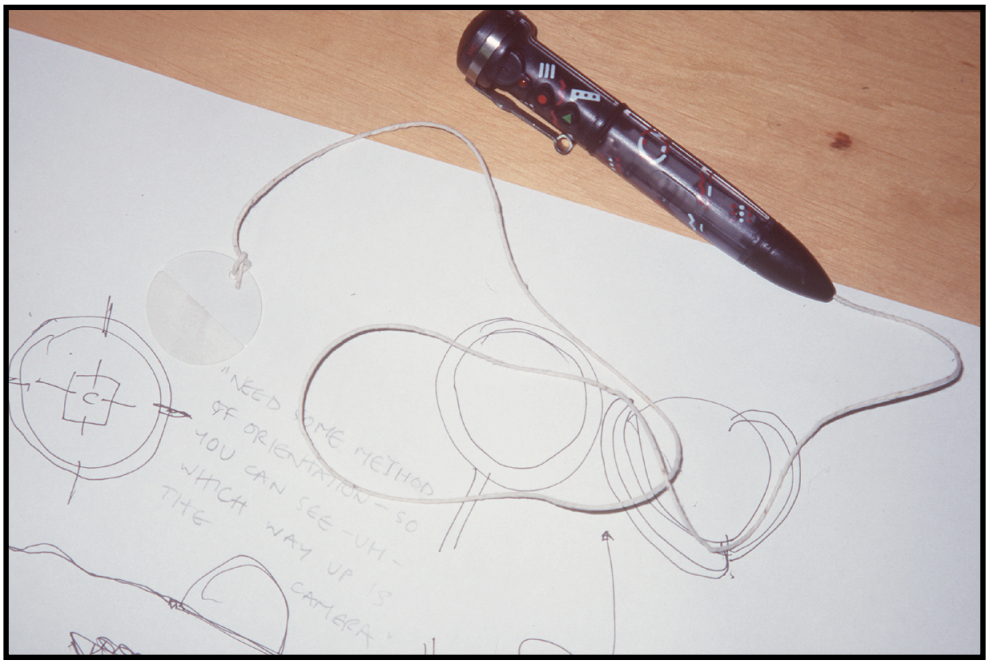

ILLUSTRATION 9

PHASE 1: PRACTICAL SET UP
Showing mock-up sound devices at the end of an episode of generative drawing

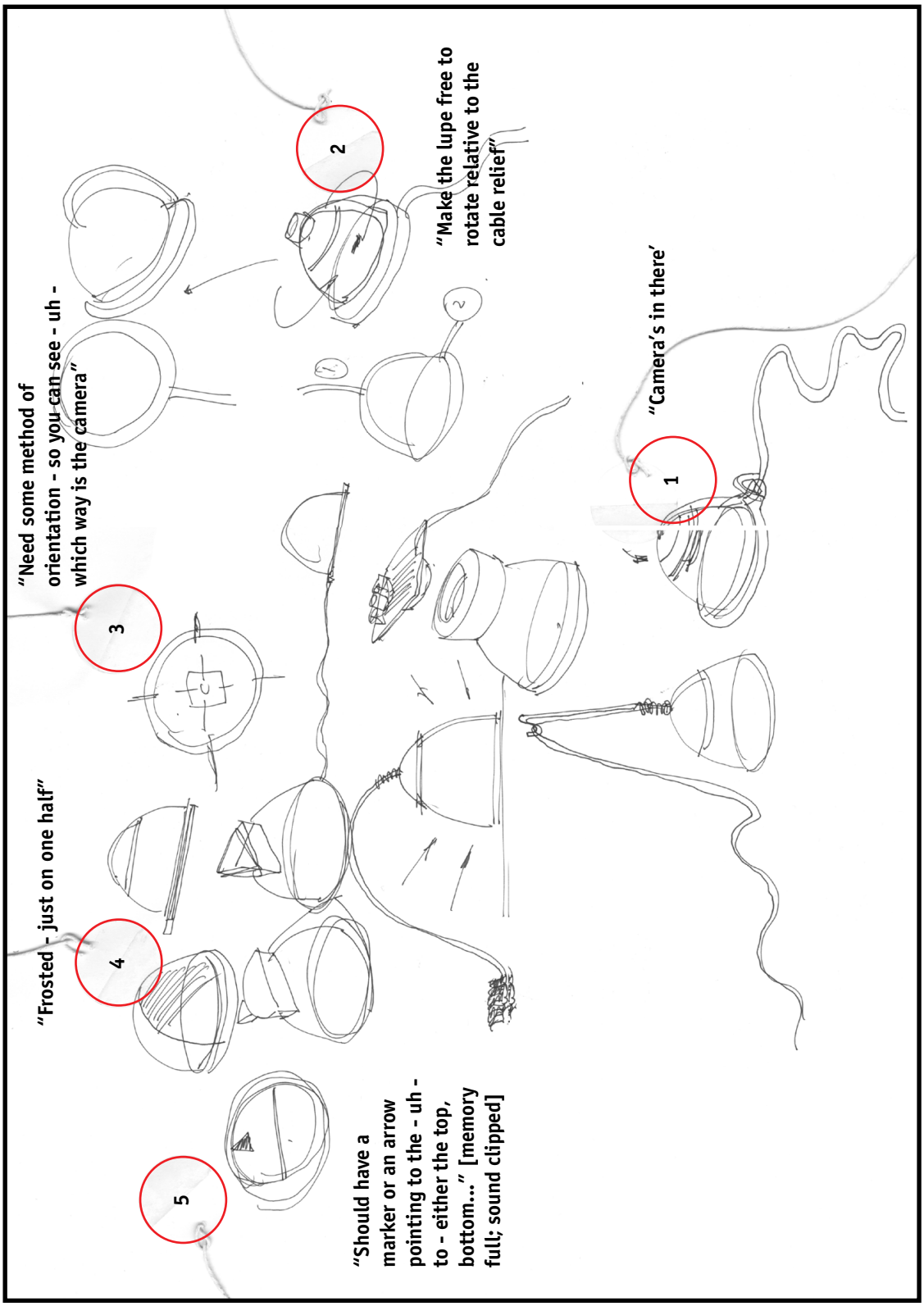

ILLUSTRATION 10

PHASE 1: EXAMPLE DRAWING WITH ANNOTATIONS ADDED
Showing example drawing at the end of an episode of generative drawing, with type written notes added once the contents of each sound device were reviewed

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ILLUSTRATION 11

PHASE 2: SHARED DRAWING SPACE - TABLE WITH DRAWING ROLL AND DVC

Neil Barron
MPhil, Royal College of Art, 2001

Digital Video Camera
(fitted to articulated arm)

Table top with double surface

ILLUSTRATION 12

PHASE 2: SHARED DRAWING SPACE - TABLE WITH DRAWING ROLL, SYMBOLIC REVIEW OBJECTS AND DVC

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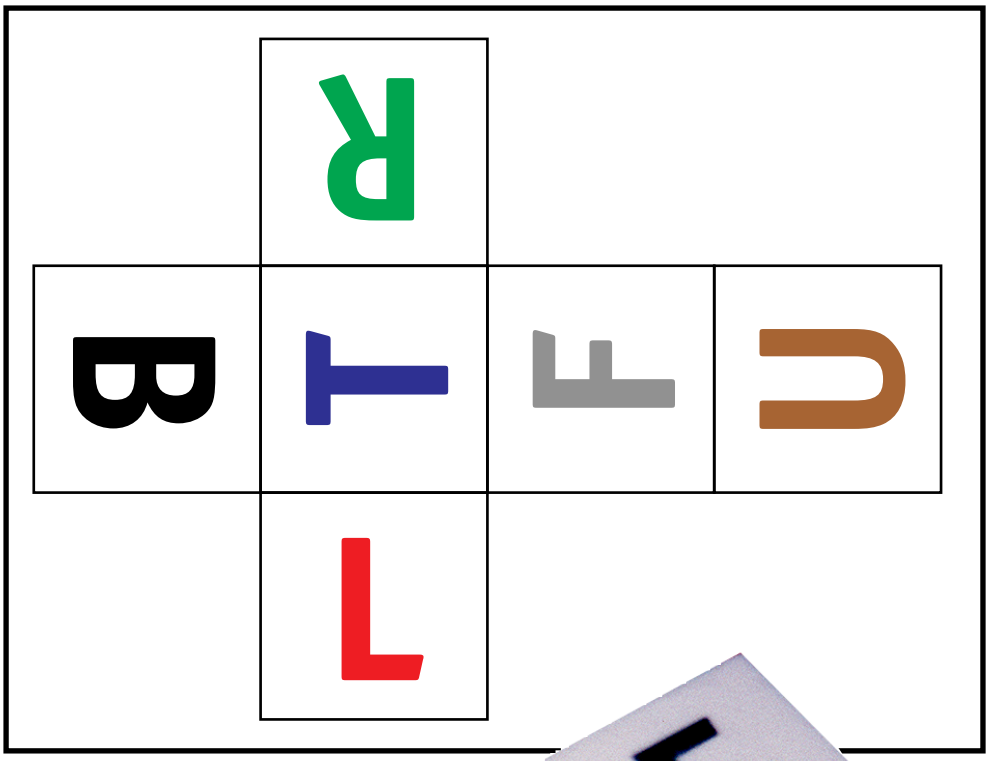
MPhil, Royal College of Art, 2001



Developed view showing all six faces of cube

ILLUSTRATION 13

PHASE 2: SYMBOLIC REVIEW OBJECTS: PROJECTION CUBE

Neil Barron
MPhil, Royal College of Art, 2001

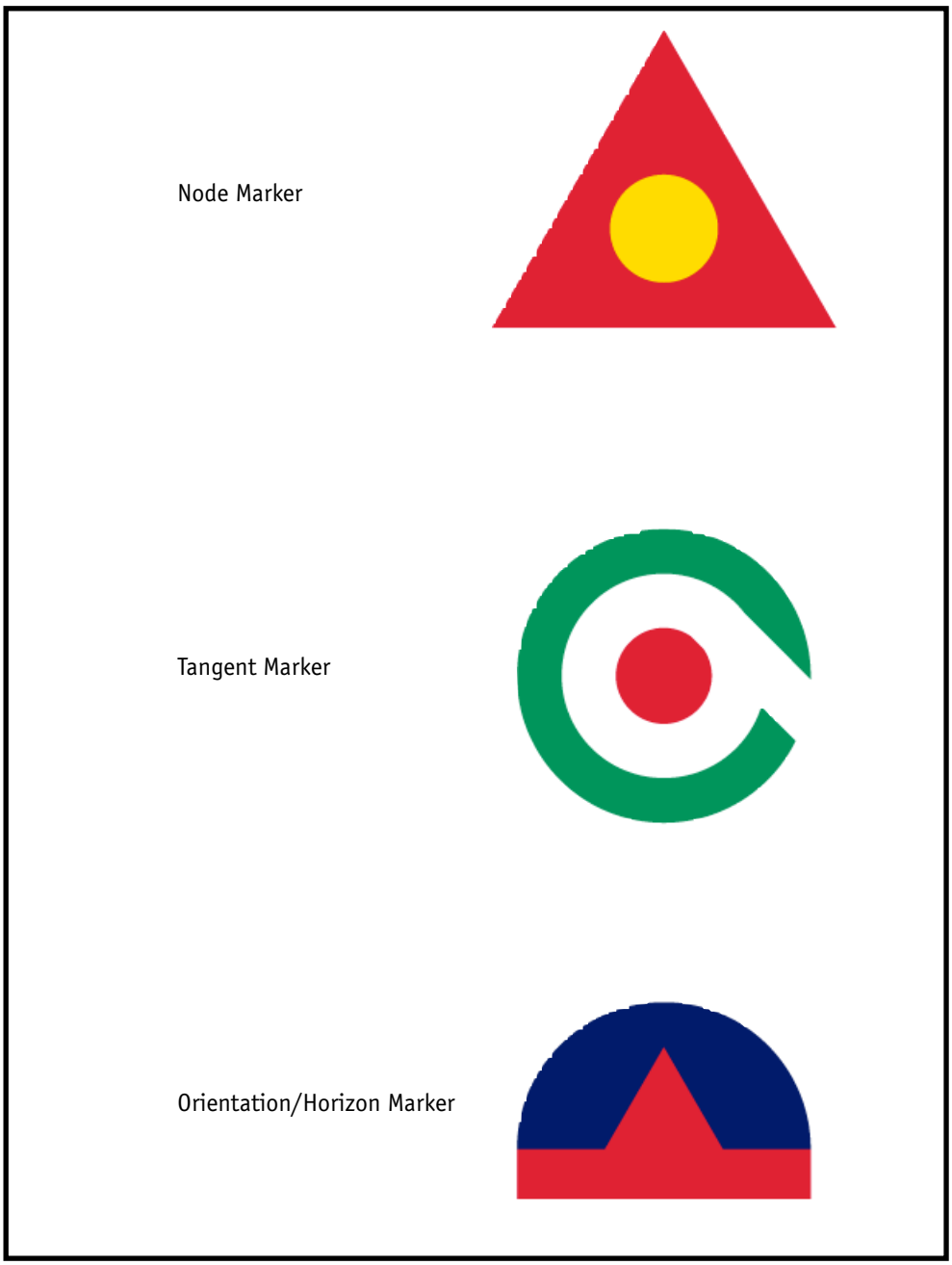
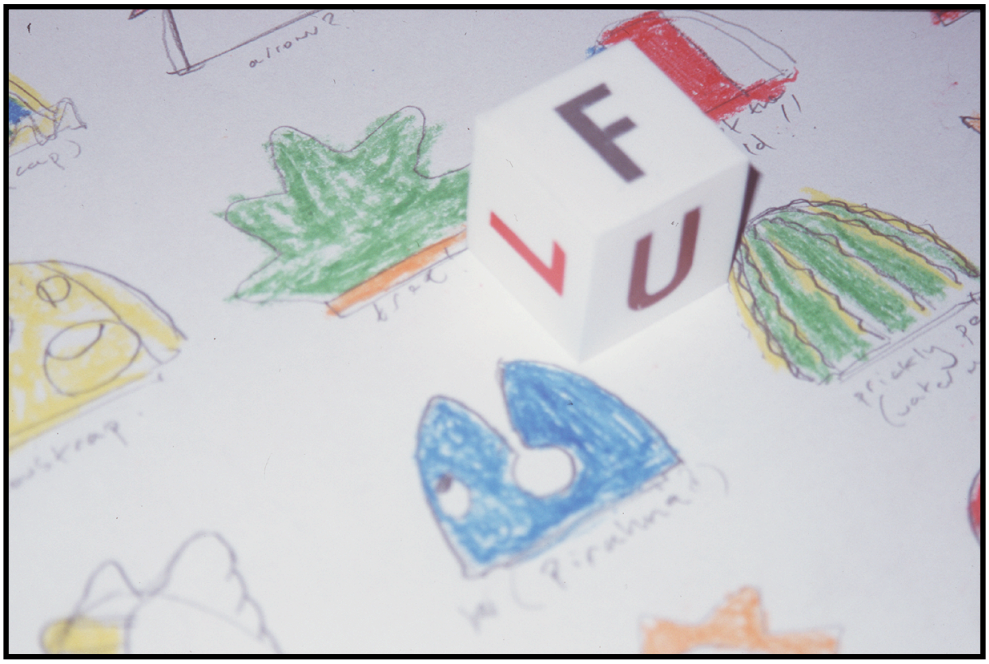


ILLUSTRATION 14

PHASE 2: SYMBOLIC REVIEW OBJECTS: NODE MARKER, TANGENT MARKER & ORIENTATION/HORIZON MARKER

(a)



(b)

ILLUSTRATIONS 15 (a) and (b)

PHASE 2: SYMBOLIC REVIEW OBJECTS
(a) shows projection cube in use on a drawing
(b) shows node marker and orientation/horizon marker in use on a drawing

Neil Barron
MPhil, Royal College of Art, 2001

(a) Priest ringing bell in response to love scene. Notice also the figure and ground effect of the focus in this image.

(b) Paper placed in film reel marks later edit

ILLUSTRATIONS 16 (a) & (b)

STILLS FROM THE FRANCO-ITALIAN FILM, 'CINEMA PARADISO', 1988
(written and directed by Giuseppe Tornatore)

Neil Barron
MPhil, Royal College of Art, 2001

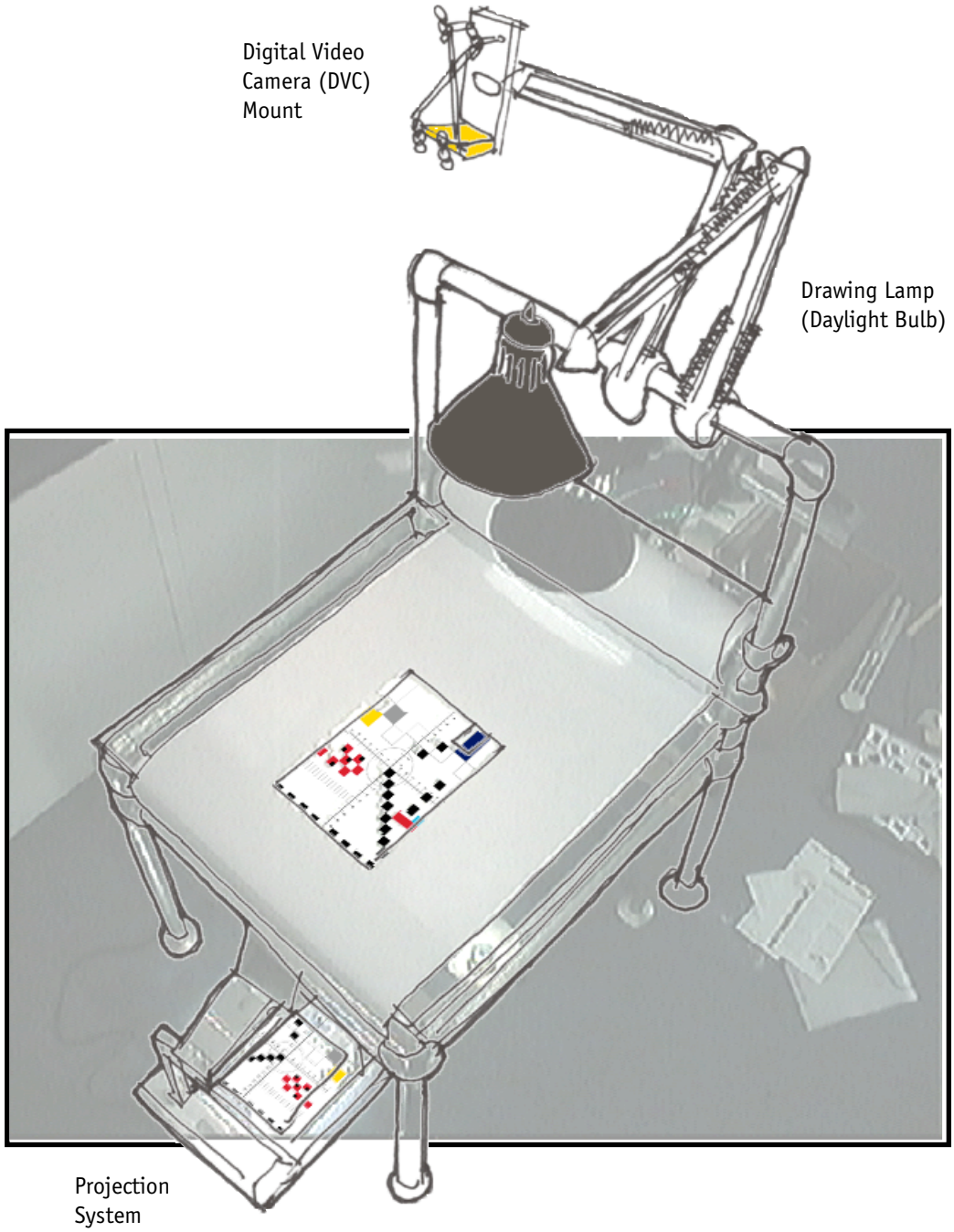
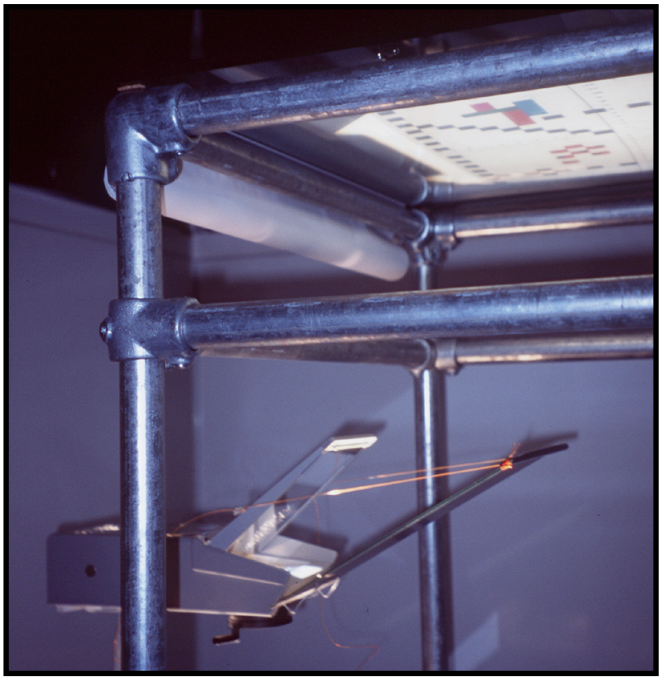
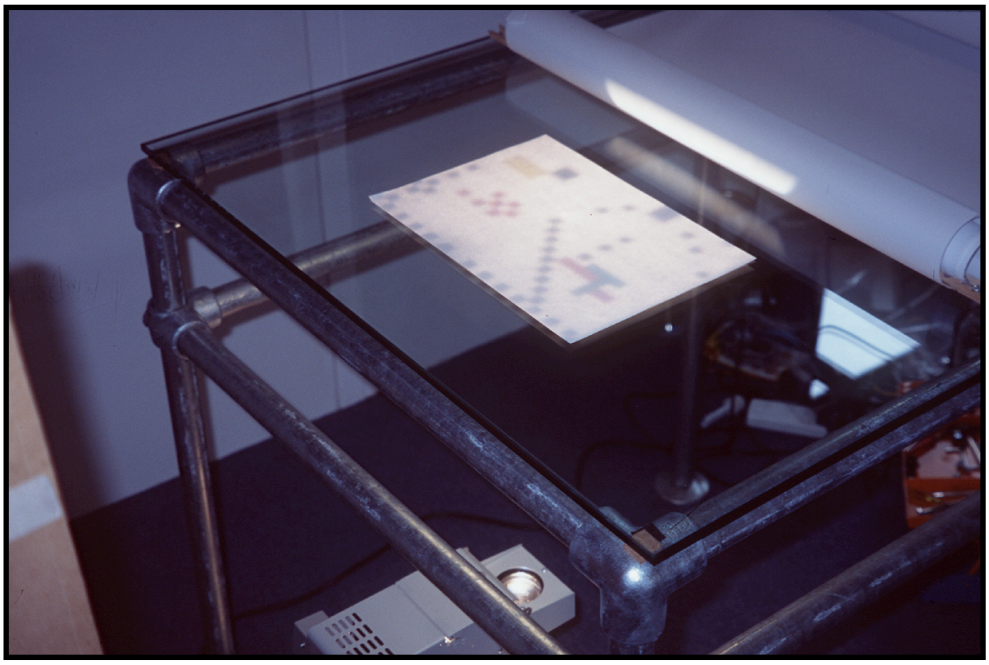


ILLUSTRATION 17

PHASE 3: BACK PROJECTION DRAWING TABLE

Neil Barron
MPhil, Royal College of Art, 2001





ILLUSTRATIONS 18 (a) & (b)

PHASE 3: BACK PROJECTION DRAWING TABLE
(a) shows a view from underneath the glass drawing surface
(b) shows a single piece of A4 paper catching an image on the glass drawing surface

Neil Barron
MPhil, Royal College of Art, 2001

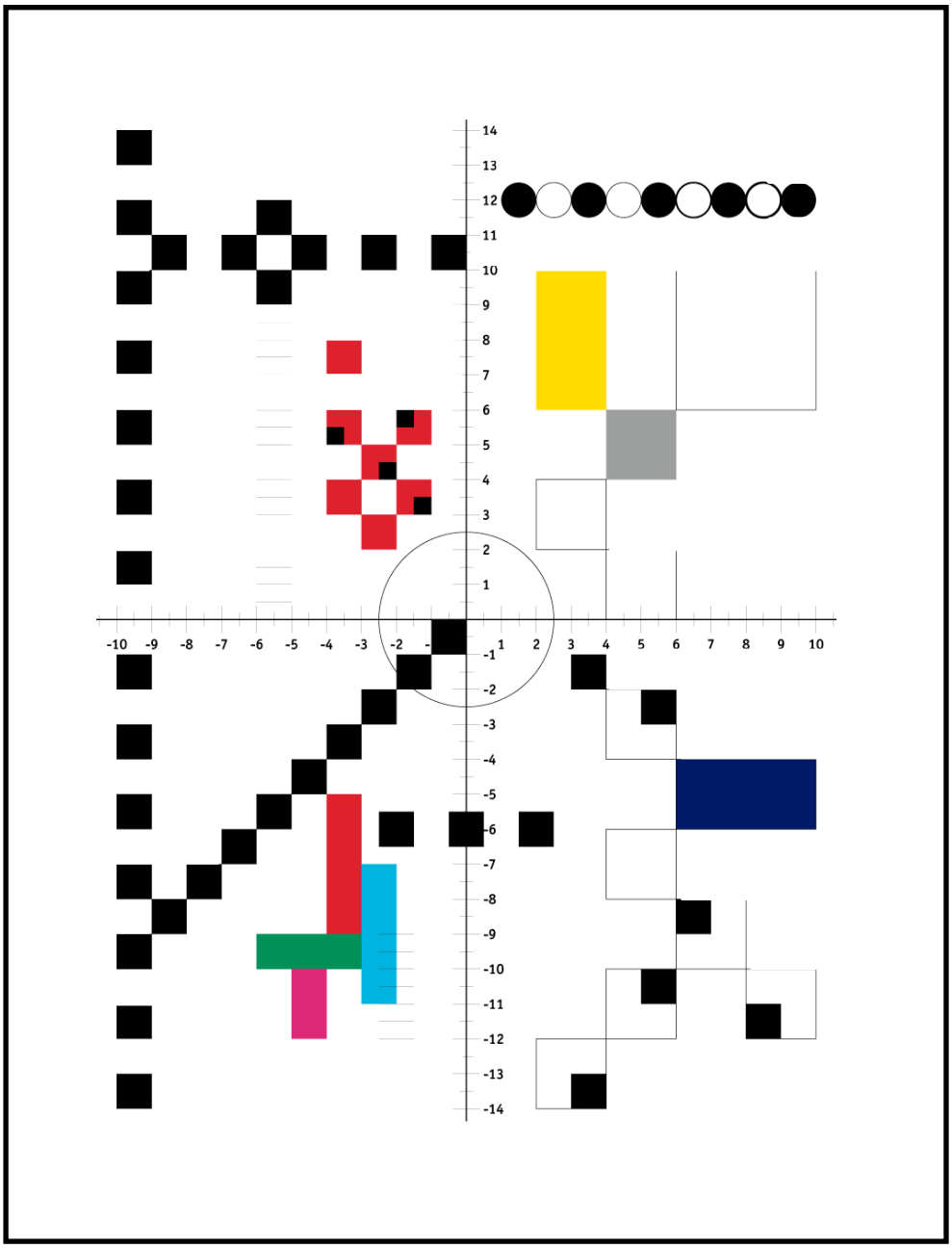


ILLUSTRATION 19

PHASE 3: BACK PROJECTION DRAWING TABLE: OPTICAL TEST PATTERN

Neil Barron
MPhil, Royal College of Art, 2001

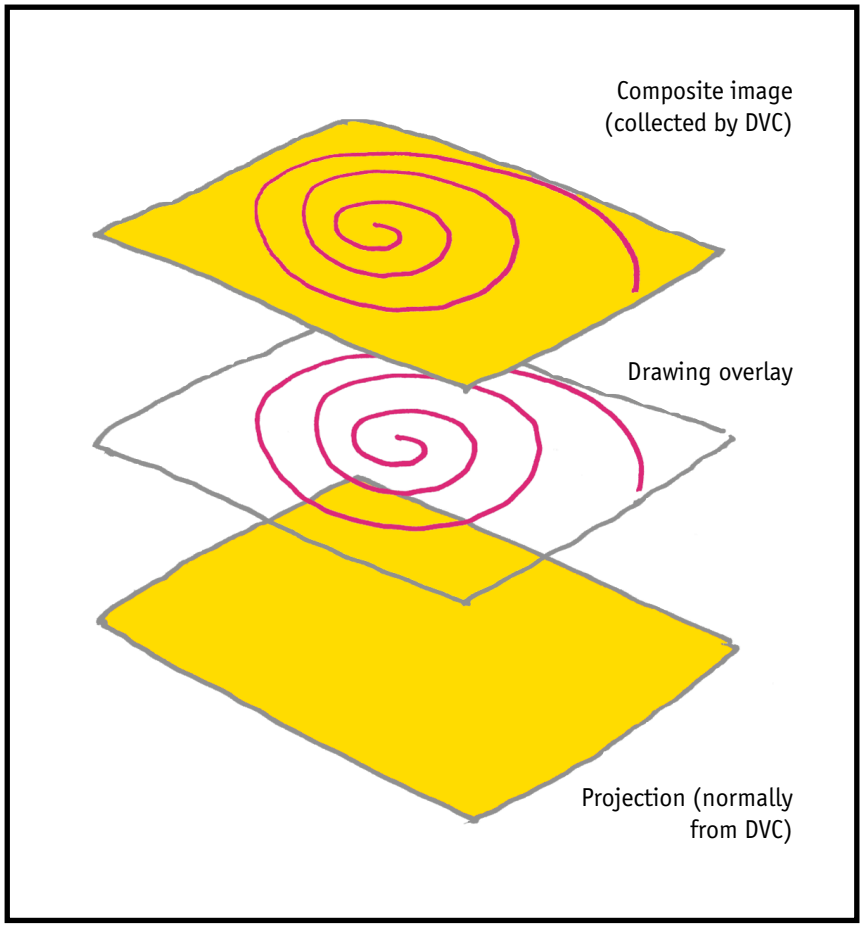
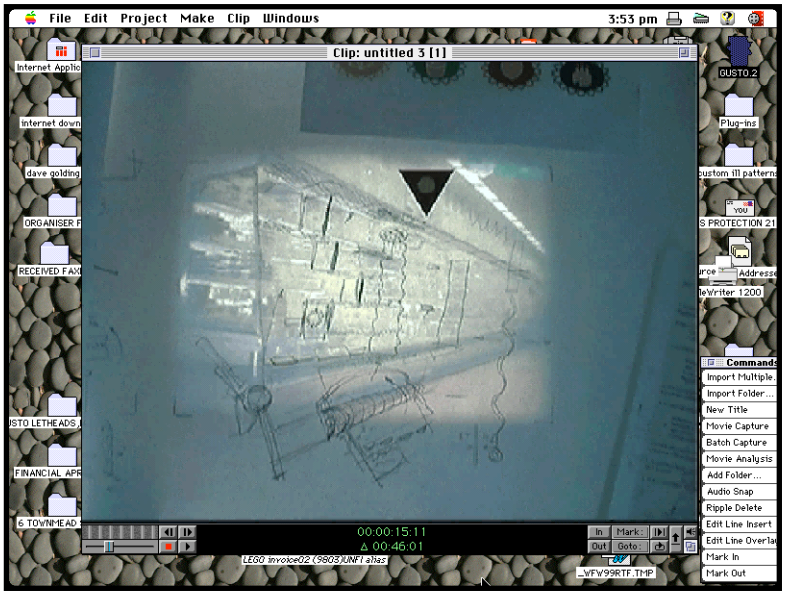
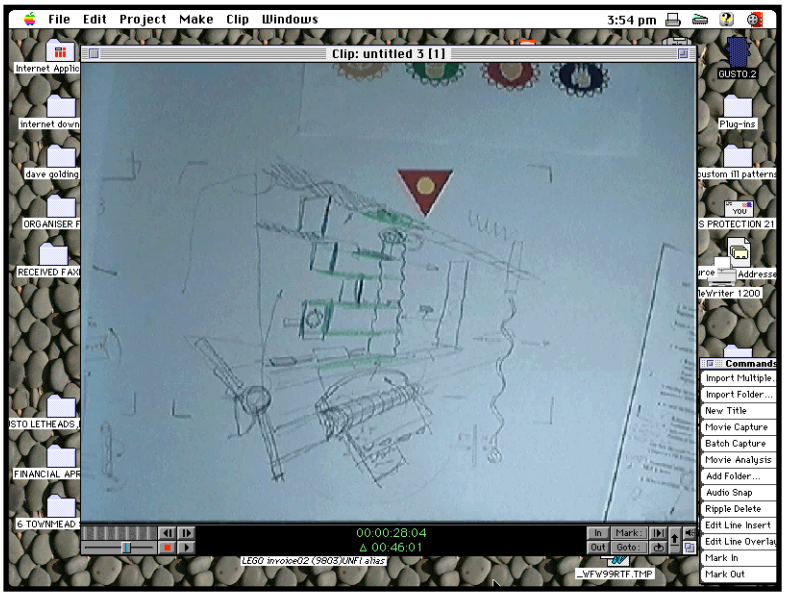


ILLUSTRATION 20

PHASE 3: BACK PROJECTION DRAWING TABLE: LAYERING OF COMPOSITE IMAGE



(a) composite image of projected image plus generative drawing, during computer review



(b) as in illustration 'a', above, but with projected image removed. Lowest discrete drawing is an example of the appropriation of the frame of reference from the projected image, with a change of scale.

ILLUSTRATIONS 21 (a) & (b)

PHASE 3: BACK PROJECTION DRAWING TABLE WITH AND WITHOUT PROJECTED IMAGE

Neil Barron
MPhil, Royal College of Art, 2001

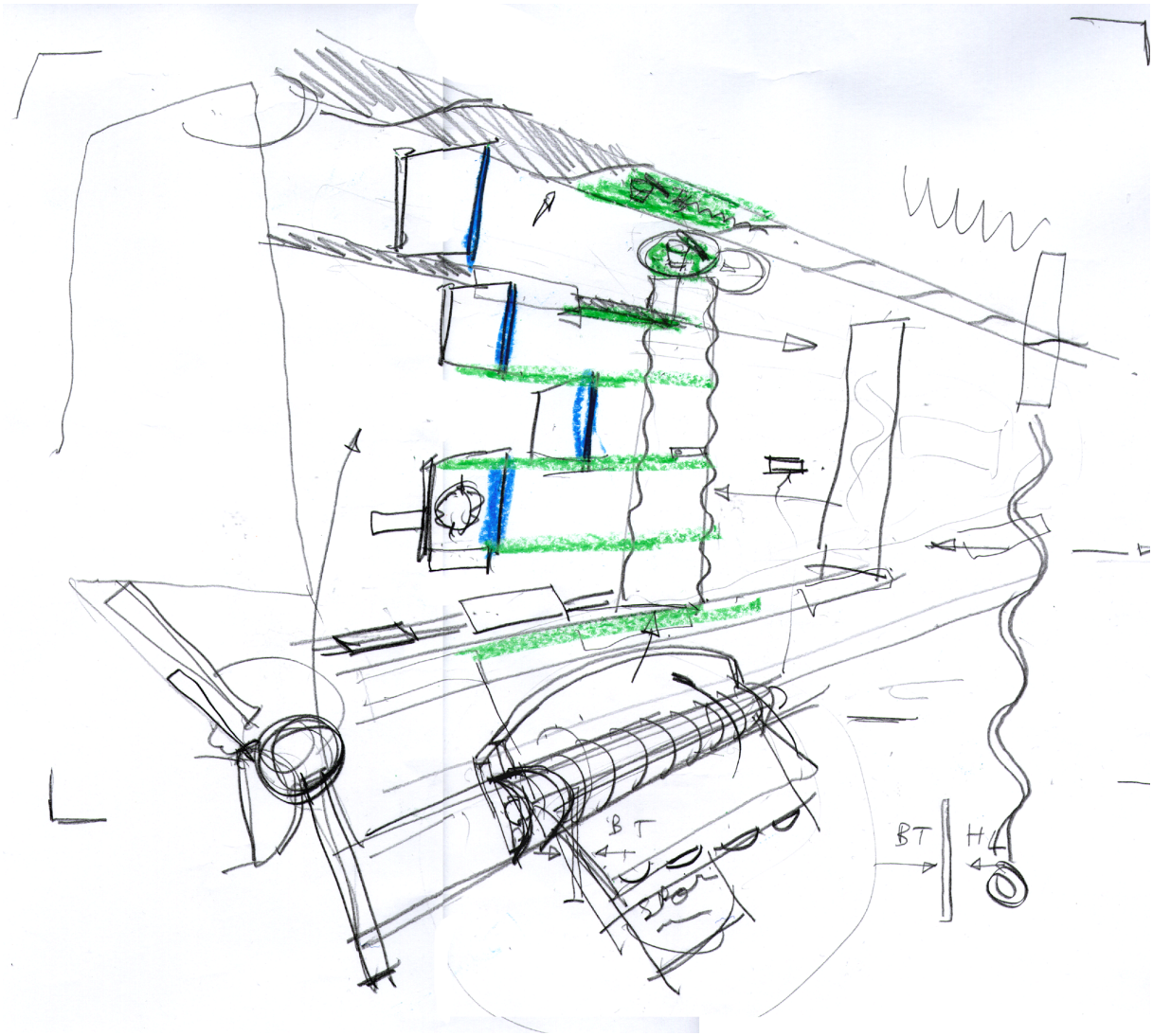


ILLUSTRATION 22

PHASE 3: DRAWING PRODUCED ON BACK PROJECTION DRAWING TABLE (1)
Shown with projected image removed. This is the drawing shown in illustration 25 (a) & (b)

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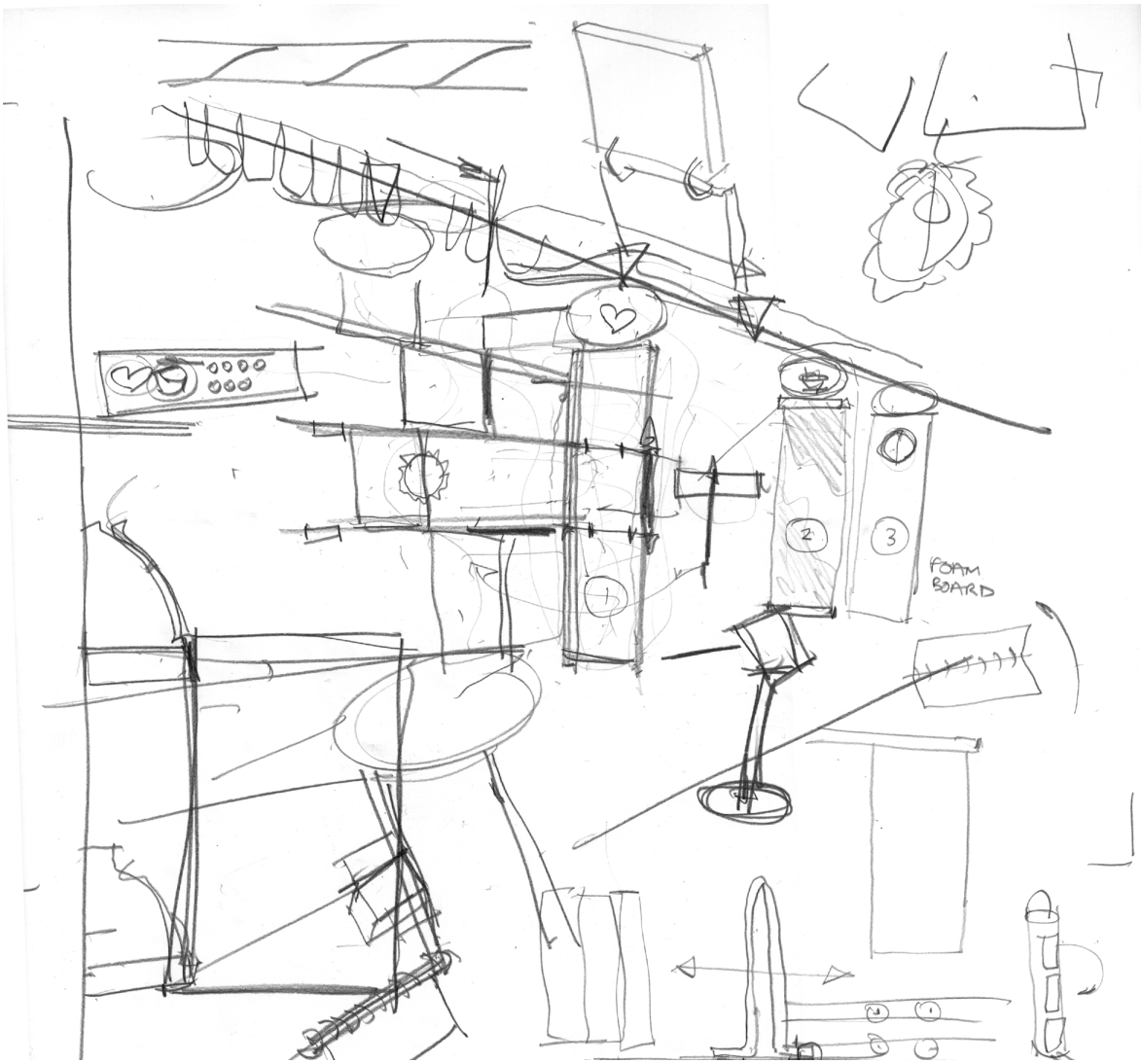
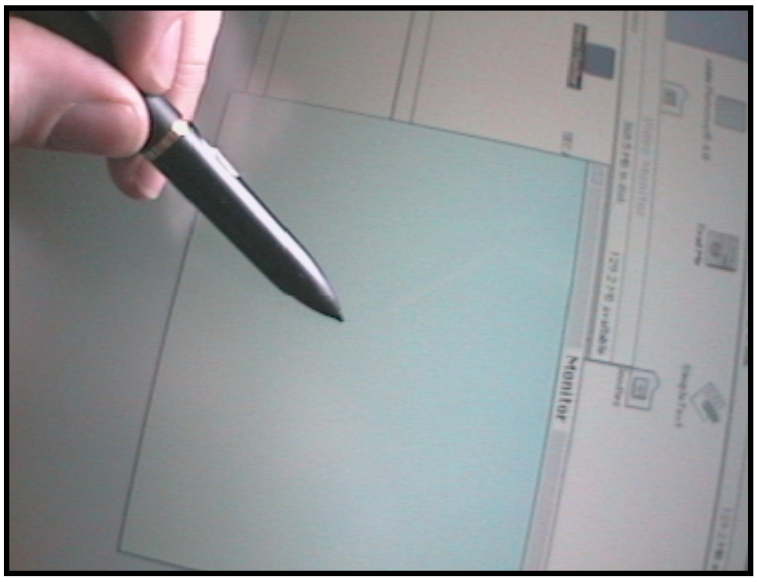


ILLUSTRATION 23

PHASE 3: DRAWING PRODUCED ON BACK PROJECTION DRAWING TABLE (2)
Shown with projected image removed

Neil Barron
MPhil, Royal College of Art, 2001

(a) Input Technologies Sketch 14" drawing interface. Image courtesy of Input Technologies Inc.



(b) Using the Phase 4 table to create an image of the action of drawing in progress

ILLUSTRATION 24 (a) & (b)

PHASE 4: SKETCH 14" PRODUCT

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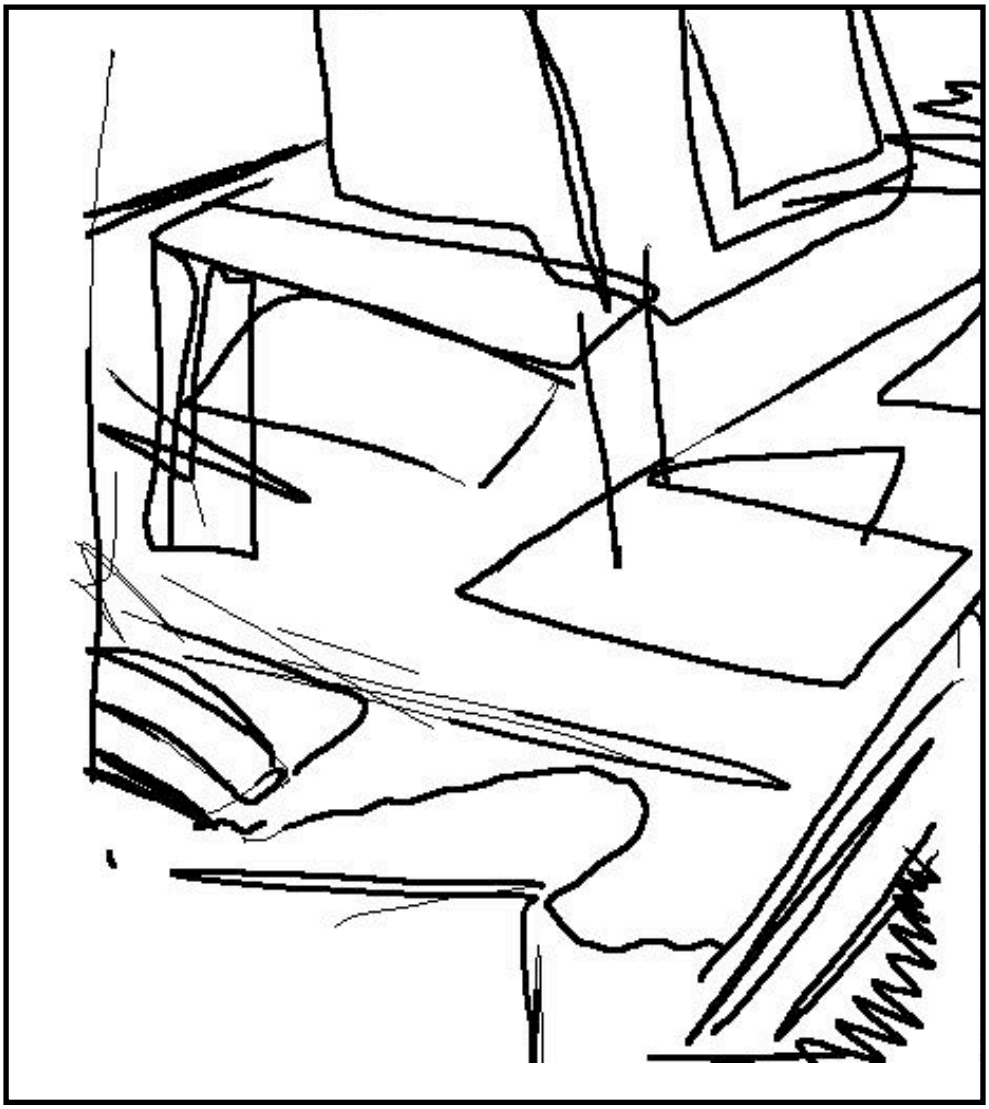

ILLUSTRATION 25

PHASE 4: FIRST DRAWING WITH 'SKETCH 14' INTERFACE

Neil Barron
MPhil, Royal College of Art, 2001

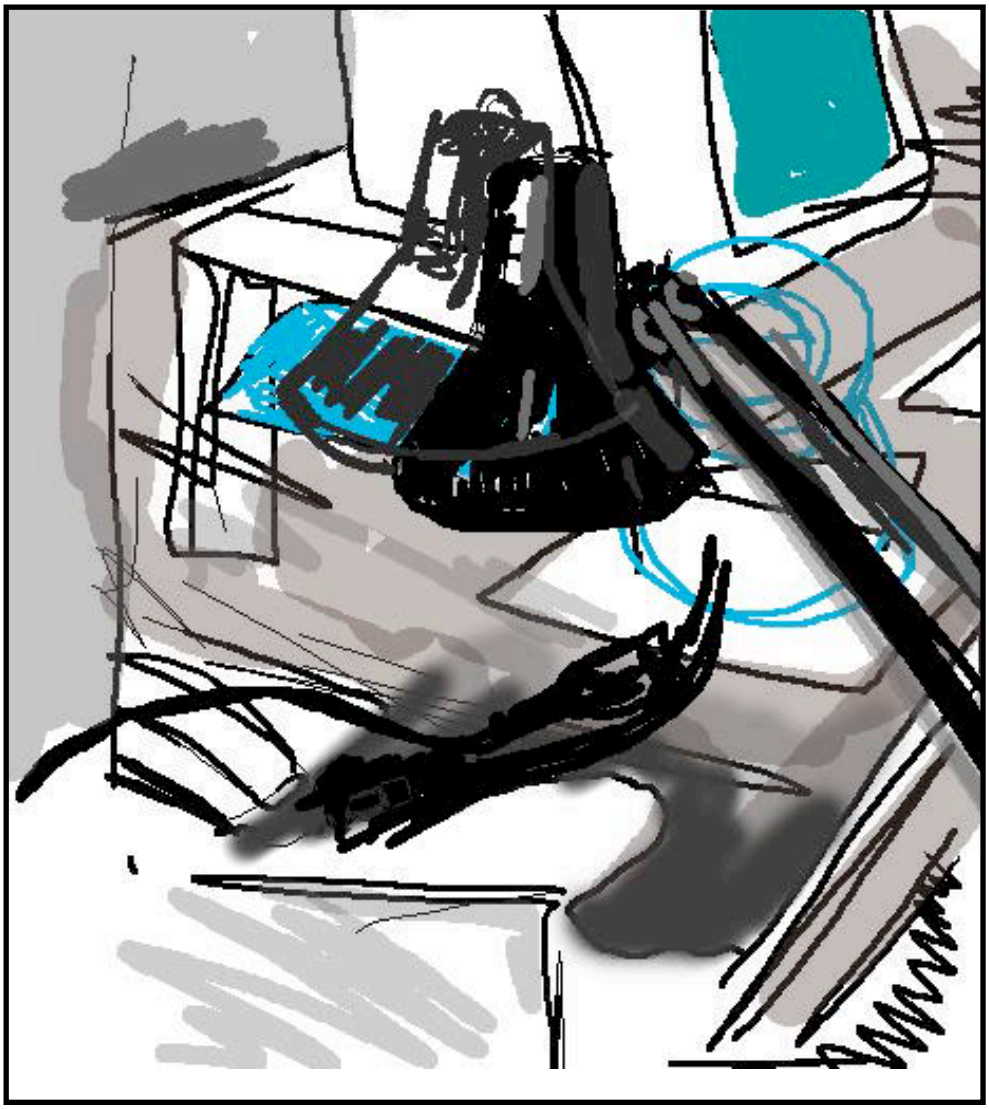

ILLUSTRATION 26

PHASE 4: FIRST DRAWING WITH 'SKETCH 14' INTERFACE

Neil Barron
MPhil, Royal College of Art, 2001

ILLUSTRATION 27

PHASE 4: TABLE WITH COMPUTER AND CCTV CAMERAS

Neil Barron
MPhil, Royal College of Art, 2001

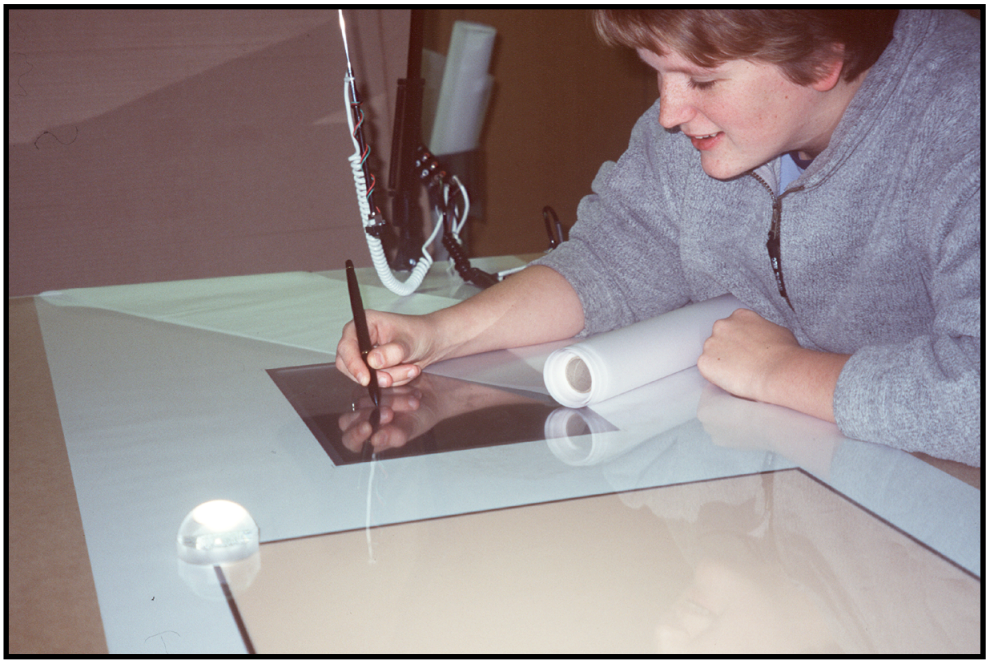

ILLUSTRATION 28

PHASE 4: TABLE SURFACE

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MPhil, Royal College of Art, 2001

ILLUSTRATION 29

PHASE 4: USING THE CCTV LUPE TO SAMPLE THE DIGITAL DRAWING

Neil Barron
MPhil, Royal College of Art, 2001

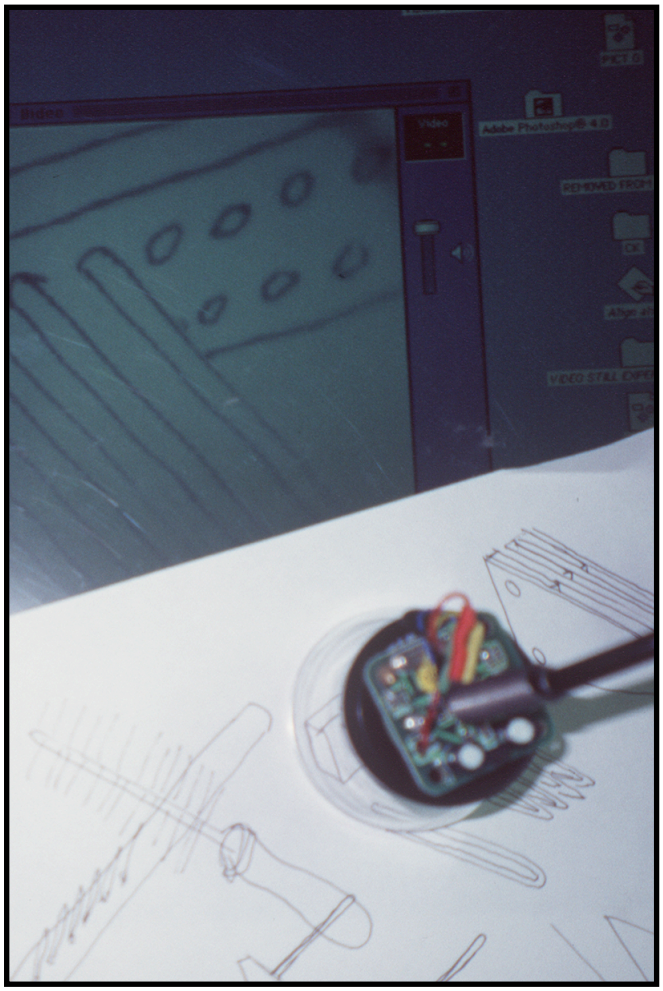

ILLUSTRATION 30

PHASE 4: USING THE CCTV LUPE TO CAPTURE THE PAPER DRAWING

Neil Barron
MPhil, Royal College of Art, 2001

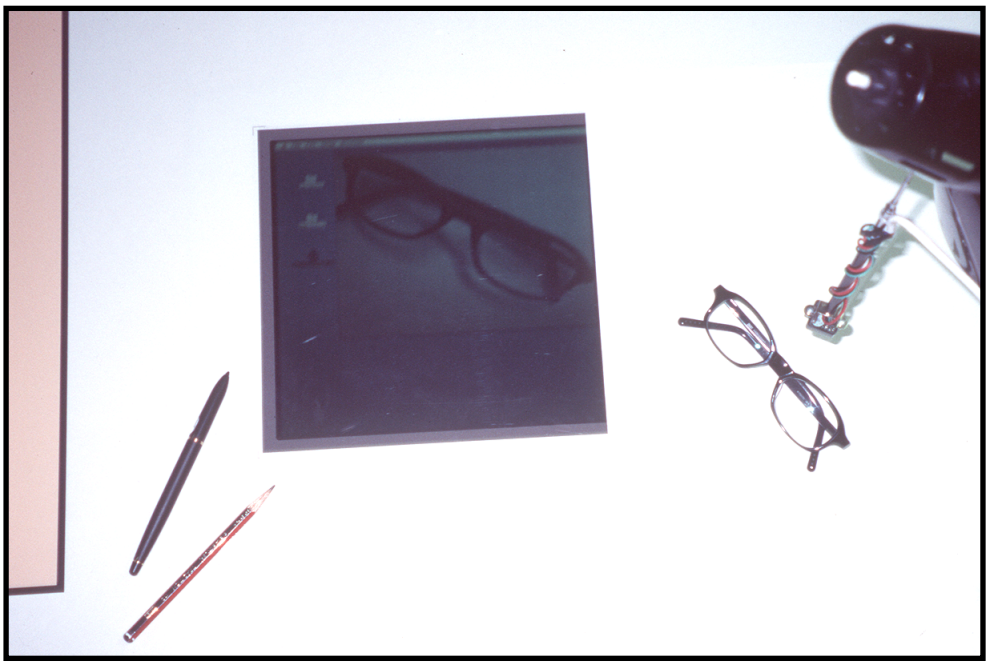

ILLUSTRATION 31

PHASE 4: USING THE AERIAL CCTV CAMERA TO CAPTURE IMAGES OF OBJECTS FOR USE IN GENERATIVE DRAWING (1)
This particular capture was used by participant C

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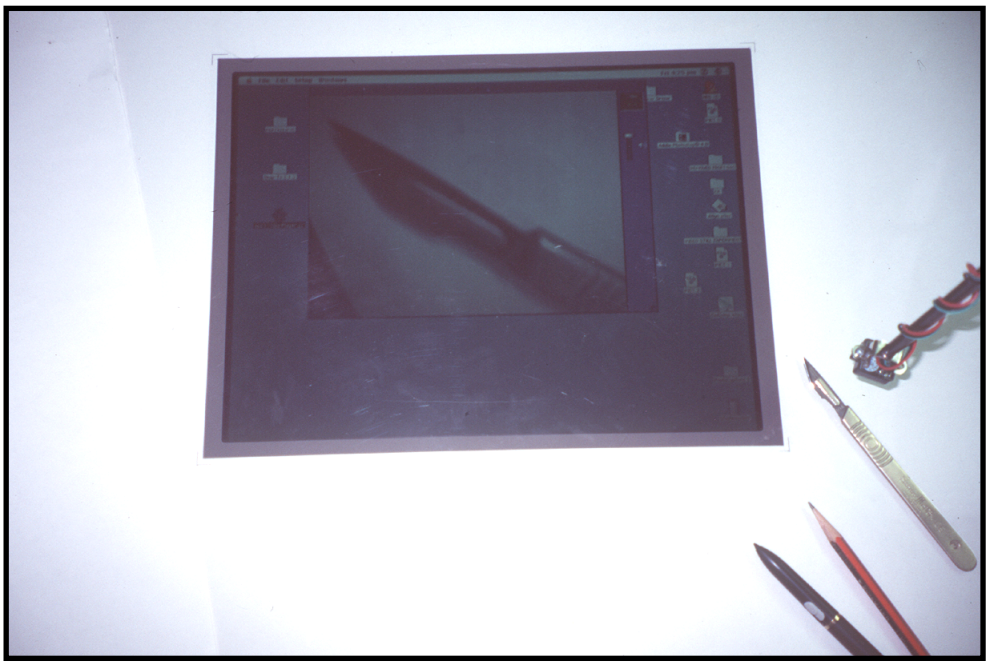
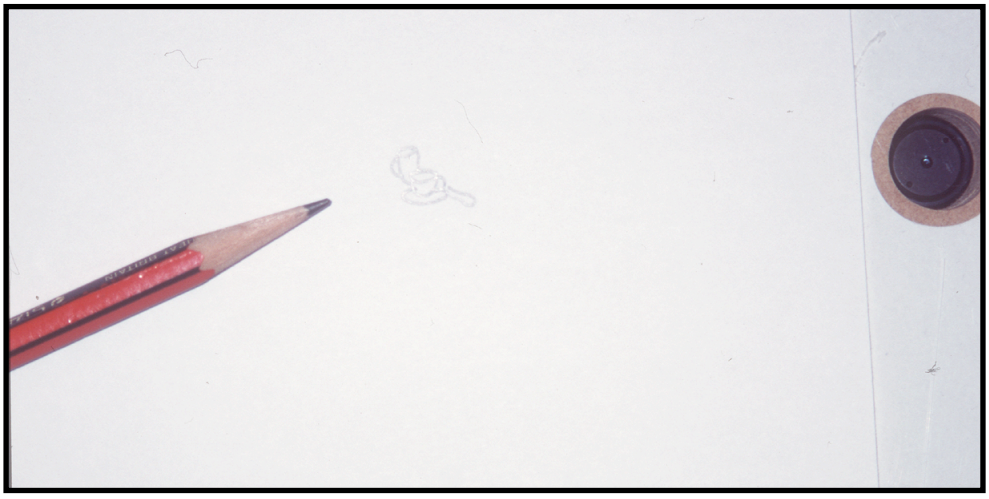
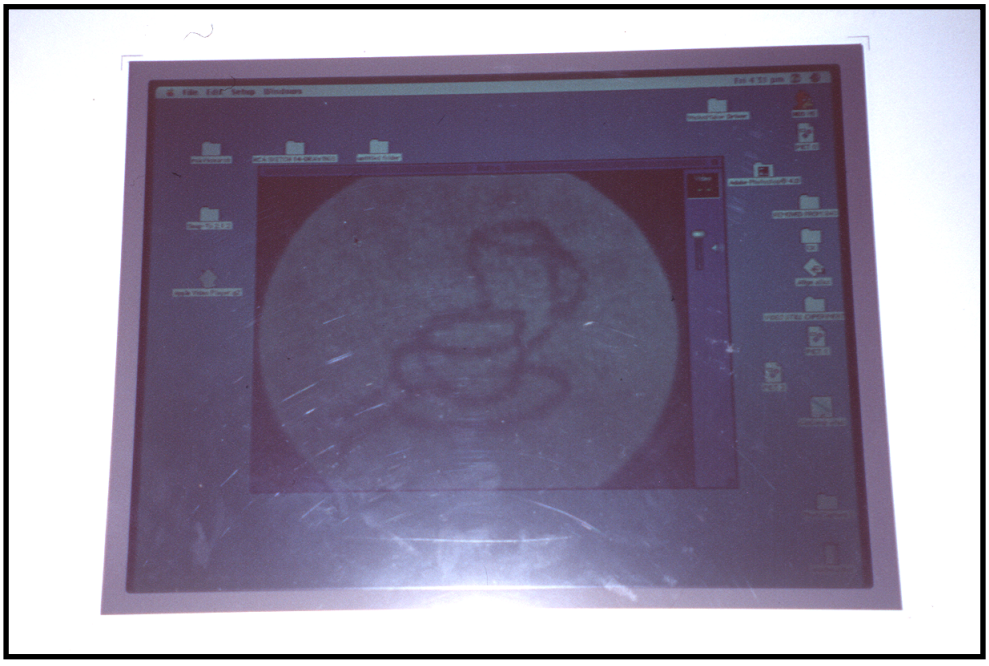


ILLUSTRATION 32

PHASE 4: USING THE AERIAL CCTV CAMERA TO CAPTURE IMAGES OF OBJECTS FOR USE IN GENERATIVE DRAWING (2)
This particular capture was used by participant B



(a)



(b)

ILLUSTRATION 33 (a) & (b)

PHASE 4: SURFACE CCTV CAMERA
(a) CCTV camera mounted in drawing surface (viewing upwards)
(b) image of paper drawing from CCTV camera (viewed from underside of paper - there is enough light to enable this)

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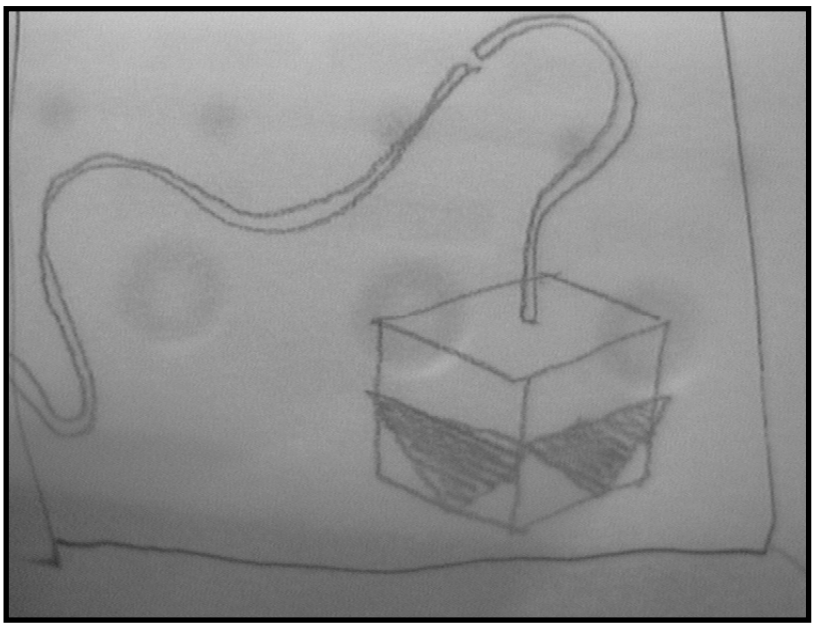
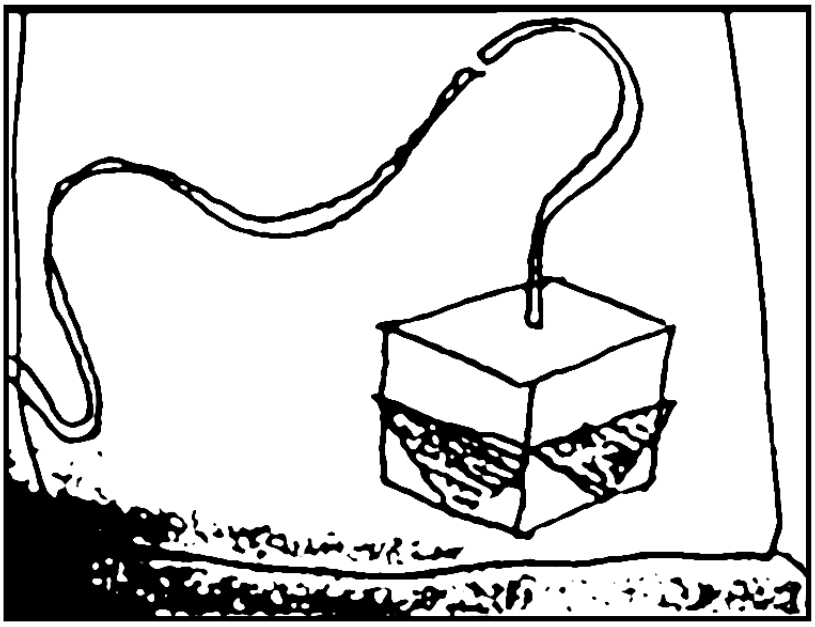


(a)



(b)

ILLUSTRATION 34 (a) & (b)

PHASE 4: FILTERING EFFECT ON CCTV IMAGE CAPTURE
(a) raw CCTV signal
(b) filtered result (instantaneous)

Neil Barron
MPhil, Royal College of Art, 2001

ILLUSTRATION 35

PHASE 4: DIGITAL DRAWING 'ROLL'

Neil Barron
MPhil, Royal College of Art, 2001

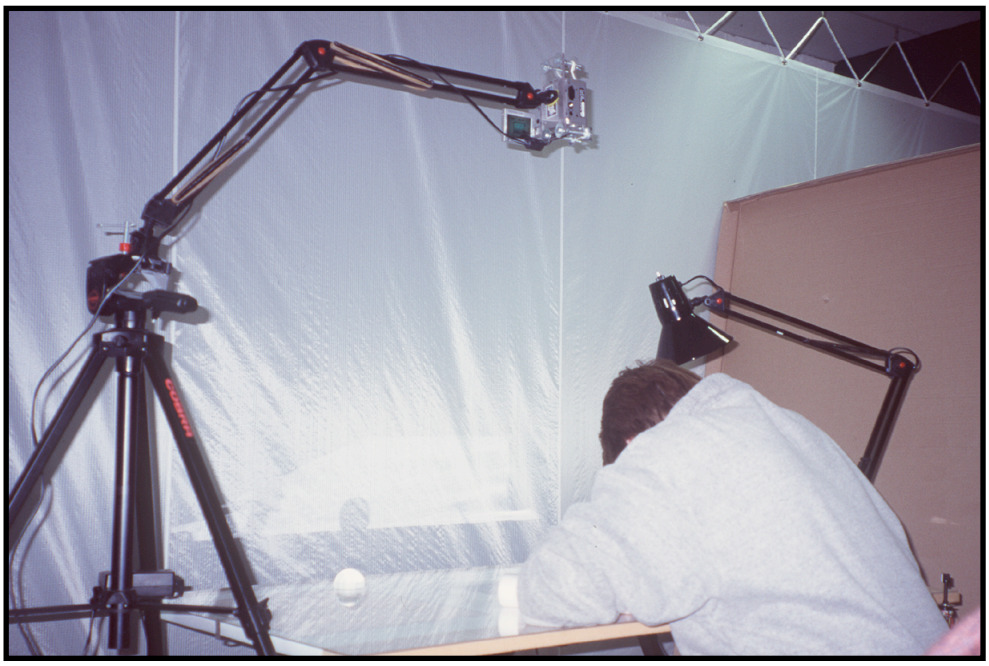


ILLUSTRATION 36

PHASE 4: PRACTICAL SET UP
Showing digital video camera (DVC) mounted above drawing table

Neil Barron
MPhil, Royal College of Art, 2001

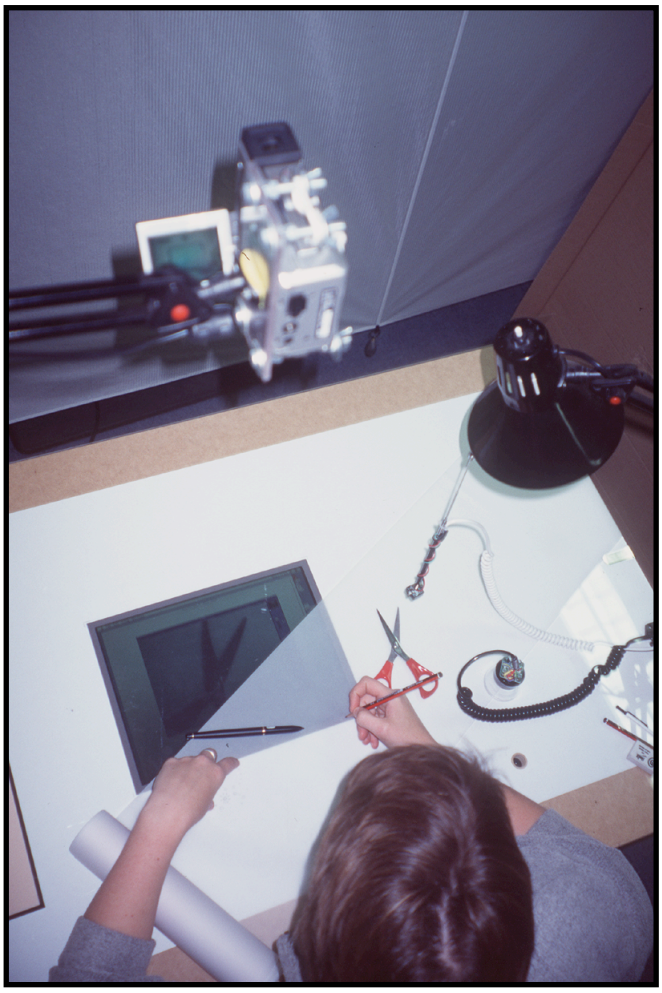
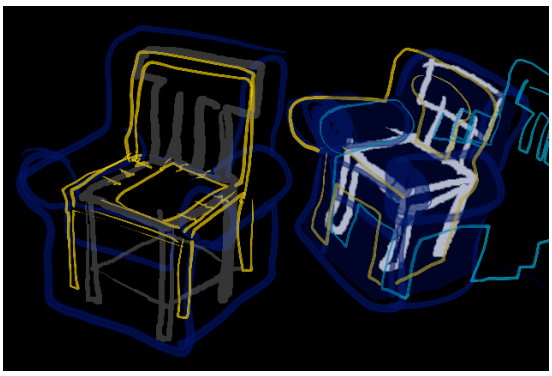


ILLUSTRATION 37

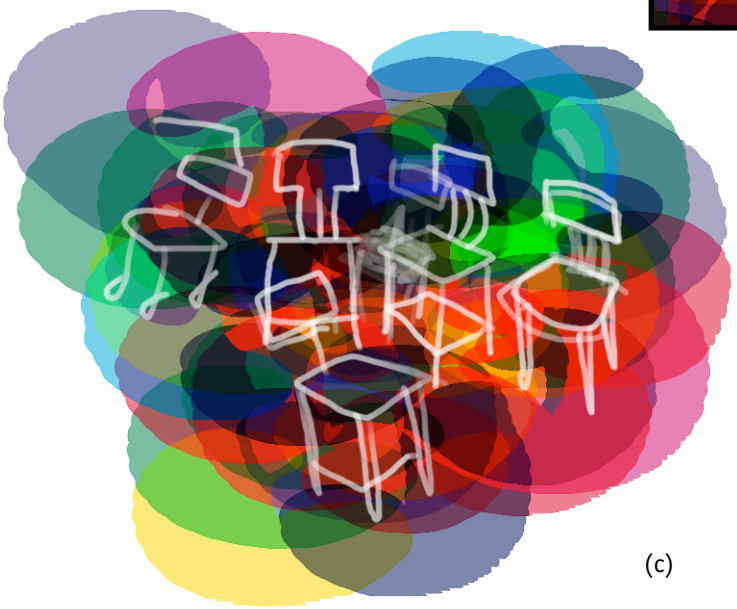
PHASE 4: PRACTICAL SET UP
SHOWING DIGITAL VIDEO CAMERA MOUNTED ABOVE TABLE

Neil Barron
MPhil, Royal College of Art, 2001



(a)

(b)



(c)

ILLUSTRATION 38

PHASE 4: EXPLORATION OF NON-BLANK, NON-WHITE DRAWING SURFACES IN ASSOCIATION WITH ERASURE