2. Digital technologies and design

One broad motivation for the research described in this thesis is to bring a deeper understanding of the working processes of creative practitioners to the development of future digital environments for creative practice. This chapter sets the research within this broader context.

Parameters of the research

Bringing designers and digital technologies together involves an understanding of many areas, including design processes (both individual and social), the designer, the role of artefacts, methods of creating digital artefacts, the human computer interface in its broadest sense (where designer and digital meet), developments in digital technologies and their application to design. The knowledge base supporting research into digital environments for creative practice is thus shared between a variety of disciplines, including design, cognitive science, human computer interaction, and digital technology.

This research focuses on the relationship between an individual designer and the media with which they work. Associated areas of research into other ways in which digital technologies might assist designers, such as systems to support collaborative working (CSCW) or knowledge support systems, lie outwith its scope, as does research specifically relating to tacit knowledge or haptics (e.g. [Prytherch 2003; Prytherch & Jerrard 2003]), enhancing 'creativity' (e.g. [Eckert & Stacey 1998; Candy & Edmonds 1999; Candy & Edmonds 2000; Eckert & Stacey 2000; Candy & Hori 2003]) or the impact of computer systems on engineering design processes (e.g. [Stacey, Petre et al. 1996; Stacey & Eckert 1999]).

Digital technologies and design

Advanced computer systems for 3D design and modelling are widely used in many areas of design and manufacturing; however the types of design representations that can be created in the virtual environment are limited. The tools for creating and working with three-dimensional models are primarily geometric techniques based on the 'design-by-

drawing' paradigm. Not only do these precise, detailed techniques promote a level of accuracy unsuited to the earlier stages of design, encouraging premature commitment, but they emphasise the creation and visualisation of three-dimensional form, rather than the more dynamic and functional aspects of working with materials. Also, the models, while shareable through data transfer, are closely bound to the tool used to create them.

In the majority of systems, a complex user interface to the digital model requires long periods of training before it can be used transparently. Working with virtual models and environments has, for most people, been mediated through a flat screen, a keyboard, and a mouse, resulting in a large discrepancy between what are often highly sophisticated three-dimensional models, and current 'two-dimensional' ways of interacting with them. For many artists and designers, the perceived distance between them and their digital medium introduced by these factors, along with the precise nature of the models, can be a barrier to using such systems, particularly for the conceptual stages of work.

Recent advances in digital technologies for creating, visualising and interacting with digital models offer the potential to bring the active, exploratory, manipulative and expressive ways in which practitioners work with real materials, using their hands and tools, into the digital realm. (Appendix B, ***Visualisation and interaction in 3D*** provides a brief introduction to this area for the reader who is not familiar with the technologies, techniques and principles involved.) The potential of such technologies to allow a less constrained, more naturalistic interaction with virtual models has increased the drive towards computer support for the whole design process, in particular for conceptual design.

Integrating advanced digital technologies and design

This chapter reviews selected examples to illustrate ways in which these technologies are being, or could be, integrated into the working processes of artists and designers. It is not concerned primarily with ways in which creative practitioners are using existing digital technologies in their material practice (e.g. [Marshall 1997; Bunnell 1998; Marshall 1998]) rather on systems being developed using new technologies specifically to support artists and designers, particularly in the early stages of design.

Supporting/enhancing the sketching process

The ID-StudioLab at Delft University of Technology is addressing the use of computers to support the conceptual stages of industrial design, in particular to "combine the advantages of the traditional media, such as sketching on paper, with the extra functionality that computers can offer" [Hoeben & Stappers 2001]. Projects include research into the psychology of sketching, human computer interface research, and creation of digital objects through gesture and sketching [Stappers & Hennessey 1999].

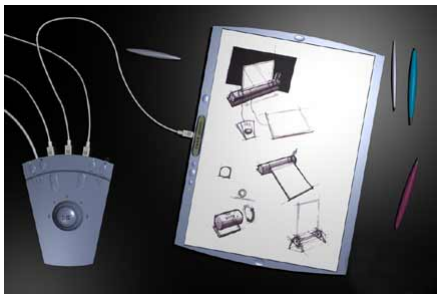

Figure 2: IDEATOR
Ralph Stuijver; reproduced by kind permission of
ID-StudioLab, Delft University of Technology

An early concept project, IDEATOR, concerned a support tool for the early stages of design, based around a stand-alone sketch tablet device on which users draw and sketch using a variety of "real-object pens": to change the style of line, the user would choose a new physical 'pen', rather than changing the properties of a single device through a menu interface (Figure 2). More recently Hoeben's 'Ideas' project has produced a first prototype of a tablet-style digital sketchbook (Figure 3) to explore the potential advantages of using a digital sketching tool: "non-destructiveness" (the ability to preserve earlier versions of a sketch, as well as changes); "unified media" (the ability to incorporate more types of digital representation than are possible in a traditional sketchbook); "transferability" (the ability to use sketches produced using this device in other media); and "portability" (the ability to store many more sketches in a similar-sized 'device') [Hoeben & Stappers 2001].

SketchBook™ Pro 2 is a drawing and painting application for tablet and stylus interface (Figure 4) [Alias]. Its "artist-friendly, gesture based interface", while based on windows and menus, is designed for use with a stylus (i.e. without a keyboard), and the stylus can represent a range of 'pressure-sensitive' tools including pens, pencils, markers, brushes

and air brushes, which can be customised as required. 'Layers' allow existing work to be preserved while further drawing development is done.

Figure 3: IDEAS
Aldo Hoeben; reproduced by kind permission of ID-StudioLab, Delft University of Technology

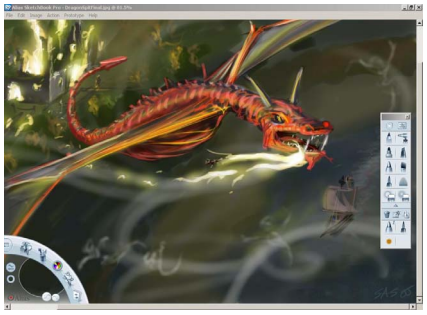

Figure 4: A screen shot from Alias® SketchBook™ Pro 2.
© 2004 Alias Systems Corp.

Sketch interfaces to 3D modelling

A number of projects aim to bring sketching processes and 3D modelling closer. Techniques include extending the concepts of sketching processes into 3D, and allowing sketching to act as the means of creating 3D models.

Digital Clay is a prototype sketch recognition program developed at the Sundance Laboratory [Schweikardt & Gross 1998]. It aimed to bridge the gap between early sketching activities and later 3D digital modelling by allowing designers to use sketching as a means of describing three-dimensional forms to modelling software. Using a tablet and stylus, designers sketch freehand projection drawings, which Digital Clay interprets using the conventions of isometric and perspective drawing to produce three-dimensional digital models (Figure 5).

A system developed at the Laboratory for Computer Science at MIT aimed to combine the fluency of sketches with the capability for variable viewpoints offered by digital 3D modelling (Figure 6) [Tolba, Dorsey et al. 1999; Tolba, Dorsey et al. 2001]. The system interprets freehand perspective sketches as lines on a spherical projective grid, the centre of which is the vanishing point. Once the sketch is in the system, the user can rotate the grid, zoom in, etc. to see different views. Designers can draw directly into the system, guided by a perspective grid, or sketch on a digital notepad. These sketches can be imported into the system, and aligned with its grid and vanishing point either manually or automatically. They can then be worked on further within the system.

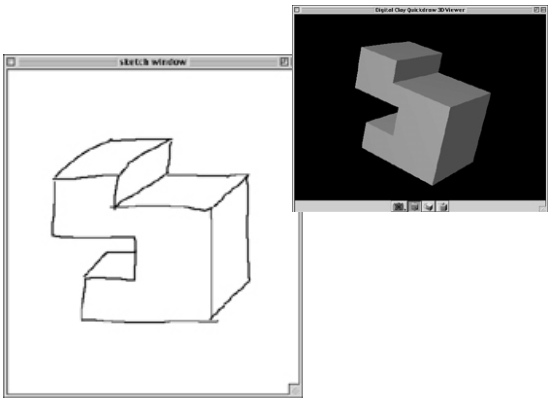

Figure 5: Digital Clay - 2D sketch and 3D model. Reproduced by kind permission of Mark D. Gross, Carnegie Mellon University

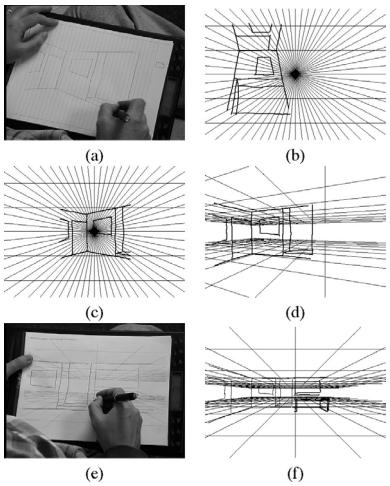

Figure 6: Sketching with Projective 2D Strokes. [Tolba, Dorsey et al. 1999] © 1999 ACM, Inc. Used by permission.

Researchers at Brown University developed SKETCH, a mouse-based gestural interface for creating three-dimensional models. This was later adapted into ErgoSketch for their prototype ErgoDesk framework [Forsberg, LaViola Jr. et al. 1998]. ErgoDesk integrated 2D pen-based and 3D tracked gestural input, physical props, and speech input around a 'stereoscopic-3D-on-demand' drafting-table-type display (Figure 7). It provided a variety of 2D and 3D interaction techniques, with seamless transitions between interactions and tasks, and supported two-handed interaction. 2D pen-based gestural input was used to create, manipulate and edit three-dimensional models, with the ability to switch to stereoscopic mode allowing 3D inspection of models.

Figure 7: ErgoDesk Reproduced by kind permission of A.S. Forsberg, Brown University Computer Graphics Group

Figure 8: NAIST Immersive Modelling Environment. Reproduced by kind permission of the Nara Institute of Science and Technology

Researchers at the Nara Institute of Science and Technology (NAIST) are developing an Immersive Modelling Environment which uses a similar approach, but allows modelling in both 2D and 3D environments (Figure 8) [Yoshimori, Matsumiya et al. 2000].

Drawing as metaphor

Surface Drawing is a system developed by Schkolne at CalTech and Bell Labs to allow artists and others to create organic and expressive 3D shapes in an intuitive and immediate manner [Schkolne, Pruett et al. 2001; Schkolne, Pruett et al. 2002]. Using their hand, users sweep out 3D marks or 'strokes' which appear to 'float' in space above the semi-immersive bench-type display. Thinner strokes can be drawn with the fingertip when the hand is held in a pointing gesture. This system extends the principles of 2D drawing to 3D space, using repeated strokes to build up surfaces. A set of physical 'tangible tools' allows the user to manipulate the 3D drawing: a pair of tongs is used to move the drawing in space (two pairs can scale the drawing up or down); an eraser tool allows small portions of the drawing to be removed, and a 'magnet' tool enables small deformations and smoothing of surfaces. Figure 10 shows a work created using the system.

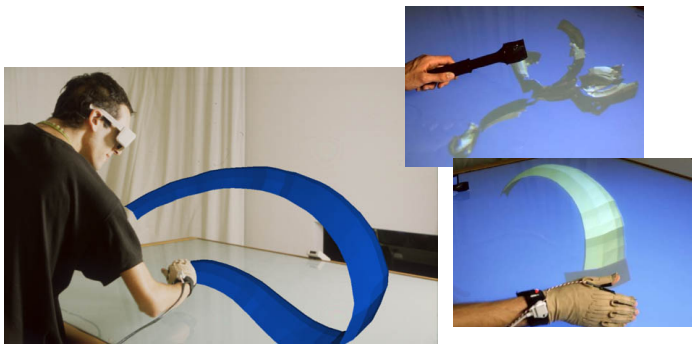

Figure 9: Surface Drawing
Reproduced by kind permission of
Steven Schkolne.

Figure 10: Artwork produced using
Surface Drawing
Reproduced by kind permission of
Steven Schkolne

A collaborative research project between an artist and a technologist in Helsinki shares some of the principles of Schkolne's work but in a CAVE-type semi-immersive environment. A prototype application 'Antrum', developed for EVE (Experimental Virtual Environment), allows freehand 'drawing in the air' (Figure 11) [Mäkelä & Ilmonen 2004]. Whereas Surface Drawing used a glove for input, and 'tangible tools', this system is single-handed and wand-based, 'extruding' an adjustable profile from a wand. Future research goals include a more flexible means of creating and modifying the line, and two-handed input.

CavePainting is a system developed by researchers at Brown University which is also designed for 3D painting in a CAVE semi-immersive environment, but uses an interface

Figure 11: EVE [Mäkelä & Ilmonen 2004]
Reproduced by kind permission of IEEE. (© 2004 IEEE)

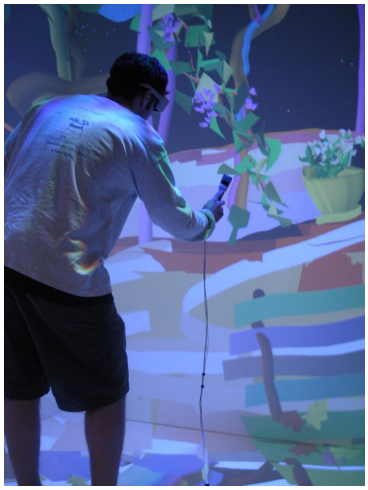

Figure 12: CavePainting
Reproduced by kind permission of
Daniel F. Keefe, Brown University

based on gesture and physical props [Keefe, Feliz et al. 2001]. The system emphasises the different types of 'strokes' that an artist will use, and the piece of work is created through the arrangement of 3D 'strokes' in space. The main elements of the interface are a tracked physical brush with an added 'toggle' button, and a table with a number of physical 'paint pots', each representing a different type of 'stroke'; a tracked physical bucket can be used to 'splash' or 'spill' paint on the CAVE's surfaces. Colour is selected via a 3D 'colour picker'. The user selects the stroke by dipping the brush into the pot – examples include 'line', 'bumpy tube', and 'Jackson_Pollack++' - and paints by moving the brush though the air while holding down the button. In some strokes the 'paint' is applied at the position of the brush tip; in others the paint continues in the direction of brush movement until it 'hits' the wall of CAVE. The system is also sensitive to the orientation of the paintbrush prop, resulting in a wide range of expressive possibilities for the artist.

Alternative techniques for creating virtual models

Other groups are devising new ways of creating virtual models as an alternative to the precise, geometric techniques currently provided. Expressive, intuitive, playful and quick methods are sought, particularly for the early stages of design. While only some of the following examples involve haptic techniques, all place strong emphasis on using the hands, and direct modelling.

'Physical' modelling

The FreeForm™ modelling system provides a 'clay sculpting'-based technique for creating 3D digital models, based around a PHANTOM® haptic device (Figure 13) [SensAble Technologies, Inc.]. Users work directly with the "digital clay" using the PHANTOM stylus as a modelling tool. The hardness and surface smoothness of the 'clay' can be varied, and different modelling 'tools' selected. Unlike real clay, you can also work from the inside out... SensAble™ recently released The FreeForm® Concept™ system: a clay-modelling application designed for use with their Omni™ device.

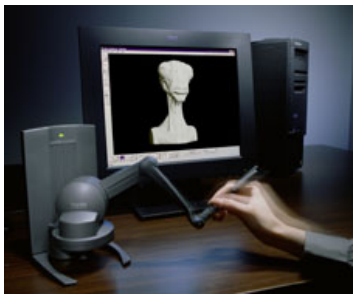

Figure 13: FreeForm® Modelling™
Reproduced by kind permission of
SensAble Technologies, Inc.®

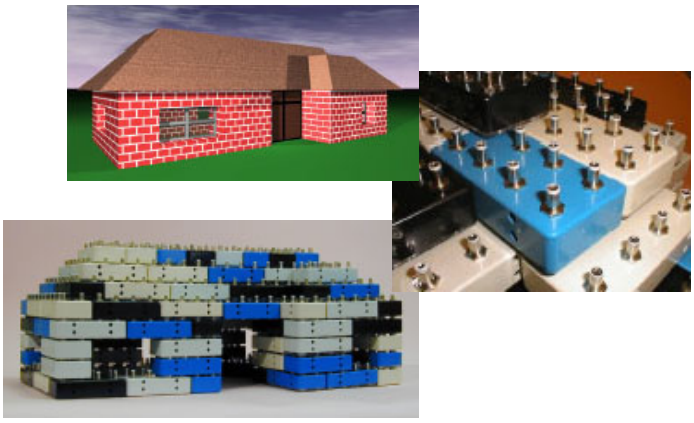

Figure 14: MERL computational building blocks
[Anderson, Frankel et al. 2000] © 2000 ACM, Inc. Used by permission.

Researchers at MERL[2] have developed a tangible modelling system which uses computational building blocks to build virtual 3D models (Figure 14) [Anderson, Frankel et al. 2000]. Instrumented blocks, whose physical form is based on the Lego™ block, can be built into structures in a similar way. The blocks communicate with each other, allowing the connections between the blocks to be mapped. Knowing the relative position of each of the blocks, the geometry of the resulting 3D structure is calculated, and the virtual model created. 'Literal renderings' show the virtual model similar in appearance to the original blocks, but 'graphical interpretations' of the structure, for example recognising elements as walls and roofs of a building, allow 'interpreted renderings' to be produced.

[2] Mitsubishi Electric Research Laboratory

Enhanced interfaces to existing software

Researchers at Alias® and the University of Toronto have explored new interaction techniques around ShapeTape™, a sensored strip that can measure its own bend and twist [Measurand Inc.]. Their prototype system used ShapeTape to control NURBS[3] curves in Maya, Alias's 3D modelling and animation software (Figure 15) [Balakrishnan, Fitzmaurice et al. 1999]. The user can directly manipulate virtual curves and surfaces with both hands, rather than using geometric techniques. This system explores more intuitive ways of creating and manipulating geometry in a more traditional modelling environment.

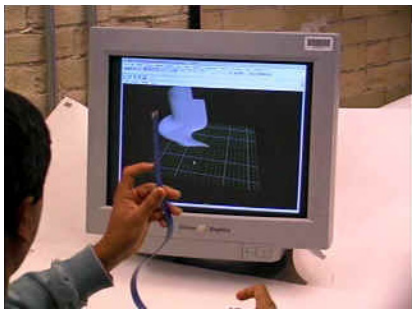

Figure 15: ShapeTape™ Photo courtesy of Measurand, Inc. Reproduced by kind permission of Measurand, Inc.

Figure 16: ClayTools™
Reproduced by kind permission of SensAble Technologies, Inc.®

The ClayTools™ system [SensAble Technologies, Inc.] has been designed to extend the facility of working intuitively, organically and at high resolution with haptic, clay-type modelling systems into existing 3D computer graphics packages such as 3ds Max, Rhinoceros and Maya (Figure 16). Users can create highly detailed models in ClayTools, and then map these 'high-resolution' surfaces onto the much lower resolution polygonal models required, for example, in games applications; they can also use ClayTools to add detail to polygonal models created with the computer graphics software. The system also extends some of the tools within the computer graphics system to use haptic feedback.

InDex is a 3D modelling tool developed around the metaphors of "sculpting with blades and magnets" and modelling with "Digital Jigs" (Figure 17) [Digital Artforms Inc.]: in this way it has similarities to solid (as opposed to surface) modelling software. It allows two-handed direct interaction with the 3D model and environment via a pair of tracked

[3] NURBS: Non-Uniform Rational B-Spline. A type of curve where control points are manipulated to define the degree of curvature

SpaceGrips button controllers (Figure 18) [LaserAid], has the option to view the model in stereo, and can import/export to many 3D modelling software packages.

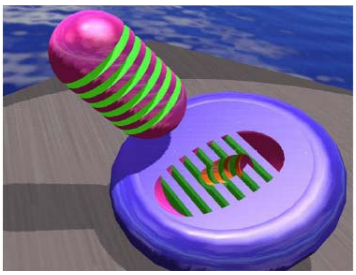

Figure 17: InDex Modelling System
Reproduced by kind permission of Digital Artforms, Inc.

Figure 18: SpaceGrips controllers
Reproduced by kind permission of LaserAid

Tangible interaction

The GeOrb is a spherical device with sensors distributed over the surface, which is held in both hands (Figures 19 & 20) [Global Haptics]. Pressing on any part of the surface deforms the virtual model mapped to the device in the direction of the pressure. Switches on the surface allow the model to be deformed inwards to or outwards from the centre of the orb, and the model to be rotated. Switching modes allows the device to be used to navigate through virtual environments.

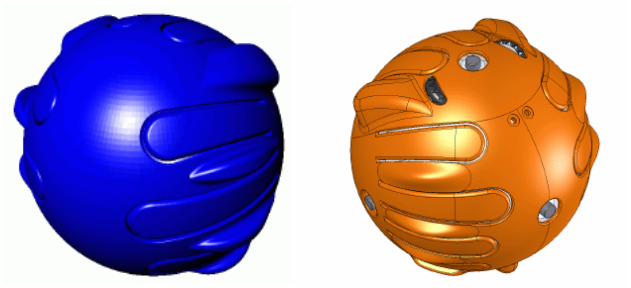

Figure 19: The GeOrb
Reproduced by kind permission of Global Haptics, Inc.

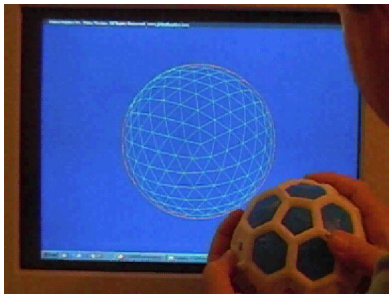

Figure 20: View of an earlier prototype in use. Reproduced by kind permission of Global Haptics, Inc.

Integrating advanced technologies for visualisation and interaction (co-incident interaction)

In an extension of their original project, researchers at the ID-StudioLab are developing 'Cubby+', which allows designers to use the Cubby 3D environment (see Appendix B) to create three-dimensional form in the early stages of design (Figure 21) [Overbeeke, Djajadiningrat et al. 2001]. This will allow designers to create and interact with the 3D

form directly in space, using both hands and a series of tools based on "a mix of tangible and augmented modelling techniques".

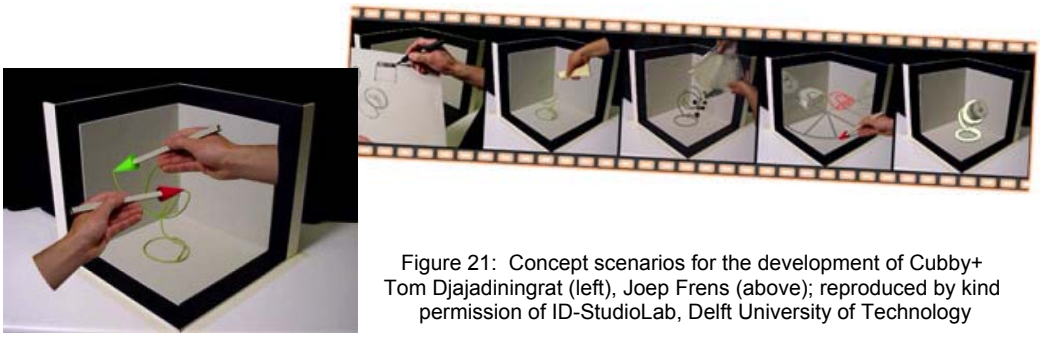

Figure 21: Concept scenarios for the development of Cubby+ Tom Djajadiningrat (left), Joep Frens (above); reproduced by kind permission of ID-StudioLab, Delft University of Technology

Research at the Digital Design Studio (DDS), Glasgow School of Art, focuses on a human centred approach to advanced digital 3D modelling, visualisation, interaction and virtual prototyping. Advanced 3D displays with integrated gesture, haptic and 3D audio technologies are being used to develop new 3D interfaces [Anderson & Slinger 2000]. AutoEval, a proof-of-concept 3D system incorporating real-time visualisation and interaction, was developed for the Ford Motor Company to support advanced design and evaluation in the automotive industry (Figure 22).

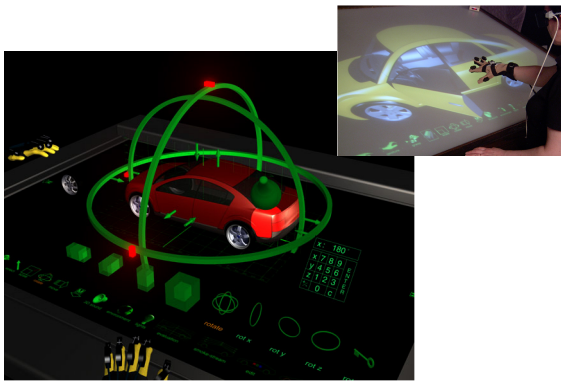

Figure 22: AutoEval - illustration of features and system in use (inset). Reproduced by kind permission of The Digital Design Studio, Glasgow School of Art

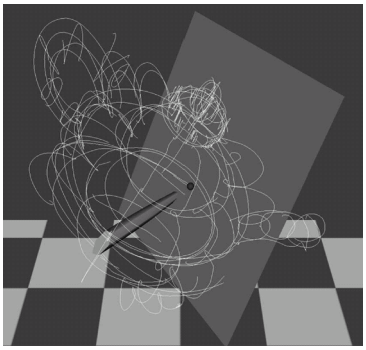

Figure 23: Tacitus project: haptics-enhanced 3D sketching application (screen capture of sketch by Tom Elliott). Reproduced from the Tacitus Project CD-ROM by kind permission of Ann Marie Shillito, Principal Investigator, Tacitus Project

The Tacitus project, a collaboration between Edinburgh College of Art and the Edinburgh Virtual Environment Centre, University of Edinburgh, has explored the potential of co-incidental haptic interaction and 3D visualisation "not to imitate the working practices of applied artists and designers, but to create a generic virtual environment that can be

applied to a variety of 3D creative disciplines" [Shillito, Wright et al. 2004]. The emphasis within the project is on developing "a new generation of interface built on a deeper understanding of the design process used by designers and applied artists, the central requirement being for rapid imprecise creation and development of designs in an exploratory manner". Haptics are used, not in the 'clay modelling' metaphor of SensAble's FreeForm software, but "as an interface element to assist interaction within a three dimensional environment" by adding an "experiential quality" to interaction. Drawing on research into artists' and designers' use of traditional media in the 'germinal' phase of the design process (particularly Physical Concept Models) [Scali, Shillito et al. 2002] a prototype system has been developed round the Reachin desktop display (incorporating the PHANTOM). This prototype is designed to engage the spatial reasoning skills that artists employ when manipulating physical objects, through a suite of tools designed on the principles of spatial, haptic, two-handed interaction. A 3D sketching application has been used to prove and develop these ideas (Figure 23). (Other aspects of this project are discussed in Chapter 3, ***Artefacts and the design process***.)

Realising digital objects

A number of artists and designers are exploring the possibilities offered by the various methods of producing physical models directly from digital data. Gordon Burnett, a metalsmith, used the unique surface characteristics produced by a CNC 3-axis milling machine in a series of aluminium clocks (Figure 24) [Margetts & Burnett 1996]. He has more recently participated in the CONNECTIVITY project, which uses rapid prototyping as part of "a collaborative international workshop that incorporates digital methods of creativity and manufacture" (Figure 25). [Connectivity]

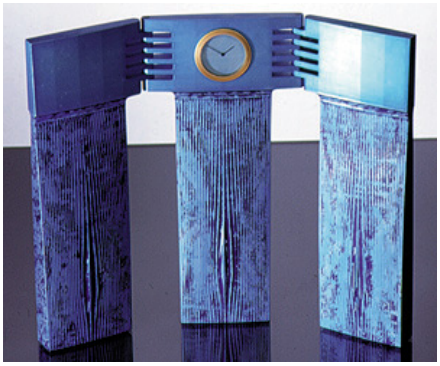

Figure 24: 'Aqua', anodised aluminium, Gordon Burnett (in collection of Aberdeen Art Gallery). Reproduced by kind permission of Gordon Burnett

Figure 25: CONNECTIVITY project (Ryuichi Tabu). Photo, Stuart Johnstone. Reproduced by kind permission of Ryuichi Tabu

The CALM (Creating Art with Layer Manufacture) project (1998) was funded by the UK Higher Education Funding Councils to allow artists and designers to experiment with these techniques principally used by engineers and, at that time, with very high costs, and to begin to investigate their potential within this new context (Figures 26 & 27) [Hodgson 1998].

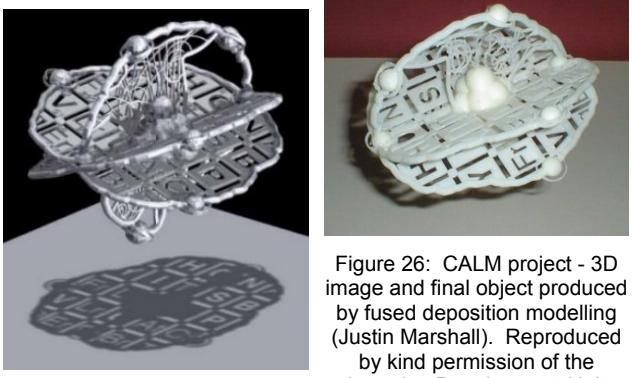

Figure 26: CALM project - 3D image and final object produced by fused deposition modelling (Justin Marshall). Reproduced by kind permission of the Learning Development Unit

Figure 27: CALM project - final object produced by stereolithography (James Jackman). Reproduced by kind permission of the Learning Development Unit

Ann Marie Shillito, an applied artist working in jewellery and metalwork, has explored a range of Rapid Prototyping (RP) techniques both in her own work, and to assess their potential for applied artists (Figure 28) [Shillito 1999].

Figure 28: Bangle with three rotating rings, produced in ABS plastic using layer manufacture technology. Designed, finished using acrylic paint and gold leaf, and photographed by Ann Marie Shillito. Reproduced from the Tacitus Project CD-ROM by kind permission of Ann Marie Shillito, Principal Investigator, Tacitus Project

Conclusions

Many recent developments in digital technologies to support creative practice focus on replicating and extending the ways in which creative practitioners currently work with

materials, or in harnessing the potential benefits that can arise from combining the capabilities of computer systems with the traditional skills and working methods of artists and designers. A lot of the projects reviewed above still favour the 'design-by-drawing' paradigm: research into more intuitive methods of creating virtual design representations tends, though not exclusively, to emphasise sketching, or the use of sketch- or gesture-based interfaces to create three-dimensional form; similarly, many research projects which address computer support for conceptual design focus on sketching, even for the creation of three-dimensional virtual objects. Systems that draw on alternative approaches to design often reflect the belief that 'hands-on' access to materials is very important to makers/creative practitioners, and should be replicated when developing new digital environments for design: this thesis challenges and clarifies this viewpoint, by analysing more closely what it is that may be important in this relationship between a practitioner and the medium with which they work.

The remainder of this thesis describes an investigation of diversity in design practice which shows that significant underlying differences exist between individual design practitioners, concerning their relationship with the medium with which they work, and its role in their practice. It demonstrates that this relationship encompasses important aspects of working and knowing that are not embedded in the material context of practice, which should be acknowledged by theory, and could be harnessed practically in the development of future digital environments for creative practice.

The next chapter, ***Artefacts and the design process***, reviews a range of design research literature to identify the roles that artefacts play in a design practitioner's process; to characterise the nature of the relationship between the practitioner and the artefacts they create and work with in their processes; and to identify possible reasons for differences in this relationship.

3. Artefacts and the design process

This research is concerned with the diversity that can be observed in design practice, in terms of the relationships between design practitioners and the artefacts and media with which they work. In looking for a cohesive theory that would encompass and satisfactorily explain these differences, my starting point was the diversity I had observed within the group of designer-makers I had interviewed for my previous research where, while some designers developed their ideas using sketching, others chose to work with three-dimensional artefacts or used a combination of both. (I use the term 'artefact' to denote the physical manifestations of a designer's processes, including sketches, models, etc.)

This chapter reviews a range of design research literature to identify the roles that artefacts play in a design practitioner's process; to characterise the nature of the relationship between the practitioner and the artefacts they create and work with in their processes; and to identify possible reasons for differences in this relationship.

Studying design practice

Although there has largely been a move away from 'prescriptive' models of design to building 'descriptive' models of design through a study of what designers actually *do*, the emphasis of much design research is still on design processes (such as the relationships between analysis, synthesis and evaluation) and design 'cognition'.

This focus on 'design thinking', examining the mental and cognitive processes that go on in designing, can be seen in the titles of Lawson's major review of design, How Designers Think [Lawson 1997]; a significant symposium on design research held in Delft in 1992: *Research in Design Thinking* [Cross, Dorst et al. 1992]; and conference series such as *Creativity and Cognition*, *Computational and Cognitive Models of Creative Design*, and *Artificial Intelligence in Design.*

While much research continues in this vein, there has been a growing interest in the external representations that designers work with in their processes, and the role that these play in design. Again, this is reflected in conference and workshop series such as *Conference on Visual and Spatial Reasoning in Design*, *Thinking with Diagrams*, and the

4th International Design Thinking Research Symposium on Design Representation [Goldschmidt & Porter 1999].

In contrast to this research which has largely focused on the process of 'design-by-drawing', there has been a recent groundswell of research into the working processes of practitioners who not only design but also make. This can be seen in the *Research into Practice* conference series (in 2004 the theme was "The Role of the Artefact in Art & Design Research") [University of Hertfordshire], and the *Pixel Raiders* series of conferences on "the issues, discourse and reflective practice at the heart of digital making" [Pixel Raiders]. However, the two research communities still seem to be largely separate: a gap which this thesis hopes to bridge.

Design: problem solving or reflective practice?

The emphasis on 'design thinking' has been influenced by cognitive scientists' interests in design, which has focused research on the cognitive activities of designers. This is reflected in descriptions of "the creative designer [as] a knowledge worker involved in activities that are not readily characterised by formal procedures" [Candy & Edmonds 1996].

Goel's study of design (discussed below) takes this stance: he states how "cognitive science is in the business of explaining intelligent human behaviour. More specifically, it wants to explain cognition as symbol manipulation or information processing" [Goel 1995]. This reflects the traditional interest of cognitive scientists in predominantly mental processes; however Brereton points out that "recent writings on distributed cognition report that cognitive achievements derive not only from the internal thought processes of people but also from the material systems and information technologies with which they work" [Brereton 1999].

Studies of artefacts in design are both informed and constrained by the model of design which underlies the researcher's approach. Much research into design cognition uses the dominant paradigm of design as problem solving, where design problems are 'wicked' or 'ill-structured', and approached through systematic exploration of the problem space.

In an alternative paradigm of design as reflective practice, Schön describes design as 'reflective conversation with the materials of a design situation' [Schön 1983; Schön 1992]. Each design situation is viewed as a unique case, a problematic situation rather than a well-defined problem. Often complex, dynamic and unstable, with conflicting

requirements, such situations are not amenable to being constrained to fit standardised techniques. This requires a shift from problem solving to problem setting, from technical expertise applied in standardised ways to skilled knowing-in-action. In this model, the design process is one of understanding though change:

> *"The unique and uncertain situation comes to be understood through the attempt to change it, and changed through the attempt to understand it." [Schön 1983]*

His term 'materials of a design situation' refers not only to the artefacts with which a designer works, but also (in the architectural context in which much of his research is situated) to the site, the previous experience or 'repertoire' of the designer, the norms of the design domain within which the designer works (for example a particular 'school' of architecture), the designer's unique appreciation of the situation, etc. Each of these contributes to what Schön describes as each designer's uniquely constructed 'design world' within which they operate. Schön concludes:

> *"All of this should be contrasted with the familiar image of designing as "search within a problem space". To the extent that designing resembles the examples I have just described, it is clear that a "problem space" is not given with the presentation of design task: the designer constructs the design world within which he sets the dimensions of his problem space and invents the moves by which he attempts to find solutions." [Schön 1992]*

Schön's model of design is distinct from the 'design as problem solving' model in a number of other important ways. He acknowledges the tacit aspects of designing:

> *"Design knowledge is knowing-in-action, revealed in and by actual designing. It is mainly tacit, in several senses of the word: designers know more than they can say, tend to give inaccurate descriptions of what they know, and can best (or only) gain access to their knowing-in-action by putting themselves into the mode of doing…" [Schön 1992]*

Schön describes knowing-in-action as "a dynamic know*ing* process, rather than a static body of know*ledge*…" [Schön 1985]. This knowing-in-action "…involves sensory, bodily knowing. The designer designs not only with the mind, but with the body and senses – a fact that poses an interesting challenge to computers" [Schön 1992]. He emphasises the physical aspects of designing and the situated nature of design:

> *"Any faithful description of designing must take account of the fact that designers work in a medium – in our examples, they draw on paper – and literally see the evolving products of their work. Models of designing that treat only of conceptual matters – emphasizing, for example, the implementation of ideas, the interplay of variables, the management of constraints, or the alternation between proposals and evaluations – are bound to miss crucially important features of the design process, whatever else they may capture." [Schön & Wiggins 1992]*

The research reviewed below draws on both models of design, although the majority of studies tend towards the 'design as problem solving' model.

Different focus and scope

All the studies reviewed examine elements of the relationship between designer and artefacts, but with different focus and scope.

Focus

Some studies concentrate on examining the designer: either in the sense that they are largely concerned with a designer's "creative cognition" or creativity and innovation; or on *what* a designer is thinking about i.e. the 'content' of their thoughts. In other studies, the object of scrutiny is the artefact: although it may be the designer's processes which are being examined, the study is made largely through an analysis of the artefacts themselves. However, the majority focus specifically on a designer's interaction (in the variety of meanings given in this context to that term) with artefacts. A few studies are concerned at a broader level with a specific element of the design activity, such as Pedgley's "attention to materials and processes", or the Tacitus project's focus on the use of 3D models in the 'germinal' phase of design.

Scope

Pedgley makes a useful distinction between two different levels at which design activity can be viewed [Pedgley 1999]. His terms 'macroscopic' and 'microscopic' refer to "descriptions at contrasting levels of proximity to the observed activity". Macroscopic views

> *"tend to show a global view of designing: visible to the naked eye; spanning across long periods of a project (e.g. days, weeks); related to long-term goals; concerned with overall strategies for designing and work constraints/opportunities"*

Microscopic views, in contrast,

> *"tend to: need a specially devised data collection method in order to be captured; be contained within discrete episodes of designing (e.g. seconds, minutes); relate to short term goals; be concerned with trains of thought and designers' reasoning"*

Studies at the macroscopic level usually focus on actual design practice, including longitudinal studies on live design projects, such as Pedgley's examination of his own practice while designing a polymer acoustic guitar, reported in his thesis. Studies at the microscopic level tend to be laboratory-based, experimental studies of designers working on an artificially constrained design task. Protocol analysis is a dominant method of analysis at this level [Pedgley 1999].

In the following review the studies fall predominantly into the "microscopic" category. However, the case studies of individual designers later in the chapter could be classed as macroscopic, as they deal with designers in the context of their normal design practice.

Focus of this thesis

My research focuses on an individual designer's relationship with the artefacts they create, and how the interaction between the two contributes to, influences or comprises the design process. While acknowledging the importance of other related areas of research, such as visualisation and perception, the haptic elements of physical interaction, and knowledge-based design systems, they lie outwith the scope of this study.

The following examples are not exhaustive; research in each of the aspects discussed below is ongoing. Those included here have been selected to illustrate a range of concerns in this area of research, and the variety of roles which artefacts are perceived to play in design.

Two-dimensional artefacts

The following studies into two-dimensional artefacts (mainly sketching) cover a number of different themes: the role of sketching in the design process; the nature of sketches or sketching processes that makes them important in the early stages of design; the relationship between a designer and the sketches they produce; and what, if anything, can be said about design activity by looking at the sketches that a designer has produced/is producing, in terms of how they're designing, or in terms of what they're thinking about?

The studies mainly focus either on the process of sketching, or on the content of sketches; however some focus on the relationship between these two elements.

The symbol system of sketching

In Sketches of Thought [Goel 1995] Goel focuses on the sketches characteristic of preliminary design, and the ways in which they support cognitive processes important to these early stages of design[4]. He considers that "design is an excellent forum for studying human symbolic activity in much of its richness and diversity".

[4] A more detailed examination of Goel's position is undertaken in Chapter 6, ***'Concepts of dialogue in design'***

Goel studied the verbal protocols, writing and drawings of twelve designers (architects, mechanical engineers and instructional designers) produced during a two-hour, "real-world" design task. From the verbal protocols, he identified distinct phases in the problem solving activity, and from an examination of the drawings produced, concluded that designers use different symbol systems which correspond to these different design phases, and so facilitate different cognitive processes.

He was particularly interested in how the sketches produced by designers in the early stages of design support cognitive activity important to this phase: "the incremental transformation of a few kernel ideas". Goel identified two types of transformations important in design: *lateral* transformations, in which "movement is from one idea to a slightly different idea", and which widen the problem space; and *vertical* transformations, where "movement is from one idea to a more detailed version of the same idea", and "deepen the problem space". He observed that "lateral transformations are generally confined to preliminary design phases whereas vertical transformations generally occur in the refinement and detailing phases".

Goel observed that the sketches that supported these lateral transformations were syntactically and semantically dense and ambiguous. He reasoned that the density or fine-grainedness of the symbol system of sketching allows for the easy transformation of one *symbol* into another. This ambiguity of symbols leads to an indeterminacy in the *content* of the symbol, which in turn facilitates the transformation from one *idea* into another. He demonstrated that if designers were restricted to using an external symbol system which did not have these properties of density and ambiguity, then the lateral transformations which are important in the early phases of design were disrupted.

> *"A notational system, such as drafting, which differs from sketching in being non-dense and unambiguous, will hamper lateral transformations. Notice that these predictions have little, if anything, to do with the depictional or 'pictorial' properties of sketches."*

Although Goel emphasises the *nature* of the symbol system, as opposed to the content of the sketches, his work does link the process of sketching and the transformation of ideas: 'what' the designer is thinking about.

Symbolic conventions in design

Whereas Goel is primarily concerned with the nature of the external symbol system of sketching, and its links to the cognitive processes of design, Do with Gross has studied the symbolic conventions used by designers and how these relate to design intent ("the

association of the drawing marks with design thinking"). In this research, they are particularly interested in the use of freehand diagrams:

> *"A diagram may indicate visual phenomena such as wind, rain and sunshine, sight views and lighting, but it can also illustrate human perceptions of the environment such as noise and heat, as well as functional aspects of the environment. A diagram, unlike a sketch, contains symbols… A sketch, in contrast, is mainly about spatial form…"* [Do & Gross 1997]

(This seems to be a narrower definition of symbolic representation than that used by Goel.) In a series of studies Do & Gross discovered that designers are consistent in their use of symbols within drawings; that they "combine symbols in specific configuration to indicate design contexts… [and] have different drawing preferences for different design concerns"; and that they share and understand each others conventions.

> *"In other words, in the domain of architectural design, the graphical marks that designers make are conventional and correspond to the specific tasks that they engage in as they solve a problem…"* [Do, Gross et al. 1999]

Neiman, Do & Gross then studied 110 drawings from Neiman's personal design project, created over a fifteen year period, to see if they could retrospectively 'piece together' the designer's original intent and design process by examining the patterns of transformation and manipulation of design elements in the drawings, and between types of representations [Neiman, Gross et al. 1999]. It became clear during the investigation that this was not possible, largely because of the complexity of the patterns of transformations, and partly as there was no record of the sequence in which the drawings were produced; it also revealed that their "puzzle solving" approach was not appropriate:

> *"As we looked at all the drawings at the same time, and found ways to link different drawings by either spatial or visual relationships, we found the design project to be more a puzzle making process. As Archea suggests, designers do not clarify their goals like problem solvers do; instead, they 'treat design as a search for the most appropriate effects that can be attained in a unique context'."*

However, they made a number of observations about the relationship between the visual transformation of drawn elements and the process of designing:

> *"A designer manipulates design objects (elements) through transforming shapes and locations, and changing viewpoints and drawing types and media to explore design alternatives… The manipulations are simple, but in combination the process became complex... We found each of the design elements transformed throughout the design process: i.e. through change of dimensions, orientation and placement."*

Goel revealed a link between different types of symbol systems, and different phases of design; Do & Gross reveal a link between symbolic conventions and design intent, and a link between visual/spatial activity (e.g. manipulating "visualized representations") and design activity.

Information patterns in sketch activity

McGown, Green & Rodgers also examined links between graphical activity and 'design intent', but as a means of measuring design activity in terms of "the pattern of information flow in the conceptual sketching activity" (ideas and quotations in this section are from [McGown, Green et al. 1998]). They were concerned with the graphical characteristics of drawings as a measure of the ideas and information contained therein, and the patterns of transformations between drawings as a measure of the development of ideas.

They examined the sketchbook drawings of four students on the Product Design Engineering course at Glasgow School of Art, generated during the fifteen week conceptual design phase of their final year project, as "a measure of the ideas and information produced". To allow this measurement, two types of data were derived from the sketches: a measure of the amount of information conveyed by each drawing in terms of the complexity of the drawing, and its size; and the patterns of transformations between (dated) sketches.

The researchers devised a scale of complexity of drawings which incorporated various factors, including the number and types of lines, the use of shading to suggest 3D form, text annotation, provision of dimensions, colour, and the 'busyness' of the drawing. A scale was also drawn up with regard to the size. They proposed (in the context of computer support for design) that "an index ratio of the information in a sketch considered against the amount of sketches produced, could be used to provide a weekly track of the quality of the designer's effort".

They classified the transformations along similar principles to Goel: lateral (a "change in thinking"), vertical ("a more detailed version of the same idea"), and duplication (where one drawing is basically a repetition of a previous one). By comparing this analysis with the final project grading given to the students, the researchers concluded that it was possible to measure the quality of a designer's work by examining these patterns of 'graphical' activity:

> *"good design is a result of balance between lateral and vertical transformation at these early stages"*

They also observed that problems experienced by one of the students could be clearly seen from the analysis of these transformations:

> *"From analysis of sketch evidence* alone *it was obvious that the student's project as a whole was not progressing; there was a lack of balance between lateral and vertical transformations and a tendency to duplicate earlier work."*

The researchers appear to be equating the 'information' (as they have defined it) contained within a sketch as a measure of, and by implication a measure of the quality of, the "ideas and information produced". This position, although based on a comparison of the patterns of each student's activity with their final project grading, appears to make certain assumptions about the extent to which a designer's thoughts are made explicit on paper. While I have reservations about these apparent assumptions, and although there is no examination of how the sketching *activity* supports the development of ideas, nevertheless this study supports the findings from the studies above, that it is changes between drawings that facilitate and/or reveal the process of design.

[Seitamaa-Hakkarainen & Hakkarainen 2000; Seitamaa-Hakkarainen & Hakkarainen 2005] used a similar classification based on Goel's work, of 'horizontal sketch development' and 'vertical sketch development', to examine the different types and development of sketches produced during a short weaving design task by four advanced students and four professional practitioners in the area of weaving design. They were interested in the "strategies of visualization" used by the participants as they "solved professional weaving design tasks".

Sketching as a graphical notational language

McFadzean's research is also concerned with the links between graphical activity and design activity, specifically with the "physical details of markmaking" [McFadzean & Cross 1999]. Her research examines the proposition that sketching is a graphical notational language for visual reasoning.

From a preliminary study [McFadzean 1998a; McFadzean 1998b] she concluded that the marks made during sketching activity in the early stages of design do constitute a graphical notational language. She then investigated how this 'physical/visual' graphical notational language links to the cognitive processes of design problem solving.

Five subjects were videotaped during an architectural design task, and their sketching activity recorded using Computational Sketch Analysis (CSA)[5] [McFadzean, Cross et al.

[5] One of the first aims of McFadzean's research was to determine a suitable method of recording the marks generated, at a level of granularity that could support the types of analysis that was required. After the first study, McFadzean concluded that a computational approach was required in order to obtain sufficient

1999]. Their sketching activity was subsequently replayed using the Sketch Analyser, and their retrospective report of their design thinking during this activity was recorded on video. This allowed their verbal retrospective accounts of their cognitive design activity to be mapped to the graphical sketching activity.

First, the data was examined to identify how design activities map to the cognitive processes of the designer; a second area of research was to identify how graphical activities map to design activities, and therefore to the problem-solving processes in design. Consistent patterns of interactions between 'Design Events' - "incidents that can be considered to be important because they emphasise the state of the design problem space… identified from the verbalizations of cognitive operations that have taken place during the design process" - could be observed, revealing how design activities were linked to the problem solving processes in design. While the second stage of the research was, at the time of writing, ongoing, McFadzean's hypothesis was

> *"that there is a measurable difference in the physical activity of the graphical notation and that these differences can be mapped to the design events. It is expected that mappings will allow the extraction of denotational sub-systems that relate the designers' mode of problem solving with the syntactic structure of the external representations."* [McFadzean 1998a]

From the analysis to date, McFadzean drew a number of conclusions about ways in which sketching supports problem solving processes in design:

> *"sketches enable designers to* handle different levels of abstraction in parallel… *They* enable identification and recall of relevant knowledge… *they* assist problem structuring though solution attempts… *[and] sketching* promotes the recognition of emergent features and properties *within the problem space. Sketches help the designer to make what Goel called 'lateral transformations' in the solution space: the creative shift to new alternatives. They also help the designer to find the unintended consequences that enable exploration. Schön called this characteristic of design thinking 'a reflective conversation with the situation'."* [McFadzean, Cross et al. 1999]

McFadzean also describes the process of sketching in terms of the relationship between the designer and the sketch:

> *"Conceptual thinking, during the design process, involves an interactive relationship between the mental processing of information and the external expression and representation of that information within the sketch. The interaction between external sketch representations and the cognitive processing of design information is a 'dialogue' of thinking aloud: conversing with oneself, a process of soliloquising about design suppositions."* [McFadzean, Cross et al. 1999]

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accuracy, and developed the technique of Computational Sketch Analysis (CSA) for subsequent studies. For further details on this technique, see [McFadzean 1998a; McFadzean 1998b].

McFadzean's research suggests that the marks made during sketching are more than a symbol system; rather they form a 'graphical notational language' with which to conduct this 'soliloquy'.

Sketching as Interactive Imagery

Goel presents sketching as an external symbol system which supports cognitive processes necessary to the early stages of design. In Goldschmidt's research, the emphasis changes from sketching as a external symbolic representation of existing mental images, to sketching as a means of generating/initiating mental imagery: sketching as visual thinking (ideas and quotations in this section are from [Goldschmidt 1994]). She makes a clear distinction between visual thinking and visualisation: visualisation is visual representation; visual thinking relates to "the production of ideas, the reasoning that gives rise to ideas and helps bring about form in design":

> *"Designers invariably use imagery to generate new form combinations which they represent through sketching. But they also do the reverse: they sketch to generate images of forms in their minds."*

She gives the example of being shown a picture of a parallelogram, and being asked to find its area: those who see that the parallelogram can be re-represented as a rectangle are able to solve the problem. The facility that enables us to do this is 'imagery' – a mental visual display that allows us to 'read off' clues as to how a problem might be solved, recalling useful things from memory. In its role of external symbolic representation, sketching is a means of recording and representing visual displays. Goldschmidt proposes that in its role of visual thinking, sketching is a means of actively generating visual displays.

Like other commentators, Goldschmidt acknowledges that design concepts emerge by an incremental process of transformation, guided by 'clues' as to how to move the design problem forward. But in a design problem, the relevant images cannot all be retrieved from memory: they must be generated. Goldschmidt proposed that the primary means of generating such relevant 'clues' is sketching:

> *"It is our belief that the purpose of this early sketching activity is primarily to avail oneself of potentially meaningful clues. If picked up, these clues can be used to form and to inform emerging design concepts. To pick up clues, the designer uses imagery in a mode very similar to the one we saw in the case of the parallelogram: one reads off the sketches more information than was invested in its making... Seeing something as something else (which is not there physically) is the essence of imagery, and since in this case imaging is brought about through sketching, we call this process* interactive imagery.*"*

Goldschmidt observed that while in many cases designers post-rationalise figures (pictorial representations) as being generated by concepts (descriptional representations), often it is a figure that has generated the concept. She concludes that the process of design features a dialectic process between figure and concept, and that such figure-concept dialogues are the building blocks of design

> *"…we notice that in these typical instances of visual thinking in designing, there is a regular and constant exchange between figural and conceptual arguments… Hence our dialectics metaphor: in the exchange between imagery in the mind and sketch on paper, we reason by way of relating figures and concepts to one another until a satisficing 'good fit' is achieved among them."*

Goldschmidt, like McFadzean, is looking at the relationship between visual thinking and design problem solving: Goldschmidt views imagery "as an interactive process of symbolic representation"; McFadzean views the marks made in sketching as a graphical notational language. Both describe an interactive relationship between the designer and the sketch, but whereas McFadzean emphasises interaction between the "mental processing of information and the external expression and representation of that information within the sketch", Goldschmidt emphasises (in the aspect of sketching with which she is dealing) that the imagery precedes the mental concept. This contrast between symbolic representation and imagery suggests that, while both are seen as enabling a process of 'dialogue with yourself', the nature of the dialogue may be slightly different.

While the above studies focus largely on the graphical aspects of sketching activity, the following two studies focus rather on what the designer was thinking about while sketching. The data for this study and the next comprised verbal protocols taken from two practising architects' and seven advanced architectural students' retrospective accounts of a 45 minute design task (generated while examining videos of their own sketching activities). Using a protocol analysis technique which focused on *the content* of the designer's thoughts, the studies investigate what the designer is thinking about, how visual aspects relate to non-visual (e.g. functional aspects), and how both of these relate to a variety of design actions, to examine the interaction between designer and sketches.

Sketching as a 'perceptual interface'

Like other studies above, Suwa & Tversky are interested in patterns of activity within the sketching process. However whereas the former examine transformations between drawings, Suwa & Tversky examined designers' retrospective verbal accounts of what

they had been thinking about during the sketching activity (ideas and quotations in this section are taken from [Suwa & Tversky 1997]).

In the first of these two studies, during which the data was gathered, Suwa & Tversky studied the verbal protocols to identify: what information architects and students perceived in their sketches; the patterns of activity (how the different types of information related to one another in a designer's thoughts over the course of the activity); and the ways in which visual aspects of design are related to the non-visual (e.g. functional, abstract). They also compared the patterns of information of experienced architects with those of students.

First, they divided the verbal protocols into segments, where each segment represented "one coherent statement about a single item/space/topic". Their analysis of the conceptual dependencies between segments revealed patterns corresponding to Goel's lateral and vertical transformations – a move to a new item/space/topic, followed by series of contiguous segments of "conceptually inter-related design thoughts", together forming what they term 'dependency chunks'.

> *"Shifts of focus allow for a lateral variety of design topics/ideas and a sequence of related thoughts allows for detailed, deep exploration of design ideas."*

Suwa & Tversky concluded that the design process consists of "cycles of focus shifts and continuing thoughts". They observed that in practising architects' protocols, shifts in focus were followed by longer contiguous segments, suggesting

> *"that once architects shift their focus of attention, they think more deeply about the topic. What causes this difference? We believe it occurs because architects are able to 'read-off' more different types of information from their sketches…"*

To examine this proposition more closely, they examined the types of information the subjects were thinking about between and within these dependency chunks, relating to depicted/emergent properties (spaces, things…), spatial relations, functional (non-visual or abstract) relations, and background knowledge. They found that in the longer sequences of segments characteristic of practicing architects there was a greater consideration of functional relations, suggesting that "practicing architects are even more adept at reading off functional issues from perception of visual features than students of architecture".

Like other studies examined here, Suwa & Tversky were concerned with the links between the visual and non-visual aspects of design, and how ideas about meanings and concepts and information are represented in or associated with visual form. They concluded that:

> *"sketches stimulate thinking about not only perceptual relations, but also about inherently non-visual functional relations…"* and that *"perception of visual attributes of sketched items, e.g. sizes and shapes/angles, plays an important role in exploring inherently non-visual functional thoughts, one important goal of a design process. In other words, sketches serve as a 'perceptual interface' though which one can discover non-visual functional relations underlying the visual features."*

Cognitive interaction with sketches

In a second study using the same data, Suwa, Gero & Purcell examined one practising architect's account of his process to identify not only what he was looking at, but also the different types of 'design actions' within the protocol, and therefore determine how a designer 'cognitively interacts' with their sketches (ideas and quotations in this section are taken from [Suwa, Gero et al. 1998]). The researchers define cognitive interaction as "a whole set of design actions consisting of drawing, paying attention to previously-drawn depictions, perceiving their visuo-spatial features, thinking of non-visual information, and so on".

The verbal protocol was segmented (as before), "in such a way that a change in his intention and in the content of his thought or actions flags the start of a new segment". Each segment was coded using four sets of categories of 'design action' - physical, perceptual, functional, and conceptual - linking the actions at the various levels to the design thoughts and intentions of the architect.

In a first stage of the research, using an excerpt from the protocol, Suwa, Gero & Purcell demonstrated a system of dependencies between these different types of design actions: perceptual actions upon physical actions, and functional actions upon perceptual:

> *"… through interaction with sketches at the physical level, designers are then able to have higher interaction at the perceptual and functional levels. This way, information 'emerges' in a bottom-up way. We conjectured that this bottom-up process is a key to understanding the roles of sketches."*

In a second stage of the research, Suwa, Gero & Purcell examined the distribution of design actions over the whole design process. They concluded that

> *"First, his design process contained three distinct phases: problem analysis, spatial arrangement, and functional exploration. Second, in the beginning of his process, the architect made depictions and perceived their visuo-spatial features without necessarily frequent thoughts of functional issues. Rather, it took a substantial time before functional thoughts began to occur frequently."*

They then examined the relationship between the physical aspects of sketching, visual perception, and the non-visual i.e. functional or abstract concepts. From their examination of the frequencies of and correlations between actions (and with their

proviso that the generality of their findings is limited due to the single subject), they concluded firstly, that sketches act as a form of external memory - ideas can be left as 'visual tokens' "so that they may be retrieved later for inspection"; secondly, that sketches provide 'visuo-spatial cues' to functional issues; and finally, that

> *"Cognitive interaction with sketches i.e. making depictions, inspecting and perceiving, enables designers to determine when to think of functional issues and how. Put differently, sketches serve as a physical setting in which design thoughts are constructed on the fly in a situated way. This coincides with the recently prevailing view … that people act not* just *in goal-oriented or knowledge intensive ways, but more often in response to visuo-spatial features of the physical setting they are in."*

Like Goldschmidt, this study discusses a designer's interaction with his sketches. Although the types of interaction under examination are different, there is a common recognition of the importance of the physical and visual aspects of sketching activity, and that sketching provides a way of thinking and reasoning visually.

In a later study [Suwa, Gero et al. 2000] which extends this work, and provides support to Goldschmidt's position, they examined the relationship between 'unexpected discoveries' arising from sketching and the 'invention of functional issues and requirements' (what they refer to as situated or 'S-inventions') during the design process. To be counted as S-inventions "an issue should be abstracted out of specific situations in sketches and become general enough to be carried through the entire design process as one of the primary design requirements". They discovered that "unexpected discoveries of visuo-spatial features in sketches and S-inventions become the driving force for the occurrences of each other" and therefore that "having perceptual interaction with one's own sketches serves as an impetus for pushing forward the co-evolution of the solution space and the problem-space".

Drawing as the medium of reflection-in-action

Schön's model of design as reflective practice was discussed earlier in this chapter; this section considers those aspects which deal directly with the relationship between designer and design medium (ideas and quotations in this section are taken from [Schön 1983; Schön 1992; Schön & Wiggins 1992]). In Schön's model of design, each design situation is viewed as a unique case, a problematic situation rather than a well-defined problem. In order to deal with each unique and complex situation, the design practitioner has to 'set' or 'frame' the problem; impose some kind of order from which to begin. By drawing on exemplars from his repertoire of previous experience, the practitioner 'sees' a way of engaging with the situation, and 'frames' it in such as way as to impose an element of

discipline and structure to allow him to proceed. This is the start of an ongoing process of framing and reframing in response to the 'talkback' of the situation. Having made his 'move', or experiment, the designer 'appreciates' the outcome, which may or may not be what he expects:

> *"Because of this complexity [of the situation], the designer's moves tend, happily or unhappily, to produce consequences other than those intended. When this happens, the designer may take account of the unintended changes he has made in the situation by forming new appreciations and understandings and by making new moves. He shapes the situation, in accordance with his initial appreciation of it, the situation 'talks back', and he responds to the situation's back talk."*

This dialogue takes place in a physical medium. Schön describes drawing and talking as "parallel ways of designing, and together make up what I will call the *language of designing*..."; he also describes design as "a conversation with materials conducted in the medium of drawing and crucially dependent on seeing…".

The 'seeing' Schön describes has a number of aspects; one of the most important is our ability to construct 'figures' – meaningful representations – from marks on a page:

> *"…But now [the designer] begins to see other figures in the footprint, illustrating as he does so how for any given set of marks on a page, different people, or the same person at different times, may construct different figures… Seeing a new figure, he sets a new problem."*

Like Goldschmidt, he emphasises the constructive nature of this process:

> *"In all this 'seeing', the designer not only visually registers information but also constructs its meaning – identifies patterns and gives them meanings beyond themselves"*

Schön sets this 'seeing' within the context of his model of the larger process of design as reflective conversation:

> *"On the basis of a figure constructed from marks on a page, the designer sets and solves the problems that inform and motivate his further designing. The schema of conversational move experiments – seeing-moving-seeing – depends, in the first instance, on our ability to construct such coherent figures."*

Three-dimensional artefacts

Compared to the number of studies which examine the use of two-dimensional artefacts in design, there are few which address the use of three-dimensional or material artefacts in design.

Some research has focused on particular types of three-dimensional artefact, or on the role making physical artefacts plays in the broader context of design. [Yang 2005] is concerned with use of prototypes in the context of mechanical engineering. Specifically,

she examined two groups of students developing electromechanical devices to compete against one another. Comparing the results for each group, her study looked at the nature of the prototypes built, the time spent building and debugging prototypes in relation to time spent designing, and correlating these factors to the quality of design outcome, rather than the relationship between students' use of prototyping activities and the development of their design ideas. In "Experimental making in multidisciplinary research" [Rust, Whitely et al. 2000] examine the role of making as a research tool, in the context of the development of a "mechanical analogy for the human skeletal arm to inform the future developments of prostheses and other artefacts". In this project, "designing activities were the main source of new knowledge". This project showed not only "how the making skills of the designer can enhance research in a field dominated by the analytical approaches of science and engineering", but supported the authors' belief "that artefacts provide the most reliable bridge between the communities concerned with a multidisciplinary research project", relating to the communication and elicitation of knowledge. [Bucciarelli 2002] discusses the role of artefacts (in their wider sense) as a means of facilitating shared communication and understanding between diverse participants on design teams.

The following studies by Harrison & Minneman and Brereton are of particular interest to this thesis, however they differ in a number of ways to the studies of two-dimensional artefacts discussed above. Where the latter focused on individual designers, these studies focus predominantly on group design activity. In many of the previous studies, the designers were asked to 'think aloud' during the design exercise. In the studies below, the design sessions were videotaped, and it is the communication and interaction between the designers which provides the raw data which is examined to explore the design activity. Brereton comments,

> *"Activities do not reveal the individual cognitive processes… but they reveal all the verbal and gestural interactions, that is the inputs and outputs of individual thinking processes made available to the group. This provides the researcher access to the external representations used in activity."* [Brereton 1999]

These studies cover a number of different themes: the role of objects in social interaction of design teams; the ways in which interacting with objects supports design activity; the different roles that physical objects or materials play in design; and the role of objects or materials in supporting learning in engineering design.

How objects support interaction in design teams

Harrison & Minneman studied the involvement of objects in the social interaction of design teams, and the ways in which interacting with objects supported design activity (ideas and quotations in this section are taken from [Harrison & Minneman 1996]). The data for this research came from the 'Delft Protocols' - video and audio recordings of three groups and two individuals undertaking a two-hour task to design a piece of equipment for mounting a backpack on a bicycle [Cross, Christiaans et al. 1996]. The designers were provided with a backpack and a bicycle, and it is their interaction with these objects on which Harrison & Minneman's research focused.

The researchers found that interaction with the design objects was "*frequently* part of the activity" throughout the design exercise. Gesturing around or with and manipulating the objects was a significant activity, and objects were often used as "stand-ins for other objects", acting as a form of representation (including where spaces between or over objects became the location of 'imaginary' objects). While Harrison & Minneman acknowledged that this representational use of objects was important, the study did not examine the use of other representations (e.g. drawing and sketching), so this aspect was not pursued.

Harrison & Minneman then examined excerpts of the protocols to identify how interaction with the objects related to design activity: "how conversation, manipulation and design development worked across a few minutes activity". They looked at the extent of engagement with the objects (e.g. looking, touching, riding the bike); the gestural aspects of this interaction - how the designer was moving with or around the object, as a means of informing themselves or communicating with others (e.g. drawing attention to features, or animating mechanisms); how interaction with objects supported verbal communication (e.g. as 'verbal props': references such as 'here', 'this'); and the context of the activity: what triggered an interaction or resulted from it. They concluded that interaction was often used as a means of getting information:

> *"…there are also quite a number of 'spontaneous' engagements. Furthermore, there appear to be other equally compelling explanations that account for the change from an activity without to one with objects: to control the dynamics of a conversation, to change topics, to ground gestures, and to confirm or to recalibrate imaginary objects."*

They attribute a variety of roles to the objects in design activity:

> *"First, that objects are more than a source of information; they are constituents of the activity. Second, that they are constituents of and frames for the communications. Third, they alter the dynamics of interaction, especially in multi-designer settings."*

In the context of their particular interest of the role of objects in the social interaction of design teams, they conclude:

> *"The significance is not that they provide a rich source of information for the designer (which they do) or that they are superior to abstract forms of information (which they may or may not be), but rather that the processes of interaction with objects have communicative value and alter the dynamics in multi-designer settings."*

Harrison & Minneman's study focused on actual objects, not material media. Although they acknowledged the importance of the representational role of objects, and proposed that it was worthy of further examination, it was not the focus of their study. However, in the following work it is a major concern of the research.

How objects support design thinking and learning

Brereton's research examines the different roles hardware plays in design; how interaction with hardware supports students learning engineering design; and how hardware supports communication (ideas and quotations in this section are taken from [Brereton 1999; Brereton & McGarry 2000]). (Brereton uses the term *hardware* "to refer collectively to physical objects and physical prototyping materials".) This had not been the original focus of Brereton's research, but in an exercise to design a mechanism for kitchen scales, where undergraduate engineering students were asked to "develop ideas and present them on a sketch pad",

> *"students were found to opportunistically seek out all sorts of miscellaneous objects to support their thinking. In a barren design environment consisting of a classroom full of chairs, tables, sketch pad and pens, students sought out inspiration from gesturing with pens, pulling and twisting a rubber band that was spotted lying on the floor and dissecting a ballpoint pen dug out from a student's back pack. They made numerous references to prior experiences with objects."*

A more detailed analysis identified nine different 'roles' (see Table 1) in which working with hardware supported students' "design thinking and communication", illustrating that objects can be used 'as themselves' (for example when testing functional constraints); as representations of other objects, to illustrate general principles, or recall experiences of using objects; and to support communication between designers. Brereton observed "the large extent to which designers appropriate objects to help them think", and that the role of material representations depends on their context of use:

> *"The problem context derives what attributes of an object people notice and in which ways they try to use an object"*

She proposed that Goel's observations on sketches have parallels in 'physical prototyping':

The Roles of Physical Objects and Prototyping Materials in Supporting Design Thinking and Communication
Hardware as a Starting Point Hardware is tangible. It exists. It serves as a starting point it is easily noticed, remembered, seen and touched. It offers a basis for comparison.
Hardware as Chameleon Hardware is always in a context of use. What the hardware reveals depends upon the context is use. A variety of informal experiments in different contexts reveals different facts.
Hardware as Thinking Prop Hardware objects have all sorts of properties that afford different actions. Hardware that was easily accessible and had a useful property was adopted as a gestural aid to support thinking.
Hardware as an Episodic Memory Trigger Episodes of experiences with physical objects serve as memory devices.
Hardware as Embodiment of Abstract Concepts (Functional and Theoretical) Observing and testing hardware reveals fundamental concepts, physical embodiments of abstract concepts; and unanticipated design issues in hardware behaviour.
Hardware as Adversary Challenging theoretical model predications against hardware behaviour reveals discrepancies and provides clues to modelling errors. This reveals theoretical assumptions, and causal relations.
Hardware as Prompt Device behaviour prompts student questions and suggest experiments. Through repetitive interaction with hardware students bring order, distilling out key operational parameters and their relationships.
Hardware as a Medium for Integration Integrating components in their functional context reveals practical limits of use, characteristics of operation, methods of connection, causal relations, and physical quantities. This empirical knowledge extends the student's hardware repertoire.
Hardware as a Communication Medium Hardware is integral to learning communications, affecting the course of inquiry, idea generation, discovery and the dynamics of group interaction. Hardware is used to command attention, to demonstrate and to persuade.

Table 1: "The roles of physical objects and prototyping materials in supporting design thinking and communication" [Brereton & McGarry 2000]

The Roles of Hardware in Mediating Design Negotiations	Design Learning Outcomes
Hardware as a Communication Medium	Hardware is integral to learning communications, affecting the course of inquiry, idea generation, discovery and the dynamics of group interaction. Hardware is used to command attention, to demonstrate and to persuade.
Hardware Starting Points and Memory Devices	Physical experiences with hardware serve as memory devices and starting points.
Hardware as Thinking Prop	Hardware with desirable properties that was easily accessible was adopted as a gestural aid to support thinking.
Hardware as Chameleon	Hardware is always in a context of use. What the hardware reveals depends upon the context of use. A variety of informal experiments in different contexts reveals different facts.
Hardware as Embodiment of Abstract Concepts (Functional and Theoretical)	Observing and testing hardware reveals: fundamental concepts; physical embodiments of abstract concepts; and unanticipated design issues in hardware behaviour.
Hardware as Adversary	Challenging theoretical model predications against hardware behaviour reveals discrepancies and provides clues to modeling errors. This reveals: theoretical assumptions, causal relations.
Hardware as Prompt	Device behaviour prompts student questions and suggests experiments. Through repetitive interaction with hardware students bring order, distilling out key operational parameters and their relationships.
Hardware as a Medium for Integration	Integrating components in their functional context reveals: practical limits of use, characteristics of operation, methods of connection, causal relations, physical quantities. This empirical knowledge extends the student's hardware repertoire.

Table 2: "The Roles of Hardware in Learning Engineering Fundamentals and the Associated Learning Outcomes" [Brereton 1999]
Reproduced by kind permission of William L. Porter, Massachusetts Institute of Technology

> *"Because physical objects can be interpreted in multiple ways depending on their context of use, they too are ambiguous and facilitate context-dependent interpretation as do sketch elements."*

From the video analysis of the above and other studies, Brereton observed that "hardware plays a very formative role in learning, rather than simply serving as a final physical testing ground for ideas that have been developed through abstract reasoning". In a second stage of research, she identified a number of roles by which hardware mediates the learning process (see Table 2); these are similar to the roles identified previously, but within the more specific context of learning. In an exercise for students to design and build an aluminium crane from kit hardware, she observed consistent movement between references to abstract representation ("design requirements or theoretical concepts") and material representation, revealing a learning process of "continually challenging abstract representations against material representations":

> *"This comparison reveals gaps, which inspire further design activity. The cycle of representation and re-representation in abstract and material forms advances the design, the designer's understanding of technical fundamentals and the designer's hardware repertoire"*

Brereton draws comparisons with these findings and her description of Schön's model of sketching activity, "being involved in a reflective conversation with the materials of a design situation, the sketch talking back and revealing issues to the designer". She

concludes that the learning process she has identified is similar to Schön's 'reflective conversation', because even more than a sketch, a material representation is an "active and evocative participant":

> *"It responds through physical behaviour. It may deform under loading, make noises, smell, wear or jam… It is intolerant of poor assumptions or overlooked details that may not reveal themselves in a sketch. It reveals or suggests such oversights through its behaviour…"*

There are similarities, in the sense that interacting with material representations reveals gaps between a model of the situation, and the actual situation, giving you a new way of 'seeing' or 'framing' the situation. Schön relates how "in answer to the situation's back-talk, the designer reflects-in-action on the construction of the problem, the strategies of action, or the model of the phenomena, which have been implicit in his moves", and that "The practitioner may surface and criticize his initial understanding of the problem, construct a new description of it, and test the new description by an on-the-spot experiment" [Schön 1983].

However, while the two positions are similar in the context of learning - challenging an abstract representation against a material representation and converging towards a fixed or 'absolute' end-point - in Schön's model of design, while you certainly converge towards a final position, the end-point is not fixed:

> *"[the] practitioner [cannot] know, at the moment of reframing [or framing], what the solution to the problem will be, nor can he be sure that the new problem will be soluble at all. But the frame he has imposed on the situation is one that lends itself to a method of inquiry in which he has confidence." [Schön 1983]*

Brereton's comparisons with Goel and Schön link findings from the earlier studies of two-dimensional artefacts to the material context.

Artefacts generally

While the studies above have focused specifically on particular types of two- or three-dimensional artefacts, the following studies consider the role of artefacts more generally within a designer's process.

Attention to materials and processes

In his thesis [Pedgley 1999] Pedgley examined the "significance of materials and manufacturing processes as elements in industrial designers' work"; however this largely concerns the selection of materials for the finished product, and where and how these are

considered during the process. He does discuss the role of 'modelling' within a designer's process, describing the different ways in which it can be used:

> *"When applied to industrial design, the activity of modelling refers to the generation of product ideas (or analogues thereof), held either solely in one's 'mind's eye' or expressed through media such as drawings or worked objects. Modelling is used by designers to explore and clarify ideas; stimulate thinking; simulate proposals; act as a record of ideas that might otherwise become lost; and can be used to communicate thinking to other people. In the context of this study, modelling can be usefully broken into three categories: cognitive modelling (i.e. seeing 'in the mind's eye'); two-dimensional (2D) modelling (e.g. drawing or generation of computer-based representations of ideas, of whatever degree of precision or abstraction); three-dimensional (3D) modelling (e.g. the making of physical objects, of whatever degree of precision or abstraction, that can be manipulated with the hands)"*

In this view,

> *"Designers' 2D and 3D modelling hold evidence of considerations having been made and decisions having been taken. For the purposes of documenting design activity, the products of 2D and 3D modelling… can be considered external manifestations of cognitive activity"*

Externalising through sketching and making physical models

The Tacitus project's review of the literature examines the creative process, particularly the roles of sketching and physical modelling in the early stages of design, with a view to developing new haptic digital tools to support designers in these early stages (aspects of the Tacitus project relating to tool development are discussed in Chapter 2).

> *"The first step is therefore a better understanding of the reasons behind the use of traditional media during conceptualisation despite the advantages brought by digitalisation…"*

(Ideas and quotations in this section are taken from [Shillito, Paynter et al. 2001; Paynter, Shillito et al. 2002; Scali, Shillito et al. 2002].) Figure 29 illustrates their model of the creative process, with two phases: a germinal phase, which they describe as 'goal orientated', a "search for solutions and possibilities" characterised by divergent thinking, rapid, imprecise and exploratory working, and a "willingness to go astray"; and a practical phase, "where the developments of the germinal phase are formalised through convergent thinking to create a definitive object".

The germinal phase is an iterative process between conceptualisation and externalisation. Conceptualisation is a cognitive process, "a 'thinking through' of a design problem". Externalisation is the expression of mental images on media, through activities such as sketching and making physical models. However:

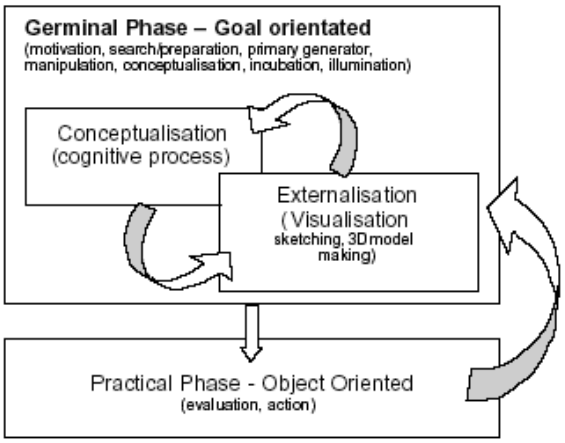

Figure 29: "Model of the creative process" by Shillito, Scali and Wright [Scali, Shillito et al. 2002]. Reproduced by kind permission of Ann Marie Shillito, Principal Investigator, Tacitus Project

> *"the purpose of externalisation is not to represent mental images but rather to describe, visually, the dialogue that gradually defines the form of the entity being developed"*

Their review identified two cognitive activities important to the creative process, relating to 'discovery' in mental imagery: 'restructuring' (figure and form), which is difficult to do mentally, and is assisted by externalisation through sketching and modelling; and 'combining', which is easier to do mentally, and can actually be disrupted by inappropriate sketching activity. Externalising using sketches and models within the germinal phase allows a designer to restructure images in ways it would be difficult to do mentally. The review also highlighted the importance in sketching of "reinterpretation through 'emergence'", discussed earlier in this chapter: the ability to 'see' elements of the drawing in new ways.

The Tacitus project focuses on the haptic elements of working, therefore the roles of physical modelling are of particular interest. Different types of models are suited to different phases of the design process: in this research, they are looking at models in the *germinal* phase of design (what they term Physical Concept Models (PCM)), not in the *practical* phase of design (the creation of a 'definitive object'). These models are therefore representations which relate in some way to the final object, but are distinct from both it and from models used in later stages of design, which have quite different characteristics.

The nature of sketches - ambiguous, 'fuzzy' and without "unnecessary precision" – is seen to support the types of cognitive activity necessary in the germinal phase of design.

The nature of models that make them useful in the germinal phase are similar to those of sketches: simple (in the sense of not detailed), 'fuzzy' (ambiguous), and vague (incomplete). Models for the germinal phase, while sharing attributes of sketches, have other attributes which make them useful: they are three-dimensional, assisting a designer to "think in space"; they should be "easily changed", "flexible" and offer "real-time feedback" (in contrast to "the snapshot in time offered by RP [rapid prototyping]", for example).

Models used in the germinal phase are therefore seen to support the creative process in similar ways to sketching, although some commentators suggest a more deliberately exploratory role. They quote Schrage:

> *"models are made to answer specific designer's questions: once the question has been answered the model is wasted and its value resides in the understanding that it brought to the design process."*

Their review highlights the widespread use of physical models in designers' processes, and identifies a number of reasons why designers may choose to make physical models over sketching. First, different types of models support particular activities. Scali et al. use Lennings et al.'s categorisation: shape models; functional models; physical behaviour testing models; presentation models; and models for stimulating group discussion.

Modelling may also reflect a preferred way of working. Paynter et. al cite studies from literature (Mawson, Borland & Welch, Anning) where subjects preferred to use modelling rather than sketching, but no additional explanation is provided. (They suggest that there are cases where such preference may be over-ridden by the practical constraints of producing models.)

> *"In the Borlex and Welch study in 2000 children and students seem to choose to begin the design process by gathering together materials and tools, moving immediately to 3D modelling as this allowed them to explore design possibilities and to strengthen mental images."*

Physical modelling offers a "'qualitatively different'" sense of engagement to drawing, and is a means to access and develop specific and different skills through spatial, haptic, two-handed interaction with physical models. Direct interaction with models supports what may be variously termed spatial reasoning, "thinking in space", or "three-dimensional reasoning", as the experience of space though manipulating three-dimensional objects with the hands is seen as an important way of understanding it. A more prosaic yet significant reason for making models is by those inexperienced in appreciating and representing 3D form in two dimensions.

Working with materials can also be seen as an integral part of an applied artist's process, both by providing a set of material constraints which provide "an affordance to the imagination, rather than a barrier", and by allowing a greater range of senses to contribute to the process.

> *"An applied artist's instinctive grasp of constructing and visualising in three dimensions, their spatial thinking and sense of touch are integral to their process of creativity. Makers combine all their sensory modalities such as sight, hand motions, and sound in order to explore and bring intended qualities to the object they are making. Results can only be achieved through ongoing dialogue between the maker, materials and process."*

In the wider context of this thesis, even though the model of design which Shillito et al. describe recognises the processes of iteration between germinal and practical phases, it is still largely 'design-then-make', with physical modelling used as a medium for design. There is no apparent suggestion that individuals might be different in their approach, or in their relationship with the artefacts that they use; although they cite studies which identify a preference for 3D modelling, the suggestion is that this might reflect a generally preferred way of working, rather than reflecting differences between individual designers.

The roles and characteristics of sketching which they identify through their review largely agree with those commentators already discussed. Scali et al. describe the relationship between conceptualisation and externalisation as a 'dialogue' and liken the designer's relationship with physical artefacts to Schön's description of design:

> *"The characterisation of the designer as "thinking with their hands" while creating or manipulating physical models echoes the sentiment of Schön when he described the act of freehand drawing as a conversation with the image."*

The role of artefacts in design

In the studies above, artefacts are perceived to play a variety of roles within a designer's process.

The majority of studies deal with two-dimensional artefacts, mainly sketching. At a cognitive level, sketches are variously viewed as an external representation of cognitive activity; an external symbol system supporting internal cognitive processes; a means of generating, as well as representing, 'mental imagery'; or a form of external memory. While some studies viewed sketching as a means of symbolic representation, others viewed it as more: a language for visual thinking and reasoning. Some studies emphasised the physical aspects of sketching, viewing it as a physical/visual language for doing design thinking, or as "a physical setting in which design thoughts are constructed

on the fly in a situated way" [Suwa, Gero et al. 1998]. Various studies stressed ways in which sketching enables thinking about the non-visuo-spatial aspects of design, either through symbolic representation of non-spatial elements, or as a 'perceptual interface' to functional and conceptual issues. Finally, it was perceived as a medium of 'reflection-in-action'.

Although fewer studies focused on the use of three-dimensional artefacts, they examined the role of objects, physical materials, and physical concept models. Objects as 'themselves' were used as a means of challenging or testing ideas, or revealing gaps in understanding; and as an embodiment of e.g. functional principles. Objects were also used to represent other objects, and to recall previous experiences of working with objects. In their role of supporting communication within design teams, objects were used as 'frames' for communication, and to alter the dynamics of interaction. Physical concept models may be used to support particular design activities; to access specific and different skills to those used in sketching; to aid spatial reasoning; or where novice designers are not skilled in representing three-dimensional objects though drawing.

At a more general level, Pedgley identifies various roles for which designers use modelling:

> *"[to] explore and clarify ideas; stimulate thinking; simulate proposals; act as a record of ideas that might otherwise become lost; and… to communicate thinking to other people."* [Pedgley 1999]

As well as the different roles which artefacts are perceived to play in design, the studies also identified various characteristics of artefacts that make them useful in design. Sketches, for example, allow designers to consider different aspects of the situation, or different levels of abstraction, in parallel. Designers in a field share symbolic conventions, where graphical marks are conventional and correspond to specific tasks. The manipulation of physical objects, or visual elements in sketches, allows designers to test both their understanding of the situation, and evaluate the consequences of design 'moves'. Sketches provide a visual means of considering non-visual aspects of the design. Marks on a page, and physical objects, can both be interpreted in different ways depending on the context of use, facilitating the development of ideas. Sketches and physical concept models share characteristics of fuzziness, ambiguity and incompleteness, supporting cognitive activity important to the early stages of design.

From this review it becomes clear that artefacts are not just passive recipients of a designer's intentions, but play a much more active role. Many of the studies emphasise

the importance of the designer's active engagement with the design situation to drive the process forwards, and view design as a process of incremental change, facilitated through and revealed by engagement with artefacts.

A number of the studies characterise the relationship between designer and artefacts not just as active, but as 'interactive'. Many commentators view the process of working with artefacts as a 'dialogue' with yourself, but this term covers a number of different phenomena. These differences relate to the level at which the dialogue takes place, and the degree of deliberate exploration or chance discovery which drives the dialogue.

Viewed at the level of the overall process, this dialogue may be driven by deliberate exploration, and arise from the external expression of ideas which the designer can evaluate and move forward. Alternatively, the dialogue is the result of unexpected consequences which arise from a designer's engagement with a unique and complex design situation: what Schön refers to as 'talkback'. McFadzean sees both as contributing to "a 'dialogue' of thinking aloud: conversing with oneself, a process of soliloquising about design suppositions" [McFadzean, Cross et al. 1999]. For Goldschmidt, the dialogue arises from

> *"…the exchange between imagery in the mind and sketch on paper… we reason by way of relating figures and concepts to one another until a satisficing 'good fit' is achieved among them."* [Goldschmidt 1994]

Neiman, Do & Gross identified both types of activity: they noted the deliberate exploration of design alternatives through transformation and manipulation of visual elements, but also that "the designer 'plays games' by defining rules, selecting strategies and design moves between self imposed rules, and discovering and evaluating the outcome" [Neiman, Gross et al. 1999].

At the level of the artefact, two similarly different concepts of dialogue can be identified. Goel described how, in the early stages of design, alternative design solutions "emerge through the incremental transformation of a few kernel ideas" [Goel 1995]. He argued that sketching facilitated *lateral* transformations, in which "movement is from one idea to a slightly different idea", and which "are necessary for widening the problem space and exploring and developing kernel ideas". He reasoned that the density or fine-grainedness of the symbol system of sketching allows for the easy transformation of one *symbol* into another. This ambiguity of symbols leads to an indeterminacy in the *content* of the symbol, which in turn facilitates the transformation from one *idea* into another. Similar to this process, but with more emphasis on discovery, is the phenomenon described by

terms such as ‘emergence’, ‘imagery’, ‘seeing’: our ability to construct figures from marks on a page, and to see more in the marks on a page than was originally intended. The Tacitus review identified both ‘restructuring’ and ‘emergence’ as important aspects of cognitive activity supported by externalisation.

Suwa, Gero & Purcell illustrated how sketches “serve as a physical setting in which design thoughts are constructed on the fly in a situated way” [Suwa, Gero et al. 1998]. They identified what can also be viewed as a form of dialogue at this level:

> *“… through interaction with sketches at the physical level, designers are then able to have higher interaction at the perceptual and functional levels. This way, information ‘emerges’ in a bottom-up way. We conjectured that this bottom-up process is a key to understanding the roles of sketches.”*

Furthermore, from their subsequent study they concluded that

> *“drawing sketches, representing the visual field in the sketches, perceiving visuo-spatial features in sketches, and conceiving of design issues or requirements are all dynamically coupled with each other. These activities as a whole form the act of designing.”* [Suwa, Gero et al. 2000]

While all these phenomena could be considered a ‘dialogue’ between designer and artefact, contrasts between them reflect underlying differences in emphasis on the role of artefacts in design, relating to the difference, for example in sketching, between symbolic representation and visual thinking; between external representation of ideas, and the external generation of ideas; and between artefacts as an external representation of cognitive activity, and working with artefacts as a means of thinking.

Differences in design

The studies above reflect different models of the design process, and different models of dialogue between designer and artefact, but few deal with individual differences between designers. Some of the studies, as well as being ‘experimental’ in the sense of using an artificially constrained design task, have examined very few subjects; in many cases this reflects the fine level of detail at which the design processes were being studied, but in the context of this thesis, it lessens the likelihood that any differences between designers will become apparent.

Most of the studies also focus on the use of one type of artefact, and comparisons between two- and three-dimensional artefacts, such as those by the Tacitus project and Brereton, are rare. However, as a group, the studies cover both types, so it is possible to look for similarities and differences between these two areas.

Similarities and differences between 2D and 3D artefacts

In her study of how objects support design thinking and learning, Brereton drew comparisons between her findings with 'hardware', and Goel and Schön's findings with two-dimensional artefacts. These relate to ambiguity of interpretation (the ability to interpret marks on a page or objects in different ways depending on the context within which they are being considered), and 'reflective conversation' (the ability of both sketches and physical objects to reveal gaps in our understanding of a problematic situation (in design or learning) or to suggest previously unanticipated ways to proceed). Sketches and objects are both seen as ways of recalling previous knowledge or experience. Pedgley's list of ways in which modelling is used within the design process applies to all types of artefacts:

> *"Modelling is used by designers to explore and clarify ideas; stimulate thinking; simulate proposals; act as a record of ideas that might otherwise become lost; and can be used to communicate thinking to other people"* [Pedgley 1999]

Although Brereton identifies similarities between working with sketches, and working with 'hardware', she also identifies differences. These appear to relate mostly to the material or 'real' properties of the physical object or prototype, which make it "a yet more active and evocative participant that the sketch", particularly in its role of challenging understanding of abstract concepts:

> *"It is intolerant of poor assumptions or overlooked details that may not reveal themselves in a sketch. It reveals or suggests such oversights through its behaviour"* [Brereton 1999]

The studies on sketching emphasise its use as symbolic representation or a means of visual thinking. Physical objects are seen largely as a means of testing ideas previously conceived by other means, or of supporting communication, although it is recognised that they also can have a representational role. In their review of the literature Shillito et al. identify a number of reasons why designers may choose to make physical models in the early stages of design, but there is less evidence as to where and why an individual designer might choose sketching over modelling, or vice versa.

There is some suggestion in the Tacitus project's review of the literature that modelling might be a preferred way of working, replaced by sketching where time and cost constraints prevail. However although the characteristics of physical concept models used in the germinal phase are similar to those of sketching (simple, incomplete, fuzzy, vague), it is not clear whether other aspects identified by commentators earlier in this chapter as important in sketching activity, such as a designer's ability to deal in parallel

with different aspects of the design, and different levels of abstraction, would be reflected in this three-dimensional modelling activity.

As there are only a small number of studies on three-dimensional artefacts, or comparisons between two- and three-dimensional artefacts, it would be unwise at this stage to draw too many conclusions about the different ways in which two-dimensional and three-dimensional artefacts might support the design process.

Differences between individual designers

Most studies in design look for consensus, not difference. This focus is evident from methods of enquiry such as Video Interaction Analysis used by Brereton, in which

> *"an interdisciplinary team (of engineers, a linguistics expert, a sociologist, an anthropologist and a computer scientist) viewed segments of tape selected by the primary investigator and identified routine practices, routine problems and resources for their solution. Only those practices confirmed by the raw data that occurred repeatedly in different parts of the tape were considered admissible in the analysis… The examples presented… are representative of activity in that they have been observed in many different groups and in many different segments of videotaped footage."* [Brereton & McGarry 2000]

Few studies are directly concerned with differences in the way designers work; many of these focus on differences between novices and experts, for example [Kavakli & Gero 2002; Atman, Cardella et al. 2005]. Some studies have focused on individual styles of problem solving in design, defined as "an individual's preferred way of action regulation in dealing with complex problems" [Eisentraut & Günther 1997; Eisentraut 1999]; these concern activities such as 'goal elaboration', 'information gathering', 'prognosing', 'planning and acting', and 'effect monitoring'. Other studies have focused on different learning styles or cognitive styles (" the term 'cognitive style' affords a narrower definition as it refers to an individual's preferred way of thinking, organising and representing information within the mind" [Roberts 2006]); these studies from architectural design examined the ways in which students with different styles performed in different stages or aspects of their architectural design studio activities, as these may require different styles [Demirbas & Demirkan 2003; Kvan & Yunyan 2005; Roberts 2006].

Two studies from engineering design are briefly reviewed here: the first, reported on by Ehrenspiel (sic), Dylla & Günter (sic) [Ehrenspiel, Dylla et al. 1992]and Fricke [Fricke 1992] compared individual designers to identify successful and less successful design processes; the second, conducted by Günther & Ehrlenspiel [Günther & Ehrlenspiel

1999], compared the design processes of methodologically educated designers, and designers from practice.

The studies have common features in their design: the subjects were engineering designers; the experimental design consisted of a very specific design task concerning the design of a mechanical device, quite tightly constrained although with no time limit for completion; and the data consisted of video-tapes of the designers working and their 'thinking aloud', along with the drawings and notes produced. In both cases, the analysis was based on formal design methods: in Günther & Ehrlenspiel's study, "the division of the design process into four phases is the basis for analysis of the process and the character of the design problem" (the linear phases are task clarification, conceptual design, rough embodiment design, and final embodiment design); a similar classification was made in the earlier study. Individual designers' processes were compared to an assessment of the quality of their final design by a panel of experts based on the layout drawings produced.

The study on which Ehrenspiel (sic), Dylla & Günter (sic) and Fricke report was concerned with "individual ways of thinking and acting in mechanical engineering design". One of the aims was to identify differences in approach between successful and less successful designers. Of the two papers reviewed[6], the first paper was largely concerned with the method, the second with the "limitations and difficulties" of implementing projects with researchers from different disciplines. However, selected findings are discussed regarding the differences between successful and unsuccessful designers (distinguished by the quality of the final design as assessed from the drawings). Fricke drew a number of conclusions about successful designers: they analyse the task intensively before starting; they focus on "important problem areas", and the "steps necessary to solve the problem"; they generate appropriate variants and reduce by assessment (less successful designers generated "too many or purposeless solutions", more successful designers "retain an overview, in that they can repeatedly reduce this multiplicity by intermediate assessment"); and they "possess a better imaginative spatial faculty and a higher heuristic competence" (the latter relating to " the capability for long range procedural planning and the correct weighting of problems").

Günther & Ehrlenspiel's study focused on different groups of designers rather than differences between individuals (although individual subjects' processes were examined

[6] A number of papers were produced on different aspects of the study

for the study). They compared "experienced designers from practice who have neither education at a university nor education in design methodology" (i.e. "a practical education as draughtsman, technician or master craftsman", who they termed 'p-designers') and "designers with education in design methodology at a university" ('m-designers'). They identified a number of differences in process. 'm-designers' tended to clarify the task extensively before proceeding to the next stage, while 'p-designers' tended to clarify the task through engaging in the conceptual design phase. The patterns of activity relating to each phase of activity were different: 'm-designers' tended to deal with each phase of the overall design through the recognised stages; 'p-designers' tended to cycle through phases for a series of individual 'sub-problems'. 'p-designers' documented their work at the conceptual stage less: rather they "elaborate concepts mainly in the head… these results are then used to draw up the rough embodiment design". 'p-designers' generate design variations in series, with new variants replacing previous ones; 'm-designers' generate a range of variants, which they assess, and select one. Finally, 'p-designers' tend to document the final product rather than the process: "solutions are worked out on a concrete level and very rapidly". Günther & Ehrlenspiel proposed a number of reasons for these differences in the processes of 'p-designers', including an educational focus on product, not process; extensive practical experience providing a "concrete idea of solutions", and the very real time constraints in design practice.

The types of differences being examined in these studies are not directly related to this thesis (although some of the individual characteristics described are interesting in the light of later chapters of this thesis); however the underlying view of 'design' revealed by these studies, with its emphasis on formal design methods and an underlying model of 'design as problem solving', is interesting in this context.

Some studies reviewed earlier in this chapter concerned differences between designers, but the differences in question are not related to this thesis: McGown, Green & Rodgers used comparisons between designers' sketching activity as a method of measuring the quality of a designer's work; Suwa & Tversky drew comparisons between practising architects and architecture students.

Pedgley [Pedgley 1999] does address the different ways in which engineers and artist-designers 'know about' materials and processes, but the differences he discusses focus largely on the characteristics of the materials to which both groups pay attention, rather than any difference in underlying approach to design. He quotes Norman [1997]:

> *"'Artists might be more concerned with colour, texture, reflections, contrasts, translucency and patterns etc. Engineers might be more concerned with surface, roughness numbers, refractive index, conductivity, resistivity, tensile strength and modulus of elasticity. These traditions represent different ways of knowing about materials.' "*

In an interview with a mechanical engineer and an artist-designer working in ceramics, he noted that in the area of ceramics,

> *"the prevalent approach to designing is to generate and develop ideas by experimenting with the end-material or a modelling material… The benefit of 3D modelling in clay is that the manipulation of the material itself solves disputes or queries over whether a particular shape, surface detail, decoration or finish (that might work on paper) is indeed achievable."*

This suggests that the modelling materials are used as a practical means of verifying design ideas, rather than that working with materials represents a different way of 'doing' design.

Case studies in design

One group of studies, referenced above but not yet reviewed, does discuss differences which are related to this thesis (and are 'value-free', in the sense that one approach is not considered superior to another), although these differences were not the specific focus of the research.

Roy, Cross & Clayburn Cross, and Candy & Edmonds have studied individual designers who have developed innovative products, to identify common key characteristics in the design processes of highly creative individuals. Roy examined the working processes of James Dyson in designing the 'Ballbarrow' and cyclone vacuum cleaner, and Mark Sanders in his design of the Strida folding bicycle. Cross & Clayburn Cross studied Gordon Murray's working methods in racing car design, and Candy & Edmonds examined the creative cognition of Mike Burrows by tracing his development of the LotusSport bicycle.

To use Pedgley's terminology, these studies take a 'macroscopic' view of design activity: actual design projects and processes, over long periods of time, concerning overall strategies for design. Significant in the context of this thesis is that many of the designers featured in these studies design and make, i.e. they are responsible for the whole process from concept to final product (including in some cases the process of getting products to market). In the industrial context within which some of these designers work, what I refer to here as a 'final product' may be a fully working 'prototype', as opposed to a product ready to exhibit or sell to the public; what is important is that the final product

has been fully realised. These case studies complement and make an interesting contrast to the studies at 'microscopic' level reviewed earlier in this chapter.

The studies variously drew on combinations of background research, informal discussions and formal interviews with the designers, and examination of artefacts – sketches, drawings, models and prototypes – produced by the designer. Although all of these case studies focused largely on creativity, creative thinking and the development of ideas – a designer's 'creative cognition' - each of the studies paid attention to the roles of sketching and modelling with the designers' processes. All the studies make reference, in Roy's case by comparison between the two designers in his study, and in Cross & Clayburn Cross and Candy & Edmonds' studies by comparison to other studies, to differences in approach relating to the roles of sketching and drawing or working with materials between different individuals' practice.

James Dyson & Mark Sanders

(Ideas and quotations in this section are taken from [Roy 1993].) In Roy's study, the main differences he identified between the designers were when immersion in the problem occurred, and the method of developing ideas.

> *"Dyson moves forward by working with physical prototypes and relatively little drawing, whereas Sanders uses sketching as his main means of problem exploration"*

Sanders' process is characterised by sketching and drawing in the generation and development of ideas. He started with a product specification, and a long period of mental immersion, "thinking about folding bicycles and jotting down ideas as they occurred". In the conceptual design stage he again "…'immersed himself in the problem' by making sketches of as many designs of folding bicycle as he could find in the literature and elsewhere and sketching new ideas as they occurred". In more detailed design stages extensive sketching was again used to "…'clarify and develop the ideas I was having in my head'…". Roy characterises the role of sketching in Sanders' process as "a dialogue with yourself". Dyson's process, in contrast, revealed a strong preference for 'thinking with the hands', and reserving the exploration of what else is 'out there' till the development stage of the process, leaving himself "relatively uninformed at the early concept stage so as not be hampered by prior solutions". For Dyson, solutions to problems come largely when working with materials:

> *"[His] particular approach to invention and creative design depends on getting ideas and solving problems when working with and observing physical objects (what Thring and Laithwaite call 'thinking with the hands') rather than by drawing or theorizing. Dyson says he almost never solves problems by getting 'brainwaves in the bath', on*

the classic psychological model of creativity; for him solutions come when 'welding or hammering something in the workshop'."

Gordon Murray

(Ideas and quotations in this section are taken from [Cross & Clayburn Cross 1996].)
Unlike Dyson, for Gordon Murray, designer of the McLaren Formula 1 racing cars, creative leaps really do occur 'in the bath'. Breakthroughs in a design problem occur as sudden illumination, usually after long periods of immersion in the problem:

"…'I know it's a cliché, but I did have a lot of good ideas in the bath, I really did.'…"

His approach to design is to work very much by "reconsidering the problem situation from first principles" ("fundamental physical principles") and this he considers crucial to innovative design:

"Gordon Murray insists on keeping experience 'at the back of your mind, not at the front' and to work from first principles when designing."

His design process is based heavily on sketching, from the early stages through to more detailed drawings, and the ability which this medium offers to work on many different levels is important to his process.

"Gordon's design process is based on starting with a quick sketch of a whole idea, which is then developed through many different refinements. 'I do a quick sketch of the whole idea, and then if there's one bit that looks good, instead of rubbing other bits out, I'd put that bit to one side; I'd do it again and expand on the good bit, and drop out the bad bit, and keep doing it, doing it; and end up with all these sketches, and eventually you end up throwing 90% of these away.' He also talks to himself – or rather, writes notes to himself on the sketches… Eventually he gets to the stage of more formal orthographic drawings, but still drawing annotated plans, elevations and sections all together."

Cross & Clayburn Cross compare Murray's approach to that of other "highly creative or innovative" designers. In a comparison with Lawson's study of architects, they remark on the importance of drawing as a 'design aid', both in its ability to support working on a number of different levels at once, and also "as a means of thinking 'aloud' or 'talking to themselves', as Gordon put it."

"The common elements in these similar descriptions are the use of drawing not only as a means of externalising cognitive images but also of actively 'thinking by drawing', and of responding, layer after layer and view after view, to the design as it emerges in the drawings."

They observe similarities to Murray's approach of working from first principles:

"There is also a sense of focusing on, or framing a problem, so precisely that it can be approached from 'first principles'; as Santiago Calatrava said: 'It is the answer to a particular problem that makes the work of the engineer… you need a very precise problem."

In a comparison between Murray's approach and that of James Dyson, as reported in Roy's study, they note the strongly contrasting ways in which the designers gain insight into problems:

> *"Roy studies two innovative industrial designers, one of whom, James Dyson, reported that (unlike Gordon Murray) he almost never solved problems by getting 'brainwaves in the bath', but more often when doing some practical work, 'welding or hammering something in the workshop'. However, this practical work may in itself be a way of letting the mind relax."*

Mike Burrows

(Ideas and quotations in this section are taken from [Candy & Edmonds 1994; Candy & Edmonds 1996].) Candy & Edmonds investigated the 'creative cognition' of Mike Burrows through interviews in conjunction with an examination of the 'artefacts' – the different models of bicycle - created during the development process which resulted eventually in the LotusSport carbon fibre monocoque bicycle. (Candy & Edmonds are using the term 'artefact' to refer to a product of the design process, rather than sketches, models etc., although on one level they too are looking at intermediary stages or 'representations' on route to a final product.) By examining (retrospectively) his processes in tandem with the way the designs for each bicycle model develop on the previous one, they draw conclusions about his processes, and the development of these processes through the long period over which the final design was achieved.

Date	Artefacts	Design Process	Knowledge Evolution
1979	First Bikes	Adopt Adapt Improve	Learning Conventions
1980	Funny Bikes	Exploration	Break Rules
1982	Universal Bike	Analysis	Formulate Problem
1985	Monocoque 1	Emergence	Evolve New Concept
1986	Monocoque 2	Analogy	Modify Concept
1988	Inter Bike	Refinement	Add Features
1990	Monocoque 3	Synthesis	Combine Features
1992	Olympic Bike	Completion	Apply Measures

Table 3: "Bicycle History Design Process and Knowledge Development" [Candy & Edmonds 1994]
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Candy & Edmonds' research is concerned with future computer systems to support designers, specifically knowledge support systems. Their studies focused on "...bike designs, design process characteristics and the knowledge evolution that took place" (see Table 3).

> *"Two forms of analysis of the interview data were made. First, the bicycle design history was examined in terms of the way each design represents a progression or extension in the knowledge that the designer used. Secondly, the design process was examined in terms of the various activities that comprised the designer's practice."*

While they are primarily interested in his 'creative cognition' – "ideas generation, problem formulation, strategies, methods and expertise" - Candy & Edmonds remark on distinctive elements in Burrows' approach, relating to the use of sketching and working with physical materials in his work. For Burrows, while sketching was used to capture ideas at the early stages of designing, much of his development work was done 'hands-on' in the workshop (although for later bike designs using carbon fibre, Burrows had to produce detailed drawings for others to manufacture).

> *"The act of designing and making an artefact was necessary to a full understanding of what had been done. Designing 'between my ears' and drawing on paper did not provide sufficient feedback: it was the thinking 'with my hands' that was essential. 'I literally think with my hands. I very seldom draw any sort of dimensions on a piece of paper. I occasionally doodle things to work at them, but I'll basically just pick pieces of metal out of the rack and drill holes in them literally and it will get bolted together…'."*

Candy & Edmonds observed a change in Burrows' design process over the ten year period of developing the bicycle:

> *"…the designer moved from adapting existing models and customising them to suit individual requirements, towards a complete re-formulation of the guiding principle of the design of the bicycle i.e. to maximise the aerodynamics. By the time the monocoque frame emerged, there had been a radical transformation in the designer's process and the knowledge he had acquired and was applying… changes took place towards a more principled and analytical approach to his designing."*

Despite what Candy & Edmonds describe as Burrows' "highly individualized approach", a comparison with Cross & Clayburn Cross' study of Gordon Murray identified similarities in cognitive style.

> *"The agreement in respect of innovation, personal goals, working from first principles and immersion and expertise across related areas of knowledge is notable. It would seem from this that the cognitive issues in the design process are similar even when the scale of complexity of the artefact, as measured in terms of component number, is far greater."*

Summary of case studies

A collective examination of these studies reveals distinct differences in design approach relating to the roles of sketching and drawing or working with materials between different individuals' practice. Differences that were identified relate to: a preference for using sketching and drawing or working with materials to develop design ideas; 'thinking with

the head' or 'thinking with the hands'; and whether creative 'leaps' occur 'in the bath' or when working with materials.

These differences are explained (at this macroscopic level, at least) either as resulting from the complex and innovative nature of the project and the product being developed (e.g. where Dyson's cyclone vacuum required "extensive empirical experimentation"), or accepted as idiosyncrasies of each designer's approach: Candy & Edmonds, for example, comment on Burrows' "highly individualized approach", and describe his process as "very dependent upon personal ways of working" [Candy & Edmonds 1996].

However, none of the studies examine these differences any further. Cross & Clayburn Cross appear to suggest that the differences between Dyson's solving problems when engaging in practical work, and Lawson's 'brainwaves in the bath', simply represent different ways of achieving a state of mental relaxation. Even though these studies acknowledge the importance for some designers of 'thinking with the hands', there seems to be no suggestion that the role of 'making' may be quite different in different designers' practice, or that it is indicative of different underlying ways of knowing:

> *"As well as drawing, innovative designers frequently like to undertake practical work related to the design solution, such as building models or mockups, or participating in construction."* [Cross & Clayburn Cross 1996]

Rather, it seems to be viewed as a practical solution to accessing information which cannot be achieved in other ways. Candy & Edmonds comment that,

> *"Sketching has a limited role in the eyes of [Burrows] because it does not take him into the detail of engineering the object."*
> *"Making design ideas into working products required the necessary methods and, therefore, craft skills play a significant part… Burrows learnt his craft skills because he needed to realize some design ideas that could not be commissioned elsewhere. However, he had no interest in craft for its own sake."* [Candy & Edmonds 1996]

Conclusions

From this review, it can be seen that while there are differences in emphasis on the role of artefacts in design (relating to the contrast, for example in sketching, between symbolic representation and visual thinking; between external representation of ideas, and the external generation of ideas; and between artefacts as an external representation of cognitive activity, and working with artefacts as a means of thinking) artefacts are considered to play an active role in a designer's process. Whether viewed as problem solving or reflective practice, design is viewed as a process of incremental transformation, facilitated through or revealed by engagement with the artefacts a

designer works with in their design process. Moreover, artefacts can be seen to play an *interactive* role, allowing the designer to have a 'dialogue with themselves' about the design situation. However the term 'dialogue' is used to refer to a number of different phenomena: differences relate to the level at which the dialogue takes place, and the degree of deliberate exploration or chance discovery which drives the dialogue.

Research into the role of artefacts in design has focused predominantly on two-dimensional artefacts, including drawings, diagrams and sketching. A smaller number of studies have examined the role of three-dimensional or material artefacts within designers' processes, and even fewer are concerned with differences in the way that 2D and 3D artefacts might support designers' processes.

There are not many studies which deal with differences in the way designers work: of those, the comparisons tend to relate to novice/expert, styles of problem solving or learning/cognitive styles, the relative quality of designers' work, good and bad design strategies, or 'trained' designers and designers from practice. In the realm of this thesis, very few studies have investigated differences between individual designers that relate to their use of artefacts within the design process.

There are a number of possible reasons for these 'gaps' in research. 'Traditional' design research in this area has focused mainly on design-by-drawing, where designers work with representations of reality, and on formal design methods, less on other areas of design which do not fit this model. A lot of studies focus on design as a cognitive activity, and view sketching as a form of symbolic representation of internal cognitive activity. It could be supposed that a designer's work with material artefacts might not be considered in this light, and therefore be of less interest to researchers in this field; however the Tacitus project's review of the role of physical models in the early stages of design, and Brerton's examination of the roles objects play in supporting design thinking, learning and communication, suggest that three-dimensional material artefacts may play similar roles in supporting design cognition.

In terms of differences between designers many studies are broadly concerned with what is to be learnt about "designing as a basic human capacity" [Pedgley 1999], viewing it as a single process to be discovered. Most studies look for consensus, rather than diversity, and the 'microscopic' level at which many of the studies are conducted is less likely to reveal differences in approach, particularly where there are few subjects, and particularly

where there are differences which may be most clearly observed in the wider spectrum of practice.

This review highlights the importance of placing the relationship between design practitioner and artefact at the core of this research, and of using a method of enquiry which enables individual differences to emerge. Comparisons within and between a number of case studies of individual designers revealed quite different personal approaches to design, relating to the roles of sketching and drawing or working with materials between different individuals' practice. These findings strengthen the position of this thesis: that clear differences in approach can be observed between individual designers, which are worthy of further investigation.

The next chapter, ***Difference as a means of enquiry***, describes the method and instruments chosen to investigate these differences, and explains the rationale behind using difference itself as the primary means of investigation.

4. Difference as a means of enquiry

This chapter explains that diversity in design practice is not only the focus of this research, but why and how it has also been used as the primary means of investigation. The details of each study are described in the relevant chapter (see ***Annotated list of chapters***), but the general principles of enquiry and how they were implemented in each study are discussed here.

Examining diversity in design practice

As discussed in Chapter 3, ***Artefacts and the design process***, 'traditional' design research has focused mainly on design-by-drawing and formal research methods, less on other areas of design which do not fit this model. In assuming that there is a single design method to be discovered, much of this research has been blind to individual differences in design practice. Previous researchers examining aspects of this relationship between designer and artefact have tended to focus on very specific aspects of practice, frequently using an experimental approach in an artificially constrained situation. Some of these studies have examined very few subjects. In many cases this reflects the fine level of detail at which the design processes were being studied, but in the context of this thesis, it lessens the likelihood that any differences between designers will become apparent. At the other end of the scale, some studies focus on an in-depth study of an individual designer.

These approaches have a number of drawbacks when exploring diversity in design practice. In an experimental situation, if you are not looking for diversity, it will not be built into the 'model', therefore it is unlikely you will find it, other than as an apparent anomaly in the data. Also, the very specific focus of many experimental studies will not pick up differences which may be most clearly observed in the wider spectrum of practice. In-depth studies of an individual designer's processes will give a very rich picture of practice, but lack the means of comparison with other designers required to elicit the dimensions of variation. (A broad comparison between such studies did reveal different personal approaches to design, relating to the roles of sketching and drawing or working with materials between different individuals' practice, but no further investigation had been made, as discussed in the previous chapter.) These factors have

prevented much existing research from observing the natural diversity in practice, and the dimensions of its variation.

One of the challenges in starting to explore this area was that there seemed to be a number of possible factors involved in this diversity, which appeared to be interdependent and difficult to isolate, and which were at different 'levels' of process. One approach to examining this diversity would be similar to the experimental studies above: constrain the context to look at each of those factors, while eliminating the influence of the others. To do this it would be necessary to predetermine what you were going to look at, but in this situation it was not clear at the beginning what factors to constrain, and what the interdependencies might be. Also, to get a clear picture of differences in approaches using this method, it would be necessary to carry out a number of different studies with the same subjects, and find ways of linking these studies.

The alternative selected for this research was to choose a method which allows the situation to be examined as a whole, and somehow 'discriminate' between the possibly interdependent factors, but further than that, enables an investigation into what some of the interdependencies might be. This method is based on a number of key principles, which are described below, but broadly uses a comparison of the differences between individual instances as a means of developing a descriptive model of an underlying phenomenon: firstly, by identifying what differences there are (or appear to be) between individuals; and secondly, by examining the relationships between these differences, to discover|propose|test an underlying model of the phenomenon.

Principles

Three related principles underpin the means of investigation used in this thesis: the comparative framework; the comparison of the individual against the collective (*difference*); and the added insight from comparing phenomena which are similar-but-different (*distance*).

Comparative framework

One way of addressing the problems identified above is to establish a comparative framework by which to describe and within which to examine this diversity in design practice. The benefit of using such a framework in this type of research is that it adds rigour to comparisons made between individual items (whether personal approaches or physical objects) by providing a context and structure within which to make the

comparison. To create such a structure, it is necessary to identify both what differences there are (or appear to be) between individuals, and what the relationships are between these differences.

The characteristics of such a framework are that it should provide a means of placing different factors in relationship to one another (and testing this relationship i.e. recognising that the original format of the framework might need to change, as the relationship between the factors may not be immediately clear). This then provides a way of examining differences between people, by using the same framework to compare and contrast individual approaches, through placing them in relation to one another.

Once established, such a framework has a number of benefits: rather than dealing with differences in design practice by constraining factors, it aims to actively use them as a means of investigation; it is one approach to dealing with a situation where there appear to be many interdependent factors; and finally, it enables a collective picture to be built, against which an individual's practice can be viewed. Building up a collective picture of the variety of ways in which designers perceive and relate to the artefacts they use, affords insight into what individuals do not do, as well as what they do. This last point is particularly important. In The Act of Writing, Chandler notes:

> *"In studying the nature of mediation, a powerful technique is the search for that which is* excluded *(or 'conspicuous by its absence'), and that which is taken for granted (which goes without saying)"* [Chandler 1995]

For this research, a variety of frameworks have been used. They differ in a number of respects: how they were created; the level of detail at which they apply; and what they were being used to compare.

A framework may be predefined and then used to examine the data, or it may be derived through an exploration of the data itself. In this thesis both approaches are used (and are discussed in more detail below for each individual study). In one case, the results emerging from one study were used as the basis of an analytical framework for another.

In some cases, the comparative frameworks used have been relatively broad: at the level of theoretical models of the creative process and disciplines, for example, in Chapter 6, ***Concepts of dialogue in design***. In other cases, they have been more detailed, such as the model of dialogue derived from a selection of these theoretical models, which has over thirty individual elements of comparison (see Chapter 7, ***Comparative study***). This latter framework could also be described as very 'tight': it was derived from a number of theoretical models, and closely specifies the structure of the framework i.e. how the

different ‘differences’ relate. In contrast, the frameworks derived in some other studies were quite loose, particularly where the study was of an exploratory nature.

Finally, the comparative frameworks have been used to examine a number of different phenomena: models of the creative process from different disciplines or theoretical viewpoints; physical artefacts; and people’s creative processes and their relationship with the media they work with (through interview data).

Comparison of individual against collective variation (*difference*)

The primary method chosen for this research is to examine an individual against the collective variation that can be observed within a group. This involves exploring, through comparison between all the individuals in a group, the ‘dimensions of difference’ within that group to determine the collective variation against which an individual can be viewed. (The term ‘dimensions of difference’ refers to distinct observable differences in various aspects of practice.) The studies described here include a range of individual v. collective comparisons: between artefacts; between theoretical positions; and between practitioners, through interview accounts of their own practice.

In the context of this research, this approach has a number of benefits: as the ‘dimensions of difference’ emerge from the data, it provides a route in to exploring a situation where there may be little previous knowledge; it can identify dimensions along which individuals may differ, particularly in regard to aspects which may not have been expected; and most importantly it can identify aspects of interest which may not be apparent from looking at one individual’s practice.

This approach also has a number of drawbacks. The comparisons are not against absolute criteria, but within the domain of enquiry (e.g. an individual’s approach in different contexts, the current set of students, all the artefacts in the collection). As the collective variation is derived from the data, it will only reveal the variation that is present within that specific group (although it may be possible to infer additional information from apparent ‘gaps’ in the resulting framework). There is frequently a large amount of data within which to start investigating, although it can be viewed at whatever level is considered appropriate. Perhaps the most significant drawback is that knowing the collective variation within the group is only the first stage of understanding the phenomenon under investigation, although it is fundamental to the next. Understanding the relationships between the different dimensions of variation is what will reveal the underlying causes or reasons for these differences.

In this research, these drawbacks have been mitigated to an extent by the different studies which comprise the research. In the Comparative Study, for example, the conceptual framework derived from a comparative review of the different theoretical positions discussed in Chapter 6 provides: an external reference against which to compare the findings from the groups under investigation; an initial point from which to start investigating the 'dimensions of difference' between individual practitioners; and an initial proposition to explain the relationships between the differences that can be observed between individuals.

The comparisons can also be made more robust by comparing frameworks, such as the comparison between the two different groups participating in the Comparative Study (see Chapter 7). This type of examination leads on to the third principle on which this research is based: that you can gain insight by comparing differences between phenomena which are similar in some respects, yet different in others.

Added insight from comparing similar-but-different (*distance*)

In The Act of Writing, Chandler states:

> *"To become aware of the ways in which we engage with a medium we need to* distance *ourselves from it: to look with other eyes, to feel with other hands and so on; making the medium more visible or tangible."* [Chandler 1995]

This idea of distancing is particularly important for those aspects of engagement of which people may not normally be explicitly aware. An element of distancing arises through contrasting individual approaches against the collective background by beginning to reveal, in Chandler's words, "that which is *excluded* (or 'conspicuous by its absence'), and that which is taken for granted (which goes without saying)". However, for this research it was desirable to find a way whereby these things could be deliberately brought into the foreground without reverting to the idea of artificial, experimental studies.

The studies in this research incorporate a number of such elements of 'distancing', as discussed below. However, the main way in which it is designed into this research is through a comparison of design and making practices in the material environment with those in the 3D digital environment. While they share the three-dimensional context, contrasts between the two environments make them suitable for the comparative role in this research.

Characteristics conventionally attributed to the digital medium (or at least those attributes which may be most immediately apparent) are immateriality; intangibility; the need to

work to a large extent with abstract, formal representations; working at a distance from the 'real' world; and freedom from material constraints. For example, digital media such as 3D computer modelling and animation software require, at least on first examination, users to be very explicit when creating objects, working with geometric representations and operations. Material practice, on the other hand, is frequently regarded as 'hands on'; rooted in physical materials; with a concrete and intuitive approach marked by a close relationship with the materials.

My interest in examining the relationship between designer and artefact more closely is to dissociate some of the ways in which design practitioners work from the physical artefacts that they use, and to gain insight into ways of working and knowing that are not embodied in the material context of the real world, that could be used to inform new digital environments for design. This research focuses on the approach, less on the *specific* physical nature of the context within which this is practised (although the significance of *a* context is recognised). Contexts which are similar enough in terms of their three-dimensional nature, yet different in terms of their physicality, are therefore of particular interest, as a means of 'factoring out' some of the elements related to the specific material context. (This position is discussed and critiqued in greater detail in Chapter 8, ***Practitioner interviews***.)

Additionally, in many respects the indeterminate nature of the digital medium - its ability to be many things to many people - makes it an ideal environment for delving deeper into the nature of this relationship, by looking at the ways in which people choose to use it. Also, because it typically is viewed as being less immediately intuitive to use, this can bring to the foreground aspects of practice which might otherwise remain unseen.

In order for these comparisons between material and digital environments to be valid and useful (particularly between similar approaches in different groups, as in the Comparative Study), it has to be demonstrated that the basis of comparison between the two environments is sound. Chapter 8, ***Practitioner interviews***, demonstrates that, at least for the participants in that study, each practitioner's overall approach is consistent across media, therefore the basis of comparing approaches between physical and digital material appears to be sound.

A phenomenographic approach?

This method has similarities to the phenomenographic approach described by Marton & Booth in their book, Learning and Awareness (all quotations in this section come from [Marton & Booth 1997]):

> *"The unit of phenomenographic research is* a way of experiencing something*… and the object of the research is the* variation *in ways of experiencing phenomena. At the root of phenomenography lies an interest in describing the phenomena in the world as others see them, and in revealing the variation therein…"*

In the general context of this thesis, the 'unit of research' is the relationship between designer and artefact, and the object of research is to explore the variations in this relationship, as a means of highlighting individual differences:

> *"…phenomenography focuses on variation. The objective of a study is to reveal the variation, captured in qualitatively different categories, of ways of experiencing the phenomenon in question, regardless of whether the differences are between individuals or within individuals…"*

Marton & Booth's area of research is learning. In that context, the different ways of experiencing phenomena are related to one another in a hierarchical manner, and of interest is the way in which individuals move from one to another: "differences between them are educationally critical differences, and changes between them we consider to be the most important kind of learning". However, my research shares the stance of Turkle & Papert and Chandler (commentators discussed in Chapter 6) that the variety of ways in which designers relate to their artefacts are of equal importance, and have to do with underlying differences in orientation *between* individuals.

Marton & Booth describe two elements of variation: the dimensions of variation (all the different ways of experiencing the phenomenon, within the collective data), and the structure of variation (the logical relationship between these different ways of experiencing):

> *"The observation was that when people read a text or listen to a presentation or try to solve a problem or reflect upon a phenomenon, that which they encounter appears to them in a limited number of qualitatively different ways. The different ways in which they experience the text, the presentation, the problem or the phenomenon are observed to be logically related to each other and to form together a complex that we have called the outcome space."*

In part of this research (see Chapter 7, ***Comparative study***), I chose to use a comparative framework as a means of examining diversity in design practice, which in effect represented a preliminary model for both the dimensions and structure of variation within

the data. Although this may be a more structured initial aspect to the study than is normal in phenomenographic studies, nevertheless it still shares elements of the approach:

> *"The researcher has a responsibility to contemplate the phenomenon, to discern its structure against the backgrounds of the situations in which it might be experienced, to distinguish its salient features, to look at it with others' eyes, and still be open to further developments. There are various ways of going about this. One way is by considering the phenomenon's treatment in other research traditions: how it appears in literature, in treatises and in textbooks or how it has been handled in the past or in different cultures"*

Marton & Booth's phenomenographic approach emphasises the importance of the figure/ground distinction - the need to view the individual against the collective picture from the group – and the particular strength of this approach:

> *"In phenomenography individuals are seen as the bearers of different ways of experiencing a phenomenon, and as the bearers of fragments of different ways of experiencing that phenomenon. The description we reach is a description of variation, a description on the collective level..."*
>
> *"In accordance with what we said earlier about not only categories of description but even their fragments being distributed across individuals, the data at the collective level are particularly robust compared with the data relating to individuals. Even if it is difficult or impossible to draw from the data, or even from the phenomenographic enterprise, the ways in which individual subjects experience a phenomenon, the ways in which idealized individuals do so can be abstracted owing to the overlap of the material seen at the collective level."*

Implementation

The next part of this chapter describes the variety of ways in which these principles have been implemented in the four main studies of the thesis. The particulars of the methods used in each study will be described in the relevant chapter, but the general principles and how they were implemented in each case are included here.

Artefact study

Chapter 5 describes an exploratory study which focused on preferences students might have for using different 'types' of artefact for generating design ideas, e.g. drawing as opposed to materials, two-dimensional as opposed to three-dimensional. This emphasis on 'dimensionality' is reflected in the design of the study, in which the participants were asked, through a series of short exercises, to use words, markmaking and materials to respond to a selection of words, markmaking outcomes and objects, then to generate design ideas. In this way, a variety of combinations of 'one'-, two- and three-dimensional artefacts could be explored. In total, nearly 200 individual 'artefacts' were produced during the study. These, together with audio recordings of short seminars held

with each sub-group of students, photographs of the students working, and notes taken during the study, formed the raw data for analysis.

In this exploratory study an examination of these artefacts (in conjunction with the students' verbal accounts, supported by the other data) to identify differences was made at a number of levels: within each individual's work (e.g. a preference for using words rather than markmaking); between individuals (e.g. different ways of using a particular type of media within the whole group of students); and within all the artefacts produced (i.e. looking at them as one giant collection without regard to media type or individual).

A loose framework for comparison emerged from this investigation which allowed a broad assessment of variation within the group at a number of different levels, but provided limited information on the relationships between these differences within each individual's practice, i.e. the structure of this variation.

Theoretical review

Chapter 6 describes a comparative review of commentators from a range of disciplines who propose alternative models of the creative process and the relationship between practitioners and artefacts, or alternative explanations of differences between individuals. The commentators can be distinguished by the nature and extent of dialogue they attribute to the relationship between practitioner and artefacts, reflected in the choice of metaphor they use, and whether such dialogue is used to characterise the overall design process, or is a degree of individual difference in approach between practitioners.

This review therefore links both the underlying models and different disciplines to form a robust comparative framework: a rigorous framework to provide strong basis for comparison between disciplines, and to understand how models from other fields might apply in design; and a complete framework which can also accommodate the broader range of studies included in the literature review.

This diversity of commentary adds to the strength of this approach in two ways: firstly, the similarities and differences between their descriptions of these differences in approach allows one to illuminate another, adding clarification, or highlighting aspects which may not be immediately obvious; secondly, it contributes to the genericity (broad applicability) and completeness (the breadth of elements of practice covered) of the model. This study also incorporates the element of 'distance', in the sense that if similar

'different' approaches appear in quite different fields, then comparing elements of these approaches across these fields will provide clarification and additional insight.

Comparative study

Chapter 7 describes a comparative study between two groups of student 3D design practitioners, one working with digital media, the other working with physical media. This study had two main aims: to establish whether differences relating to the nature and extent of a dialogue between design practitioner and media could be observed within each group; and to establish whether similar differences could be observed within both groups. If similar differences in approach were observed within these two groups of 3D practitioners, a comparison of how each type of approach manifests itself in the material and digital environments could provide additional insight into elements of this relationship, arising from the similarities and differences between these two environments. Interviews were chosen as the most appropriate method of data collection for this study, as the aspects of practice with which I am concerned involve people's experiences, opinions, and emotions, as well as accounts of their own process.

Two different stages and contrasting modes of analysis were used in this study. First, a comparative framework was derived from a systematic analysis of the literature discussed in Chapter 6, which suggested the formal/concrete axis as an organising principle for differences in approach across disciplines and across a number of levels of practice. This framework comprised a set of around thirty 'indicators' representing those aspects of a practitioner's process that can be examined to determine the nature and extent of the dialogue they experience with the media. In a preliminary analysis, each individual's approach was categorised using this comparative framework, and an assessment made of the distribution of the approaches within each group.

The second stage of the study involved both an examination of the collective variation within each group across a number of 'dimensions of difference' which emerged from the data, and a comparison of these emergent dimensions between groups. The process of identifying these emergent dimensions partly referred back to the framework used in the preliminary analysis, but did not assume that the relationships between these dimensions would follow the inherently 'two-dimensional' structure of this original model. It also allowed for the possibility that other 'dimensions' might emerge. The comparison between the emergent dimensions from each group contributes the element of 'distance',

clarifying aspects of individuals' approach and affording insights which arise from the differences between the physical and digital environments.

An additional element of distancing in this study comes from those working in the digital medium who have previously worked with physical media, through their own experiences of the similarities and differences in their practice. These might include, for example, those aspects which they had previously 'taken for granted', in Chandler's terms, and which now have been foregrounded for the practitioner through their relationship with this different medium.

Practitioner interviews

Chapter 8 describes an interview study of three 3D practitioners who have an established material practice, and a substantial body of work in digital practice, to examine how their experience, perceptions, skills and working processes transferred from the material to the digital environment. An important aim of the study was to determine whether, in support of the principle of 'distancing' described earlier in this chapter, a practitioner's approach is consistent across media, and what insight into their approach can be gained from the differences in their processes between physical and digital media. These interviews also provide a useful insight into issues that are important, but which might not be immediately obvious in the two 'single' environment elements of the comparative study between digital and material practice described in Chapter 7.

This study uses a comparison between each practitioners' material and digital practice to gain insight into key elements of their relationships with the medium they use and the artefacts they create. (These might have explicitly come to the practitioners' attention through their move from material to digital practice, or be things that they may not be aware of, but which can be inferred from their accounts of practice or revealed by the types of comparison made during this study.) In particular, I was interested in how they view the digital medium, how they engage with it, and how their material practice relates to their digital practice. I was also keen to identify insights they had obtained into their own practice in moving from material to digital, and the differences they highlight between the two working environments. There are a number of levels at which this 'foregrounding' or 'distancing' between media may take place, giving insight into the practitioner's general practice, approach, and relationship with the medium, or the concerns, content or theme of their work.

A two-stage analysis was made of the interview data, in both cases examining themes that emerged from the data, but within the broad theoretical framework discussed in Chapter 7. Firstly, a comparison was made between each individual's digital practice and their material practice, to characterise their approach in each. Secondly, a comparison was made between practitioners, focusing on aspects of their digital practice including: their view of the digital as a medium; their overall approach to the medium; and the role of the medium in their practice.

While the primary focus of this study was the 'distancing' that could be achieved through the comparison of material and digital practice, this second part of the research did contribute aspects of 'difference', through the differences that could be observed between practitioners in terms of their relationship with the medium, and its role in their practice.

Summary

This chapter has described how, through a number of principles described above, diversity in design practice has been used as the means of enquiry as well as the focus for this research.

The following chapters describe the studies outlined here in more detail, and illustrate how this approach has allowed the research to move from an initial position of exploration and uncertainty to its thesis:

> *that individual practitioners experience different relationships with the artefacts they create and work with in their processes, and that elements of these differences can be attributed to the nature and extent of a dialogue between designer and media.*

5. Artefact study

In Chapter 1, ***Introduction***, I described how the starting point for this research was a previous investigation I had made of the working processes of designer-makers to better understand the role of materials within their processes, as a possible paradigm for future computer systems for creative practice. At that time I was looking for characteristics of 'the' designer-maker approach to creative practice: an approach typified by a close relationship with materials. However, my interviews with a range of designer-makers revealed a spectrum of approaches, ranging from design-then-make, to design-through-make, to make-as-design. While some practitioners developed their ideas using sketching, others chose to work with materials (either to design, or making with the medium), or used a combination of both. This suggested that the role of materials in different practitioners' processes might not be the same, and require further investigation. Chapter 3, ***Artefacts and the design process***, describes how very few studies have examined differences in the ways that 2D and 3D artefacts might support designers' processes, or differences between individual designers that relate to their use of artefacts within the design process. An empirical approach was therefore adopted to investigate these differences further.

This chapter describes an exploratory study of a group of 3rd Year undergraduate students on the Silversmithing & Jewellery degree course at Glasgow School of Art (GSA). The study had two main objectives: to ascertain, broadly, whether clear differences could be distinguished between students' approaches to and preferences for using 2D or 3D artefacts to generate design ideas; and to identify any other significant observations relating to individual differences which could inform the design of future, more focused, studies.

Design of study

This study was conducted as one element of a Technical Roundabout in which third year Silversmithing & Jewellery students are introduced to new techniques such as working with the lathe, enamelling, colouring and printing on aluminium, and working with plastics. It was presented in the form of a one-day workshop – an 'Artefact Mini-

roundabout' – in which students were encouraged to explore ways of working with a variety of media, then to use these media to generate design ideas. A research proposal was produced for the course leader, outlining the context of the research, the research objectives, the learning objectives (as the study was being carried out as part of the students' coursework), data collection techniques that would be used, an explanation of consent procedures, and the format of the study (see Appendix C). Normal procedures were used to obtain consent from the participants.

This study focused on preferences students might have for using different 'types' of artefact for generating design ideas, e.g. drawing as opposed to materials, two-dimensional as opposed to three-dimensional. This emphasis on 'dimensionality' is reflected in the design of the study, in which the participants were asked, through a series of short exercises, to use Words, Markmaking and Materials to respond to a selection of words, markmaking outcomes and objects, then to generate design ideas. (The term 'markmaking' is used to describe the practice of using a variety of techniques to produce marks on a page. It is used in a less restrictive sense than people may associate with the term 'drawing'.) Although the original comparative emphasis was on 2D/3D, the use of 'one'-dimensional media (Words) was included for completeness, resulting in a spectrum of 'materiality'. In this way, a variety of combinations of one-, two- and three-dimensional artefacts could be explored.

Figure 30: A workshop in progress within the studio

Four workshops were held over a four week period, each with a small group of students (thirteen students participated in total). All four workshops were held in the students' normal studio (Figure 30). Before the workshop, each student was given a handout

which introduced the workshop and its aims, described the format it would take, and gave a timetable for the day (Appendix D).

Workshop plan

Each workshop started with a general introduction discussing the role of artefacts in design, and the aim of the day. This was followed by three sections focusing on a different media type (Words, Markmaking and Materials), each of which consisted of a short introduction and a set of exercises. A group seminar completed the day. A plan of the workshop, giving details of the introductions, each exercise and the times allotted, is given in Appendix E.

Exercises

The exercises in each 'media' section were of two types, reflecting both reflective/appreciative and constructive aspects of designing. The first group of exercises asked students to respond, using the media type, to a selection of artefacts. The final exercise in each section asked students to use the media to generate design ideas in response to a brief. This brief was deliberately left non-specific: the aim was to give a focus for the students to work towards, without overly constraining their response. The Markmaking and Materials sections also included an exploratory exercise where students could try out a variety of techniques: this allowed students to gain some degree of familiarity in working with what might be unfamiliar media or in unfamiliar ways. A full listing of the exercises is given in Table 4; Appendix F lists these along with the times taken in each workshop.

The term 'respond to', when asking students to do the exercises, was chosen very deliberately to avoid as much as possible the idea that they were being asked, for example, to draw an object in the traditional sense, or describe an object in the Words exercises. I wanted to prescribe as little as possible the ways in students felt they could respond to the object, within the given media confines of the exercise. Similarly, the categories were defined as Words, Markmaking and Materials to allow as broad an interpretation as possible. In Markmaking, for example, this was partly to dissociate the two-dimensional aspect from the representational and/or depictional aspects often associated with drawing.

Words Please respond using words to: • an object that interests you • an experience - eating a cake/cakes or fruit • a person or animal that is significant to you • a piece of text from the sheets provided Using only words, generate design ideas for an object to be worn to celebrate a special personality (i.e. human, animal), place or event in your life. (You can use words both to generate ideas, and to represent the actual piece)
Mark Making Explore a variety of techniques to make marks Please respond using marks to: • an object - suggest using a number of different techniques • an object that you can touch, but not see • a piece of text / words from earlier workout Using only marks, generate design ideas for an object to be worn [if you like, to celebrate a special personality (i.e. human, animal), place or event in your life]. (You can use marks both to generate ideas, and to represent the actual piece)
Materials Exploring a variety of techniques and types of material, make some objects that appeal to you Please respond using materials to: • an object • a piece of text / words from earlier workout • one of your mark-making outcomes Using only materials, generate design ideas for an object to be worn [if you like, to celebrate a special personality (i.e. human, animal), place or event in your life]. (You can use materials both to generate ideas, and to represent the actual piece)

Table 4: List of exercises

The result of having a number of combinations of dimensions e.g. words responding to an object, or the experience of eating a cake; or marks responding to words, or an object that couldn't be seen, is that normal ways of working with media, or the normal context of working with media, is disrupted while retaining elements of the underlying relationships with media. This allowed the students (and me) to become more aware of ways in which they related to different types of media while creating and working with artefacts. (In retrospect, this has resonances with the technique of *distancing* that Chandler describes in The Act of Writing [Chandler 1995], as a way of examining mediation in working with media: see Chapters 4 and 6). It also provides several different 'ways in' to seeing how a student approaches and uses the media, on the principle that looking at something from a variety of angles is an appropriate alternative to repeated observations from the same angle.

A variety of source objects, including excerpts from texts, were provided for the students to use, along with a range of different tools, inks, paints, paper, card and a whole mixture of other materials including fabrics, plastics and an assortment of recycled materials. The pictures in Figure 31, taken during the workshops, illustrate the range of items provided

Figure 31: A selection of the materials, tools and source objects available during the workshops

(a copy of the texts is given in Appendix G). In some cases the students augmented these with implements and materials that they had available in the studio.

Seminar

The structure of the group seminar was similar to critiques at the end of projects, where students meet as a group with their tutor to review the project work. However, the seminar did not focus on a critical evaluation of each student's work, but was rather an opportunity for students to describe the approach they had taken (and why), along with any observations of their own on aspects of the work they had found difficult, surprising, familiar, unfamiliar, and so on. It also let them see, compare and discuss the range of approaches that had been taken.

In terms of the design of the study, the group seminar provided the only opportunity to gather comments directly from students on their preferences, opinions, reasons for acting in particular ways, difficulties and surprises, etc. These generally emerged from the discussion, although some prompts were given. It could be argued that a more rigorous approach, where greater care was taken to ensure that identical data was collected for each student, would have been more appropriate. However, the exploratory nature of this study was not designed to accommodate such a prescribed approach. It was not clear

before the study what parameters would have been most appropriate, and the preference was to focus on aspects of working which had been most noticeable to the student, considering that any such aspects highlighted by the student (or indeed not highlighted) would be those that were most significant.

Although the emphasis of the design is clearly exploratory, and may at first appear to be extremely open in the sense that the students were given a large range of source objects to choose from, in an overall respect it is highly structured. The combination of exercises given to the students allows a variety of comparisons along the dimensions of 'dimensionality' to be made within the data.

Implications of the educational context

As this study was being carried out in an educational context, the introductions to the workshop and each media section included examples of ways in which the various types of media might be used. Also, the students were encouraged to explore a variety of techniques and ways of working other than they might normally use or be familiar with. It could be argued that this prejudiced the ways in which students approached using the different media, and influenced them to work in ways not natural for them: one of the aims of the study was to see if students had preferences for particular ways of working, and this might therefore distort the results. I believe that this concern, while to some extent legitimate may, for the following reasons, be of less significance than might be supposed.

Some students did say that they had tried things because they had been suggested. However, quite different approaches were taken by students even within the same workshop, who were given exactly the same introduction. This implies to a certain extent that even if students did try techniques because they were suggested - and certainly if they kept using these techniques - that they had aspects that appealed to the student's underlying approach.

The very nature of the workshop (and part of its educational objectives) meant that students were quite deliberately liable to find themselves working in ways outwith their normal experience (this could be the case even if the 'dimensions' were the same), as a means of examining their underlying approach. Further, it became clear during the study that the ways in which the students used media in the context of the workshop did not necessarily relate to ways in which they would use them in design, in any case.

Implementation

The first workshop acted as a pilot for the following three and a number of changes, mostly administrative, were made for subsequent workshops. Most importantly, a written plan was created listing key points for the introductions to the workshop and the sections, possible 'prompts' for students during the exercises, and the intended timings of each exercise, to ensure as much as possible a consistent approach for each workshop. Other changes included altering the layout of the printed materials (the consent form, the introductory handout, and the text handout for the workshop) after consultation with GSA's dyslexia co-ordinator, to try and minimize any disadvantage to students who might be dyslexic, particularly within the Words section. These changes are not likely to have materially affected the outcomes of the workshop.

Two changes to the content of the workshop were made (one unintentionally, one deliberately) which may have had a more significant impact. In the first workshop, the full range of materials was not available during the Words section, as it was for subsequent workshops. As a wider range of materials was used in this section by students in subsequent workshops than I had anticipated, this could have affected the first group's response to this section. However, although some students in later workshops made use of this wide range of materials, others did not, so the impact cannot be accurately assessed. Secondly, an additional exercise was added to the Markmaking section of the workshop: the 'feely bag' exercise, where students were asked to respond to an object they could touch, but not see. The only impact this had is that the data for this exercise is not available for three of the students, which has to be taken into account during analysis.

Data collection

In total, the students produced nearly 200 artefacts during the study, which were photographed for permanent record. These, together with audio recordings of the seminars held with each group of students, photographs of the students working, and notes made by myself during the study of actions or comments of particular interest made by the students, formed the raw data for analysis.

Finding a suitable means of storing, cataloguing and analysing this large quantity of chiefly visual data (around 750 images, comprising photographs of the artefacts, and photographs taken during the workshop), but also text presented a number of practical

challenges. StorySpace (software designed for developing hypertexts, which can hold images and text within its data structures and create dynamic links between them) was chosen as an appropriate means to catalogue and support the analysis of the visual and textual data from this study [Eastgate Systems Inc.]. Linked coding structures could be built up in a similar way to standard qualitative analysis packages available at that time, but with more flexibility, including the ability to examine any selection of artefacts at one time. A screen shot illustrating the StorySpace software with excerpts of the analysis structure is shown in Figure 32.

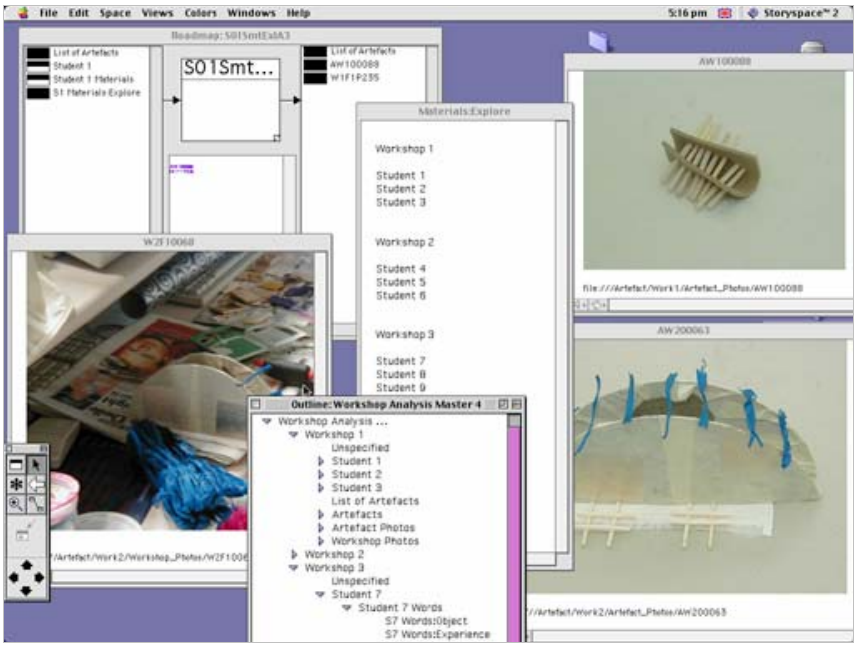

Figure 32: Screen shot showing the data structures in StorySpace

Analysis

In line with the overall method, this study was designed to use the examination of differences between students and artefacts as the primary means of analysis. There are a number of reasons why this approach is appropriate. In a study of this type, the majority of the data is not information-based; it is visual and material, where the qualities under investigation are neither explicit nor absolute. This makes it difficult to evaluate an object in isolation: comparison across a group provides a method of examining and evaluating individual practice/outcomes against the collective background of the group. (Whilst this does not allow 'absolute' claims to be made of the data, it does allow for a comparison between the members of the group, which is the aim of this study.) This

collective view makes it easier to see what people have *not* done, as well as what they have done, giving additional information about their approach. Finally, the exploratory nature of this study meant that the results were not anticipated in advance, making evaluation against pre-arranged criteria less useful.

Initial analysis of the data comprised an examination of the transcriptions of the group seminars and an examination of the artefacts produced by the students, by exercise, for each media section: Words, Markmaking, and Materials.

The transcriptions were examined to see what students had said about: preferences for one way of working over another; particular benefits or drawbacks they had noticed in working with each media type; within each section, any differences in the methods they had used, due to taking a different approach, or because they had experienced difficulties; how familiar they were with the media types, and if they used them in their design processes; information to complement and support the analysis of the artefacts themselves (for example where students explained why they had used a particular technique, or acted in a particular way); and any unexpected points that the students made.

In the analysis of the artefacts themselves, I was looking for: ways in which they differed, either in an aspect of the artefacts themselves, or in differences in approach that could be deduced from the artefacts; consistency, or especially distinctive differences, between artefacts produced by a student within a section; and cases where students had responded to the same source – text or object – which could give additional insight into any differences, particularly in the Markmaking and Material sections where differences may be less obvious to spot.

The examination of the artefacts (in conjunction with the students' verbal accounts, supported by the other data) to identify differences was made at a number of levels: within each individual's work (e.g. a preference for using words rather than markmaking); between individuals (e.g. different ways of using a particular type of media within the whole group of students); and within all the artefacts produced (i.e. looking at them as one giant collection without regard to media type or individual).

Different dimensions

These inspections of the textual and visual data resulted in a series of categories for each section (Words, Markmaking and Materials) in which differences were observed. A full

listing is given in Appendix H, but the most notable will be described below, with examples. It should be re-emphasised that the differences identified in these categories are collective: they emerged from the examination of all the artefacts in each exercise. Individual artefacts may include more than one of the features identified. The important thing is that the categories provide a collective comparative structure, derived from an examination of the artefacts themselves, against which individual artefacts and practice can be examined.

Words

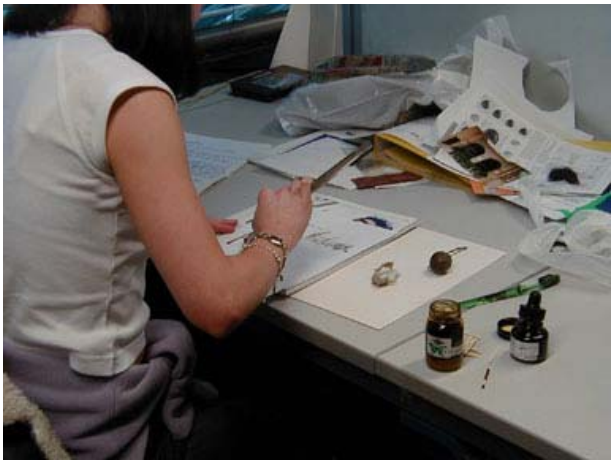

Figure 33: A student using Words to respond to an object

The differences between artefacts in the Words section were particularly striking. This may be for a number of reasons: of all three media types, this was the one most likely to be unfamiliar to students in the design context (a number of students said they 'weren't words people'); as one student commented, "you're very explicit with words", therefore some types of evidence of different approaches are more easily recognised in this than in other media; and when the focus is on words/language, any significance placed on other media becomes particularly obvious.

Differences in the Words section can be observed on a number of different levels. The first of these is the extent to which the physical qualities of the words are significant, for example their look or sound: in effect, the word as an object. This can be observed where people have used the style of writing to convey some aspect of the object being responded to, for example (see Figure 34).

Figure 34: Examples illustrating the physical aspects of words

A second difference relates to the 'content' of the words – what they are being used for (signified as opposed to signifier). I have identified three major categories: descriptive, where the student is primarily describing qualities or aspects relating to the source itself; responsive, where the student is primarily concerned with their feelings or personal response to the source; and generative, where the student is using words to generate new ideas (found primarily, but not exclusively, in the design exercise). Examples can be observed in the exercise where the students were asked to respond to a person. Two students chose their Mum: one student's artefact emphasized descriptions of her Mum and her qualities, and what she was like; the other student's piece emphasized her feelings about her Mum, and about her relationship with her Mum. Similar contrasts can be observed in responses to poems: one student seemed to approach the poem 'literally' and dissect it, examining each phrase as she went along; other students responded to the poems they had chosen with how it made them feel. (See Figure 35). This contrast between objective and subjective approaches to the source continues through each of the media types, and suggests that this may be an important element of the relationship between designer and artefact.

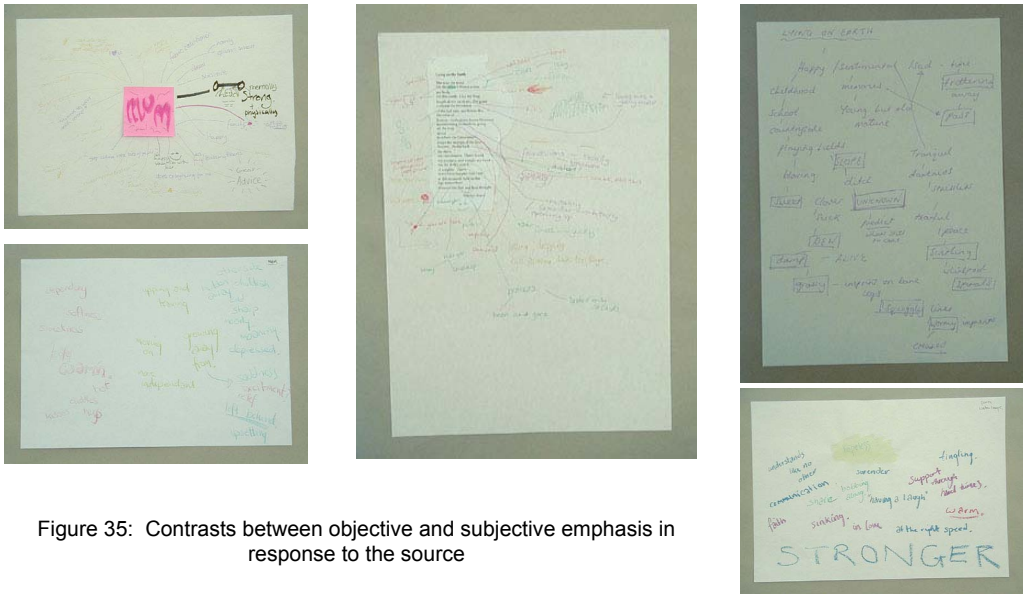

Figure 35: Contrasts between objective and subjective emphasis in response to the source

A third difference concerns the organization or placement of words on the page, relating to how they were being used. This ranged from mind mapping and brainstorming approaches, to narrative approaches, to one student who used words almost like physical objects in a material piece. Related to this was the use of single words, short phrases, or longer narratives. (See Figure 36.)

One of the most noticeable differences was the role of the physical materials within the artefacts produced. Although Words was the 'medium' in this section, the importance of the materials ranged from almost incidental to being integral to the piece to the extent that they had certainly equal, possibly higher significance than the words themselves (see Figure 37). The difference between students in the extent to which the material played either a background or foreground role was striking. This material aspect was not something that was suggested to the students, but arose spontaneously from their individual practice.

Relationship with Words

Some interesting remarks were made about using words during the seminar. A number of students commented that they normally did not use words or felt uncomfortable using words. One student said,

> *"I don't like working with words, I have to say… I have a kind of block as if I can't do it therefore it was quite difficult but I quite enjoyed it."*

Figure 36: Different styles of layout of words on page

Figure 37: Examples illustrating a range of 'importance' of physical materials within the students' responses

Another student observed that using words in this way was very personal: "a bit too personal", more so than drawing. This resonated with a number of students. One commented that she found using words "kind of disturbing". This disclosive nature of words was particularly relevant in the educational setting, where work is viewed by tutors and others. It was also interesting, given the visual emphasis within designing, that one student commented,

"you can be more ambiguous if you're drawing, but you're very direct with words"

Some students found the Words exercises particularly difficult in situations where the source they were responding to wasn't physically present, for example 'a person or animal significant to them', or designing a piece for an event that happened in the past (e.g. getting into art school). One student felt that this was because "we didn't have an object or anything", and therefore she had to "sort of think back", whereas in the other exercises the source was in front of them.

A number of students changed their approach depending on which exercise they were doing, particularly if they were recalling things from memory. One student moved from a more narrative approach to a brainstorming technique; another from a narrative approach to making lists.

Some students, most of whom did use words in the normal course of work, liked the way that it helped generate ideas, and for going back to if you got stuck:

"You can go off on a tangent and maybe get better ideas by doing that."

Although a number of students found it very frustrating that they couldn't draw in the 'design' exercise using Words, nevertheless some had a very clear image of the piece they would make in their head by the end of the exercise. However, they joked, "whether we'd be able to draw it…"

Markmaking

Differences between artefacts in the Markmaking section can also be observed at a number of levels.

As with Words, differences can be observed in the 'content' of the marks: the type of response the student is making to the source. The categories are similar to those defined in the Words section: descriptive, responsive, and generative (see Figure 39): whether the student is responding to qualities of the source object itself, their personal associations to the object, or using marks to generate ideas (again, notably in the design exercise). (It

Figure 38: A student using Marks to respond to an object

should be emphasised again that this was an exploratory study, and that these preliminary categories emerged from an examination of apparent differences within the data.)

Figure 39: Examples of descriptive, responsive, generative responses

A related difference concerns the 'representational' extent of the artefact. Whereas the categories above concern the type of response to the source object, this category is concerned with the extent to which the marks used are literal or abstract, illustrative or evocative. Some students in this section responded with almost traditional drawings (in an 'illustrative' sense): for others the marks were more expressive or abstract. (See Figure 40.)

Figure 40: Examples of different representational extent of responses

Within this section, differences could also be observed relating to the role of the physical materials in the artefacts the students produced, ranging from ‘background’ to ‘foreground’ as with Words (Figure 41).

Figure 41: Examples illustrating a range of ‘importance’ of physical materials within the students’ responses

A ‘cluster’ of categories (including techniques used, types of marks, use of unusual tools or techniques, and use of media) collectively relate to the extent to which students appeared to exercise control over the marks, or leave it to chance; and an openness to try new techniques, and experiment (Figure 42). These differences were not so readily observed in the Words exercises; however it may be that the underlying differences

(control, chance) would, on further investigation, reveal themselves but manifested in other ways.

Figure 42: Variations in degree of control or chance, unusual techniques

Relationship with Markmaking

The majority of students did not normally use Markmaking: some were aware of it as a technique, but others had never used it before. For example, one student said she had been exposed to it in First Year but struggled with it because she "didn't really understand it".

One student commented that she had liked it because it was "much more painterly and loose" that the usual way she drew, and thought it would be a technique she would use again. Another student described it like "sitting on the phone doodling".

One student commented that through using it she'd come up with ideas for objects that she didn't think she would have otherwise. Another student commented that with markmaking "you didn't always know what impression it would make, like it… could be hard impression could be… faded or… and that led to other possibilities".

Materials

Figure 43: Student exploring Materials

As with Words and Markmaking, differences at a number of levels were observed in the Materials section.

One difference concerns they way in which the artefact is linked to the source: in a sense its representational extent e.g. illustrative (like making a model), symbolic, or abstract (Figure 44: top row). Another concerns the qualities of the source that the student is responding to: for example its visual/physical/material qualities, its evocative or associative qualities, or the student's personal response to the object (Figure 44: bottom row). (This is similar to categories identified in Words and Markmaking.)

Figure 44: Responses illustrating different representational extent (top)
Three students' responses to a head of barley (bottom)

Other differences concerned the extent to which the materials were tailored to suit, or were used 'as is' (Figure 45). For example, materials like beads or bits of plastic might be used as they are, as elements within a construction. On the other hand, materials might be modified quite significantly. This is linked to differences in the ways in which an object is created e.g. assembly, construction, modelling/addition, carving.

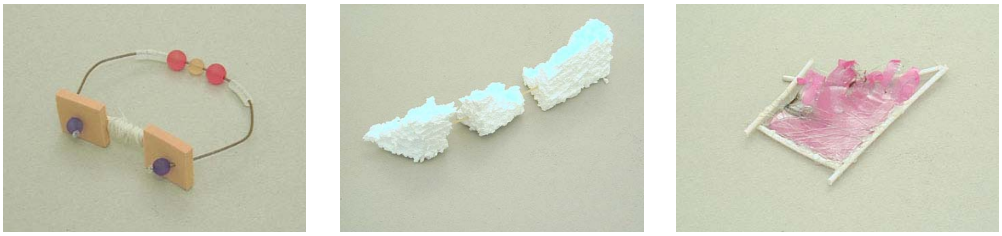

Figure 45: Materials used 'as is' or tailored to suit

A cluster of categories are collectively related to the extent to which the materials are subordinate to an 'idea' that the student has had, or significantly influence the final artefact produced. These include 'aspects of materials used' (e.g. colour or texture, its symbolism or associations), 'choice of material' (e.g. chosen for its visual/aesthetic qualities, its material/functional qualities, or its associations), 'extent of response due to material' (how much the final form of the artefact was influenced by the materials that were used) (Figure 46).

Figure 46: (l) Materials subordinate to idea. (r) Idea for puppet came from old tights!

Relationship with Materials

As they are on a design/applied art course, the students are familiar with working with a range of materials in the production of pieces, but their experience of using materials in the idea generating element of design was less universal. Some who did like using

materials said that they really liked making models, or that as soon as they got their hands on materials they wanted to make something.

Some students commented that they liked the Materials exercises because you "kind of got an end result… you could do something with it if you wanted to take it further", or "you're just getting stuck right in there". One commented that "I could see possibilities for that, going onto make something, make some sort of object of that… which I wouldn't have thought, I would have came up with."

Another student said "when you first said Materials it was just like, oh no…", and "the idea of constructing things, really doesn't appeal to me". However, she began using a folding technique which she liked. Interestingly, despite this dislike of being asked to use materials, it was the material aspects of the Words exercise that she enjoyed: the pens, the paper and the physical act of writing.

One student who had enjoyed the Materials exercises, but who didn't usually make models said she felt she should use this approach more often: she commented that a friend who was an architectural student had previously suggested the technique to her when she had got 'stuck', and she had found that it had helped. Another student said that she didn't use materials much, but seemed to feel that she should:

> *"I sketch more but it's probably more out of laziness than anything else, you know just starting to sketch, instead of actually getting down and getting the materials together…"*

Given the recognised importance of drawing as a means (though not the sole means) of developing ideas within the design context within which the students work, a feeling of guilt for not using materials is interesting.

Limitations of the study

While these observations, derived during the production of the categories of difference, are individually interesting and collectively useful, they offer little in the way of direct comparison between students. The true power of this analytic approach would only be derived through a second examination of all the artefacts, using a selection of the most significant categories identified during this first examination to assess each one. Patterns observed within the categories would allow each student's work to be assessed against the collective view. This would more reliably determine whether differences in approach do exist for students *between sections* (e.g. Markmaking as opposed to Materials), and

also whether there are clear indications of more fundamental differences in approach *between students*, along the lines suggested by the differences already noted. An examination of the patterns of difference would quite probably reveal other significant factors; likewise, it might reveal more subtle distinctions than can be observed from the current data.

However, although some of the differences and comments noted for Words, Markmaking and Materials may seem incidental, or non-generalisable due to the variety of responses and variations in exercises, taken together they begin to build a picture of very different ways in which the students relate to the objects they work with.

Conclusions

The original objectives of this study were to ascertain, broadly, whether clear differences could be distinguished between students' approaches to and preferences for using 2D or 3D artefacts to generate design ideas; and to identify any other significant observations relating to individual differences which could inform the design of future, more focused, studies.

While a number of students expressed preferences for ways of working, this cannot necessarily be correlated to preferences for ways of working in their design processes. For example, one student who did not consider herself a 'words person', and who did not use words when designing, nevertheless liked the Words section because she found it challenging; one student commented that she normally did use words to an extent in design, but had not found in the Words design exercise that it had sparked off any ideas (perhaps because it was playing a different role in the workshop context, or being used in isolation); and one student's approach in the Words section changed quite dramatically between the 'responsive' exercises and the 'design' exercise, because she was 'designing' (Figure 47). (Possible explanations for these observations are addressed in Chapter 9, ***Discussion***.)

Within the limitations of the existing analysis of the data, no clear conclusions can be drawn that the primary differences between individuals related to a preference for working in 2D rather than 3D, although some students did say that they were more comfortable working with some types of media than others. What became apparent during the study was that striking differences could be observed *within* as opposed to *between* media type.

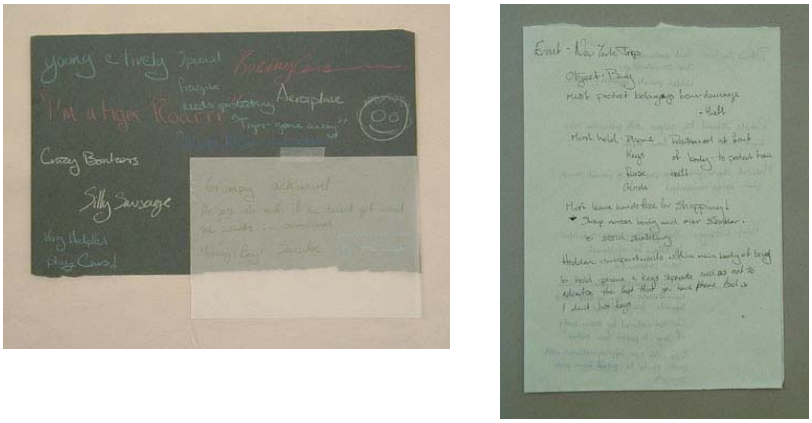

Figure 47: Change in type of response from 'responding' to 'designing'

A number of recurrent differences emerged from the collective examination of all the artefacts: regarding the relationship between the student and the source object, a subjective or objective approach towards the object; the extent to which the materials play a background or foreground role in the artefact (this is especially noticeable in some students' work in the non-Materials exercises); within the design exercises, the extent to which the design is derived by the student and then expressed in the media, or is derived through working with the media. Without further analysis it cannot be claimed that an individual student will relate in a similar way to objects across all media types, although a number of examples suggest that this might be the case. These preliminary themes, while emerging from the data within this study, have counterparts in themes arising from the comparative study of literature from a variety of disciplines (Chapter 6, ***Concepts of dialogue in design***), later empirical studies (Chapters 7, ***Comparative study*** and 8, ***Practitioner interviews***), and from further comparisons between literature from different disciplines made in Chapter 9, ***Discussion***.

The findings from this study suggest that design practitioners may well use the same media quite differently; that for some participants, materials seemed to play a much more significant part in *all* their responses than others; and that a blunt comparison between 2D and 3D may therefore be of little value. This is not to deny that there may be differences between individuals which relate to a preferences for working in 1D, 2D or 3D, and which might be revealed by a fuller analysis of the data, but that the differences I had observed between individuals did not relate specifically to a preference for 2D/3D, but more to different ways of relating to artefacts, and the role of media within their creative practice.

These findings reinforced the position that the research should focus on the relationship between an individual design practitioner and the artefacts and media they work with within their creative practice. They also suggested that for future studies it would be not only necessary but valuable to look beyond my original categories and examine more closely differences in the ways that individual design practitioners perceive and relate to the artefacts and media they use to support their processes.

The next chapter, ***Concepts of dialogue in design***, describes how, while few studies of three-dimensional design have examined difference of this nature, commentators from other fields – writing, epistemology & learning, and anthropology – discuss differences between practitioners which resonate strongly with the tentative ideas arising from this study, and from my previous research. A review of these commentaries indicates that differences exist between individual design practitioners which represent wholly different approaches to design, elements of which relate to the nature and extent of a dialogue between practitioner and medium.

6. Concepts of dialogue in design

The research undertaken so far in this thesis has revealed design as a process of incremental transformation, facilitated through or revealed by a practitioner's active engagement with artefacts. It thus reinforces the importance of placing the relationship between practitioner and artefact at the centre of the research. However, it has made less progress in providing a satisfactory explanation for the diversity between practitioners which I had observed in my previous research.

The review of design literature in Chapter 3, ***Artefacts and the design process***, discusses case studies of individual designers which make reference to differences in approach relating to the roles of sketching and drawing or working with materials between individuals' practice, but do not examine these further. It concludes that there exists little design literature to assist in explanation. Chapter 5, ***Artefact study,*** reported on initial enquiries concerning practitioners' preferences for working in two or three dimensions to generate design ideas, which concluded that there may be more fundamental differences between individuals in their relationship with the medium in which they work. It identified differences in the ways in which individual design practitioners perceive and relate to the artefacts and media they use to support their processes, but the tentative evidence from this exploratory study could only hint at possible explanations.

While existing research in design has little to offer in this regard, Chandler's phenomenological study of writers [Chandler 1995] and Turkle & Papert's studies of student programmers [Turkle & Papert 1990; Turkle & Papert 1991] discuss differences in approach which can broadly be described in terms of the nature and extent of a dialogue between practitioner and medium, although the metaphors used by the two commentators are slightly different. They are therefore of direct relevance to this research. This chapter provides a comparative review between these commentators and other studies from design and writing which propose alternative models of the creative process and the relationship between practitioners and artefacts, or alternative explanations of differences between individuals.

Reflection, negotiation, mediation: concepts of dialogue in design

These commentaries can be distinguished by the nature and extent of dialogue they attribute to the relationship between practitioner and artefacts, which is reflected in the choice of metaphor used to describe this relationship: reflection, negotiation, or mediation. In some cases the dialogic metaphor is used to describe the design process generally, as in Schön's description of "design as reflective conversation with the materials of a design situation" [Schön 1992]; in others it is the extent of dialogue between practitioner and medium which characterises differences between individual practitioners.

The review examines, for each commentator, the role of artefacts/media in the creative process, the nature of individual differences in approach, if any, discussed by the commentator, and how these differences relate to the nature and extent of a dialogue between designer and artefact. It also examines the conceptual view of the design process which lies behind each of these models, and how these influence/impact the model of dialogue which is being proposed. This review therefore links both the underlying models and different disciplines to form a robust comparative framework.

The chapter starts by revisiting two commentators who exemplify the main models of the design process and the relationship between design practitioner and artefacts so far discussed in this thesis, which are shared by a number of other commentators discussed here: Goel's description of design as ill-structured problem solving where sketches, for example, are viewed as an external symbol system to support internal cognitive processes [Goel 1995]; and Schön's description of "design as reflective conversation with the materials of a design situation", where the artefact is the medium of reflection-in-action.

Goel

Chapter 3 discussed Sketches of Thought, Goel's intensive exploration of design activity, which he views as a good example of ill-structured problem solving. (The ideas and quotations in this section come from that publication [Goel 1995].) He focuses on the sketches characteristic of preliminary design, and proposes that the cognitive processes associated with sketching activity are important in the early stages of design; that the dense and ambiguous nature of the symbol system of sketching supports these cognitive

processes; and shows that when the designer is restricted to using an external symbol system which does not have these features, these cognitive processes are disrupted.

Goel focuses on design as a cognitive process, which has a number of implications. In the early stages of design with which he is dealing, his emphasis is very heavily on the transformations of ideas, supported by the properties of the external symbol system of sketching. He proposes that "different thought contents may require different symbol systems for their expression", suggesting that, in this context, the sketch is a direct and external representation of internal cognitive activity. It is also reflected in the way the designer's relationship to the environment and the design context is seen in terms of information:

> *"This transformation and exploration of alternative solutions is facilitated by the abstract nature of the information being considered (a large percentage still concerned with people and behaviour)"*

In Goel's studies, he observed that the exploration of ideas characteristic of the early stages of design emerges by "incremental transformation of a few kernel ideas", particularly through "a large number of lateral transformations". Although the lateral transformation of ideas is crucial to the exploration, there is little sense of a dialogue between designer and sketch in this transformation - certainly not in the sense that Schön describes - more the notion that sketching is a form of external thinking, as can be seen in his description of the comparison between the effects of the two different external symbol systems (sketching and draughting):

> *"One actually gets the sense that the exploration and transformation of ideas is happening on the paper in front of one's eyes as the subject moves from sketch to sketch. Indeed, designers have very strong intuitions to this effect. When a new idea is generated in MacDraw, its external representation (in MacDraw) seems to fixate and stifle further exploration. Most subsequent effort after the initial generation is devoted to either detailing and refining the same idea or generating the next idea. One gets the feeling that all the work is being done internally with a different type of symbol system and recorded after the fact, presumably because the external symbol system can not support such operations."*

In the study, Goel doesn't consider any individual differences in process (other than that his subjects came from different disciplines – 2D and 3D - and the design briefs they were given were appropriate to those disciplines). This may have a number of different reasons: firstly, and probably most significantly, the purpose of the studies was not to examine difference; secondly, the studies were focused on one very particular aspect of the design process (sketching in the early stages of design), and the types of differences in which I am interested may not be observed at this level; and thirdly, although the subjects were given a two-hour, "real-world" design task, it nonetheless was an

artificially constrained experimental situation, where again, individual differences may not as easily be observed.

Schön

In his paradigm of design as reflective practice, discussed in Chapter 3, Schön describes design as 'reflective conversation with the materials of a design situation'. (The ideas and quotations in this section come from [Schön 1983; Schön 1992; Schön & Wiggins 1992].) Each design situation is viewed as a unique case, a problematic situation rather than a well-defined problem. This requires a shift from problem solving to problem setting, skilled knowing-in-action rather than technical expertise applied in standardised ways, where each designer's repertoire of experience contributes to their uniquely constructed 'design world' within which they operate. Schön's model of the design process is one of understanding through change. By drawing on exemplars from his repertoire of previous experience, the practitioner 'sees' a way of engaging with the situation, and 'frames' it in such as way as to impose an element of discipline and structure to allow him to proceed. This is the start of a process of framing and reframing: having made his 'move', or experiment, the designer 'appreciates' the outcome, which may or may not be what he expects, and responds to the 'talkback' of the situation. This dialogue is a factor of the uniqueness and complexity of the design situation. Underpinning this process is another type of dialogue, dependent on visual 'seeing' - the ability to construct figures from marks on a page. This emphasises the situated nature of design, where the medium in which the designer works is the medium of reflection-in-action.

Yet even though Schön's model of design incorporates these aspects of dialogue, it does not seem to accommodate the differences that can be observed between design practitioners. He recognises the uniqueness of each individual's practice, but the differences he discusses arise from the personal and situational context within which the practitioner is working - their unique 'design world' - rather than wholly different approaches to design. While Schön stresses the importance of the interaction between designer and artefacts, the dialogue he describes is a dialogue with yourself *through* the medium - shifting internal appreciations through reflection on external representations - rather than what I would characterise as a dialogue *with* the medium experienced by many makers.

Much of Schön's research focuses on architectural practice: the design is substantially complete before 'making' commences; the designer rarely builds the final outcome; and the designer works with representations of reality, rather than reality itself. (Schön further refines his description of design in this context as "conversation with materials, conducted in the medium of drawing and crucially dependent on seeing".) The context with which I am concerned is closer to the studio practice of designer-makers, where the practitioner is in charge of the whole process from concept to execution, and where it is possible to observe differences in approach that in more focused situations might not be seen.

Louridas

Design as Bricolage: Anthropology Meets Design Thinking offers a possible extension to Schön's model of dialogue. In this theoretical paper Louridas compares two types of design - unselfconscious design and selfconscious design[7]. (The ideas and quotations in this section come from [Louridas 1999].) Unselfconscious design is design without designers, vernacular design in a context of stable cultures, where 'good' design is the produce of a long tradition of design. Selfconscious design is contemporary design, professional design, characterised by design-by-drawing. Unselfconscious design is 'literal' design, design at the level of the artefact; selfconscious design is 'metaphorical' design, design at the level of the representation.

Drawing on Levi-Strauss's distinction between the concrete approaches of the bricoleur and the formal approaches of the engineer as a metaphor to explain his ideas behind the contrast between science and mythical thought [Levi-Strauss 1966], Louridas proposes that self-conscious and unselfconscious design can both be viewed as processes of bricolage: a 'dialogue with the materials and means of execution':

> *"we show that both are the same activity applied to different means; both follow the same logic applied to different contexts"*

The bricoleur does not go out and seek materials specifically for each project, but makes do with the materials, tools and skills available in a 'heterogeneous' collection he has built up over time, i.e. he works with an inventory that is 'closed'. Because of this, items in the inventory may be used for purposes other than which they were intended, for their

[7] The terms 'unselfconscious design' and 'selfconscious design' were introduced by Christopher Alexander in Notes on the Synthesis of Form [Louridas 1999].

'secondary' qualities: what they could be or could do, rather than what they are or are 'for'. Because his inventory is closed, the bricoleur must enter into a dialogue with this inventory to see the 'space of possibilities' that exist within it, and how he might use it for the project in hand. Because the bricoleur is using items other than for their original purpose, there is an uncertainty about the consequences of his actions, which leads to the bricolage process being one of continual dialogue with the items in the inventory as 'interlocutors':

> *"Bricolage is therefore at the mercy of contingencies, either external, in the form of influences, constraints and adversities of the external world, or internal, in the form of the creator's idiosyncrasy. This is in contrast to the scientific process: science brackets out events and secondary qualities to arrive at the essentials and primary qualities. It uses structures, in the form of its underlying theories and hypotheses, to arrive at its results, which take the form of events. Bricolage works in the opposite way; it creates structures, in the form of its artefacts, by means of contingent events."*

Using bricolage as a metaphor for design, Louridas argues that unselfconscious and selfconscious design can both be viewed as processes of bricolage, with respect to the contingent events of occasion, execution and purpose, and with respect to the bricoleur's characteristics of immediacy and directness in working with his inventory. *Occasion* is an external contingent, relating to what the project is, and why it is being done; *execution* is internal to the process (Levi-Strauss talks about communicating with the materials, but Louridas includes "the artist's style and skill"); and *purpose* is an external constraint, but looking to 'after the event', a 'dialogue' with the wants and needs of a future user.

Unselfconscious design (vernacular design) is characterised by tradition and directness – these force a bricolage process on the designer, by imposing these contingencies:

> *"Since tradition determines what constitutes a problem, it limits the purpose contingencies. Since it determines what materials can enter in the designer's consideration, it limits the execution contingencies. Since it determines the way the designer perceives the situation, it limits the occasion contingencies."*

In selfconscious design (professional design), these contingent events are no longer determined by tradition: the designer is free to determine them - indeed he is responsible for determining them. This freedom apparently contradicts the argument for selfconscious design as bricolage. However, Louridas argues that the difference between selfconscious design and unselfconscious design in this matter is not qualitative, but quantitative. The designer may be free to choose his inventory, but once it is chosen he has to design within it; he has to work within many constraints, "financial, environmental, social, regulatory and so forth…"; and he is not free to control the interpretation of his work. Moreover,

> *"this threefold liberation of the design process imposes significant demands on the designer. The designer must now possess special skills to handle the increased complexity of the design problem… It is, therefore, imperative to find ways to handle design complexity. Design-by-drawing is such a way. In fact, it is the major way and it is the most distinguishing characteristic of selfconscious design."*

Selfconscious design, by working with a model of the artefact, rather than the artefact itself, appears to contradict the bricolage characteristics of immediacy and directness in working with materials; Louridas proposes that this too can be resolved, by relating these to the context and level at which the designer is working: the unselfconscious designer is working at the literal level, the level of the artefact; the selfconscious designer is working at the metaphorical level, the level of the model, or representation.

Both unselfconscious and self-conscious design can therefore be viewed in terms of bricolage; both can be seen as a dialogue with the equivalent of the bricoleur's inventory: the 'contingent events' of occasion, execution and purpose. Differences arise partly as a matter of degrees of freedom or choice (a selfconscious designer has responsibility for selecting his 'materials and means of execution', within which he then has to work; an unselfconscious designer has the choices forced upon him by tradition; and a bricoleur chooses to work within the boundaries of his inventory) and partly as a matter of context (the selfconscious designer is working at the 'metaphorical' level, at the level of the model or representation, while the unselfconscious designer and bricoleur are working at the 'literal' level, at the level of the artefact).

Viewed this way, these are not different ways of working, but similar processes along the lines of Schön's model, one at the 'metaphorical' level of design representation, and one at the 'literal' level of the artefact:

> *"This is in accordance with the view of design as a reflective conversation with the situation at hand. In this view, design is a discussion conducted with the materials in the medium with which the designer works. It is a hermeneutic process, a process of iterative understanding."*

Louridas is primarily comparing two different types of design: traditional/vernacular, and contemporary/professional. He doesn't explicitly discuss differences between individuals although, as with Schön's model, an element of difference will arise from each individual's way of seeing the situation, and the skills and experience they bring to it. Nevertheless his comparison between design-by-drawing and design with materials is interesting within the context of this thesis, and his proposal that they are not different processes, but the same process on different levels.

The practice of design on which I am focusing does not fit neatly into Louridas' two categories. Most designer-makers are professionally trained designers, but they do not all work in a design-then-make fashion, where

> *"The object of design is primarily the diagram; this is translated to the real world object later on."*

Those designer-makers who prefer to work at what could be considered a 'literal' level do not conform to the profile of unselfconscious design where their process is bounded by tradition. Indeed, designer-makers as a body are characteristically viewed as pushing the boundaries of what is possible with materials. However, by dissociating the two elements with which he deals, designer-makers could be seen as more like selfconscious designers in terms of their freedoms within the process, while choosing to design primarily at either a metaphorical or literal level. This is in line with his view that differences don't relate to the process itself, but the context within which it takes place. So is my suggestion that there are in fact two quite different approaches spurious in the context of Louridas' argument?

It is worth emphasising that Louridas is not saying that design *is* bricolage, but that is can be viewed *as* bricolage. In the next section, I discuss a study from another discipline which also draws on Levi-Strauss's work and ideas on bricolage, but which proposes that individuals differ quite fundamentally in their approaches to design activities.

Turkle & Papert

In Epistemological Pluralism and the Revaluation of the Concrete and Epistemological Pluralism: Styles and Voices Within the Computer Culture Turkle & Papert describe the approaches which they observed both in children working with computer systems and in college students' programming styles (the ideas and quotations in this section come from these publications [Turkle & Papert 1990; Turkle & Papert 1991]). While the canonical approach to computer programming is structured, planned, and hierarchical, Turkle & Papert's research revealed a diversity of approaches and intellectual styles. They draw parallels with Levi-Strauss's metaphor of bricolage:

> *"Lévi-Strauss used the term 'bricolage' to contrast the analytic methodology of western science with what he called a 'science of the concrete' in primitive societies. The bricoleurs he describes do not move abstractly and hierarchically from axiom to theorem to corollary. Bricoleurs construct theories by arranging and rearranging, by negotiating and renegotiating with a set of well-known materials.*
> *Lévi-Strauss's descriptions of the two scientific approaches, divested of his efforts to localize them culturally, suggest the variety of ways that people approach computers.*

> *For some people in our study, what is exciting about computers is working within a rule-driven system that can be mastered in a top-down, divide and conquer way. This is the 'planner's' approach taught in the Harvard programming course… Lisa, Robin and others like them offer examples of a very different style. They are not drawn to structured programming; their work at the computer is marked by a desire to play with the elements of a program, to move them around almost as though they were material elements – the words in a sentence, the notes in a musical composition, the elements of a collage."*

(Note that Turkle & Papert's use of the term 'style' is different to my use when referring to a designer's 'personal style', as discussed in Chapter 1.) Turkle & Papert's research revealed two quite different approaches to programming: "we isolate two approaches which serve as ideal types, theoretical prisms through which to see simplified projections of more complex realities". Turkle & Papert designate these two types 'hard' and 'soft':

> *"The ideal typical hard and soft approaches are each characterized by a cluster of attributes. Some involve organisation of work (the hards prefer abstract thinking and systematic planning; the softs prefer a negotiational approach and concrete forms of reasoning); other attributes concern the kind of relationship that the subject forms with computational objects. Hard mastery is characterised by a distanced stance, soft mastery by closeness to objects."*

Within these two broad categorisations, an examination of Turkle & Papert's papers reveals several 'dimensions of difference', covering a wide range of aspects of the work and process. (These have been analysed in detail to contribute to the development of the analytical framework discussed in Chapter 7, ***Comparative study***; the main characteristics of each approach are described below.)

The *hard* ('planner') approach is characterised by control and conscious purpose. *Hards* focus on explicit goals; they predetermine the form of their work by planning, maintaining control of complexity by breaking the problem down, and imposing a hierarchical structure. They think algebraically: computational objects are viewed as abstract, and for their formal properties ('what they are for'). This preference for control is also seen in *hards'* attitude to unexpected events: risk is minimised, and mistakes are viewed as problems to be overcome. The *hards'* relationship with computational objects is objective, formal and distanced: they prefer to maintain boundaries between themselves and the details of the implementation, using opacity and 'black-boxing' to work at an abstract level. Their approach to thinking is characterised by analysis, abstraction and reasoning in terms of rules. *Hards* approach learning through analysis, and a desire to know how things are 'supposed to' work. In dialogic terms a *hard's* relationship with their medium could be characterised in terms of a monologue: the programming 'medium' is a tool to achieve a predetermined purpose.

In contrast, the *soft* ('bricoleur') situated, relational approach is characterised by negotiation and a willingness to 'forget yourself' and be open to experience. *Softs* have tacit aims which allow the form of the work to emerge through processes of negotiation with the medium. Complexity is handled through "a mastery of associations and interactions" by finding pattern or 'rhythm' within the work, or a process of 'growing' or 'sculpting'; it is therefore imperative to maintain contact with the details at all times. The *softs'* approach to risk is quite different to that of their *hard* counterparts: mistakes and unexpected events are seen as an essential part of the process of negotiation. The *softs'* close relationship with objects is subjective, concrete and situated, with a contextual approach to thinking characterised by transparency and a mastery of details, and concrete, bodily and intuitive forms of reasoning. Computational objects are viewed for their concrete or tangible properties ('what they can do'). The *softs*' approach to learning has similar characteristics:

> *"…the bricoleurs are happy to get to know a new object by interacting with it, learning about it through its behaviour the way you would learn about a person, while the planners usually find this intolerable. Their more analytic approach demands knowing how the program works before interacting with it. They demand the assurance that comes from transparent understanding, from dissection and demonstration"*

In dialogic terms, therefore, a *soft's* relationship with the medium could be characterised as a conversation: they achieve their goals "in a collaborative venture with the machine".

The following example illustrates some of these differences between the canonical 'formal' approach to programming and the 'soft', 'concrete' style of programming observed by Turkle & Papert. They discuss one student's approach to producing a Logo program which uses 'sprites'[8] – in her program birds fly over the horizon, disappear, and then reappear elsewhere on the screen:

> *"One method of achieving this end calls for an algebraic style of thinking: you make the program store each bird's original colour as the value of a variable, then you change all colours to invisible and recall the appropriate variable when the bird is to reappear. Anne knows how to use the algebraic method, but prefers one that allows her to turn programming into the manipulation of familiar objects. As Anne programs, she uses analogies with traditional art materials. When you want to hide something on a canvas, you paint it out, you cover it with something that looks like the background. Anne uses this technique to solve her programming problem. She lets each bird keep its colour, but she makes her program hide it by placing a screen over it. Anne designs a sprite that will screen the bird when she doesn't want it seen, a sky-*

[8] "A sprite is a second Logo icon… Once you give a sprite a speed and a heading, it moves with that state of uniform motion until something is done to change it…"

colored screen that makes the bird disappear. Anne is programming a computer, but she is thinking like a painter."

These descriptions of different approaches to programming, itself a creative activity, resonated very strongly with my earlier observations: the 'hard' or formal approach characterised by control, planning and working at the level of the representation had similarities with the design-then-make approach, while the 'soft' situated relational approach characterised by negotiation, transparency and a closeness to objects had its counterpart in those whose design develops through working with materials. This observation of similar differences in a quite different area suggested that there may indeed be underlying differences in approach between the designer-makers I observed, which relate to the relationship between each practitioner and the media they use in their creative processes.

The above studies are drawn from a number of different disciplines and areas of practice. However, similarly different models of the creative process and the relationship between practitioner and artefacts can be found within the discipline of writing. The chapter next discusses three studies of writing which relate closely in ideas to the studies by Goel, Schön and Turkle & Papert. All of these discuss the writer's relationships with external media, but from different viewpoints.

Sharples & Pemberton

Sharples & Pemberton's view of the writing process has strong links to Goel's view of the design process (the ideas and quotations in this section are from [Sharples & Pemberton 1992]). Like Goel, they are examining it from the viewpoint of cognitive science. Goel sees design as an 'ill-structured' or 'wicked' problem; Sharples & Pemberton see writing as "goal directed and decomposable into a series of subgoals", but where there is no well-defined goal state. As it isn't a "simple goal-directed search", general problem-solving methods are not appropriate; however, it can be viewed as "a goal-directed task governed by multiple constraints". Goel identified distinct phases in the design problem solving activity, and from an examination of the drawings produced, concluded that designers use different symbol systems which correspond to these different design phases, and thus facilitate different cognitive processes. Sharples & Pemberton describe writing as a sequence of stages (not necessarily linear), in each of which the writer may use different external symbolic representations to facilitate cognitive processes.

They discuss how previous models of the writing process, such as that by Flower & Hayes, have focused very broadly on the relationship between internal process and external representation. In their model Flower & Hayes class the main operations of the writing process as planning, translating and reviewing, where translating is "the action of taking material from memory, under the guidance of plans and goals, and transforming it into coherent sentences".

These and other studies have contributed to what Sharples & Pemberton describe as the 'consensus model' of writing:

> *"the picture of cognition and writing that has emerged from the past ten years of research is a goal directed task governed by multiple constraints. There is no simple progression from one stage to another, but instead a cycle of planning, text generation and revision, with the written words acting as triggers for further planning."*

Within this consensus, there is recognition that there are broadly different approaches to writing, which can be described in these terms: for example, Mozartian ("who produces detailed plans before text") and Beethovian ("who creates text to find out what he thinks, interleaving planning and translation").

However, this model of writing has a number of limitations: it does not differentiate between different types of external representations the writer may use; there "is no clear distinction between mental structures and analogous ones on an external medium"; and they also perceive the need for an "'intermediate representation', a bridge between mental structures and text, with some of the properties of each".

Sharples & Pemberton present a framework comprising different external representational structures that support different cognitive phases in writing [Sharples & Pemberton 1992]. Although they focus on cognitive processes, they recognise that this process is not independent of the medium, as the choice of medium constrains the process of writing, by influencing the construction of the symbolic representations.

This framework accommodates different types of 'external representational structures', along with techniques used to produce them (see Table 5). They propose that there are three types of text item a writer produces: instantiated items (pieces of connected prose, large or small); uninstantiated items or 'idea labels' ("index to a mental schema and as a placeholder for a piece of text still to be created"); and annotational items (a comment on another item – used in editing and revision). In this particular framework, they focus on the first two types. They propose that there are also three types of view: unorganised, non-linear, and linear. "Normally, non-linear views act as intermediate representations

	UNINSTANTIATED	INSTANTIATED
UNORGANISED	Techniques: • brainstorming Representations: • idea-labels	Techniques: • note-taking (verbatim) • collecting quotes Representations: • notes
NON-LINEAR ORGANISATION	Techniques: • following a thread • writing as dialectic Representations: • network of idea-labels	Techniques: • organising notes • filing Representations: • network of notes
LINEAR ORGANISATION	Techniques: • linear planning Representations: • list of idea-labels • table of contents	Techniques: • drafting text • revising text • copying text Representations: • linear text

Table 5: "A framework for describing the writing process" [Sharples & Pemberton 1992]

between the arrangement of items in the writer's semantic memory and the string of words in a finished text".

> *"The two dimensions, of* instantiation *and* view type*, characterise a writer's representation of items on some external medium"*

Within this framework of views (external representational structures), they define strategies as movements across views, operations as manipulating material within or between representations, techniques as "a means of creating all or part of a representational structure" (e.g. brainstorming) and methods as "techniques carried out on a particular medium". (The views or representational structures are therefore distinct from the methods and media used to generate them.) In their view, "one advantage of the six-box framework is that it allows an explicit distinction to be made between those processes which a writer carries out on some external medium, and those which are performed mentally or bypassed altogether". For example, "a writer who has already mentally assembled the material she needs for a document may begin at box 4 [e.g. organising notes] or even box 6 [e.g. drafting text]"

Like Goel, there appears to be a direct correlation between the external representations used and the mental processes going on. Further, like Goel, they conclude "that the choice of writing medium constrains the process of writing and influences the structure of these representations". Again, there appears to be little sense of dialogue in the manner that Schön describes: although the 'Beethovian' approach proposed by others might seem

to be along these lines – the writer "creates text to find out what he thinks, interleaving planning and translation" – it is more an internal cognitive process: "as the text emerges it serves to direct the search of long term memory and to constrain the selection and organisation of ideas". However, whereas Goel does not address individual differences in process (he focuses solely on sketching in the early stages of design, not on the whole 'design and make' process), Sharples & Pemberton provide a framework within which it is possible to map out not only those different approaches and strategies which have already been observed by a number of studies, but also to suggest other possible approaches, other sequences through the framework. Differences in approach relate to the sequence of stages the writer goes through, and those aspects of the process which they do mentally versus those for which they generate 'external symbolic representations'.

Sharples

In Writing as Creative Design Sharples extends this previous work "to consider the writer as a creative thinker and a designer of text" (the ideas and quotations in this section come from this publication [Sharples 1995]). In this model, writing is no longer viewed as a problem solving process, rather as a process where "the problem must be generated as it is being solved"; in this it has parallels to Schön's model of design with the shift from problem solving to problem setting. They have other similarities: Schön describes the designer as constructing their own unique design world; Sharples describes the writer as "a thinker in a self-constructed environment which affords, constrains, and mediates the writing process".

In his earlier paper, Sharples with Pemberton examined the variety of representational structures that writers may use within their processes, and described the writing process in terms of operations on and moves between these views. This later paper looks more broadly at the "interaction between creative thinking and the recording of ideas as text on an external medium". The emphasis is still largely on cognitive activity: the new model of writing is based around a model of creativity as the deliberate exploration and transformation of the writer's conceptual space:

> *"creativity involves setting appropriate constraints to form a conceptual space that is relevant to the writer's purpose, and then deliberately exploring and transforming it to create an original and valuable product"*

Sharples describes the process of writing in terms of two activities relating to the writer's conceptual space: 'engagement' and 'reflection'.

> *"writing involves both engagement (the direct recording of conceptual associations) and reflection (the deliberate and cognitively demanding process of re-representing embedded processes and exploring cognitive structures). An engaged writer who has created an appropriate context and constraints can be carried along by the flow of mental association, without deliberate effort."*

These activities are quite different. *Engagement* is the production of text through conceptual association: it requires "devolving full attention to the task of creating text", and is "guided by tacit constraint". Engagement involves tacit forms of knowing and thinking. "The act of transcribing into text is sequential and demanding, leaving no opportunity for deliberate mental exploration" - it is "thinking with the writing". What has been set down on paper acts "as a prompt for further association and writing" and "provides material for consideration". *Reflection*, on the other hand, is "the deliberate and cognitively demanding process of re-representing embedded processes and exploring cognitive structures". Reflection involves explicit forms of knowing and thinking. It is a process of standing back, "thinking about the writing", and reinterpretation.

Sharples proposes a model of writing as cycles of these two activities:

> *"in order to reflect on past actions we must be able to re-represent them as explicit mental structures… Reflection is an amalgam of mental processes. It interacts with engaged writing through the component activities of reviewing, contemplation and planning"*

He also uses this framework to explain differences in approach that have previously been be observed between writers: 'planners' and 'discoverers'. While he points out that most writers can, if necessary, adapt the way they work to fit other demands, for some writers the emphasis is on the generation of text by conceptual association, guided by tacit constraints, while others place a strong emphasis on deliberately exploring and transforming the conceptual space.

> *"Writers with a Planner orientation are driven by reflection - for these people, writing flows from understanding. They spend a large proportion of their time on exploring ideas and on generating plans and constraints to guide their composing. When they write, it is primarily to carry out a pre-prepared plan. Conversely, those with a Discoverer orientation are driven by engagement with the text - for them, understanding arises from writing. They may prefer to begin a writing task by scribbling out a draft which reveals their thoughts to them"*

The other significant difference between this and earlier models is the role of external media. In their previous study Sharples & Pemberton were concerned with different types of symbolic representations, and how "the representational properties of resources

affect the processes of idea generation and written composition" [Sharples & Pemberton 1992]. However, in Sharples' model of the 'writer as designer of text',

> *"the emphasis is not on problem solving, but on writing as design, with the task environment not just influencing performance, but extending cognition"*

External representations play a number of roles within the process: they act as external memory, they are used for communicating ideas to others and oneself at a later date, and they provide "a means of capturing intermediate products in a form that is intermediate between mental schemas and a finished text." However, more particularly,

> *"cognition is not simply 'expressed' or 'amplified' through the use of external representations, but rather the nature of thought is determined by the mind's dialectical interaction with the world as constructed by human beings. Notes, sketches, outlines, tables, topic lists, concept maps, and argument structures are both representations of mental content and things in themselves, new stimuli dissociated from the moment of their production and available for reinterpretation."*

This account that Sharples gives of writing has similarities to Schön's view of design as 'reflective conversation with the materials of a design situation', where a designer 'surfaces' their understanding of the problem in order to consider how to proceed:

> *"As a writer's thoughts are externalised in sketches, notes, drafts and annotations, these designs become grist for an iterative process of interpretation and redrafting"*

Sharples' cyclic relationship between the two types of activity - ***engage-reflect***[review, re-represent, contemplate, plan]-***re-engage*** - has similarities to Schön's process of 'seeing-moving-seeing'; Schön's 'unique design world' compares with Sharples' description of the writer's environment, with its mix of constraints, external and internal: "the schemas, inter-related concepts, genres, and knowledge of language that form a writer's conceptual space".

However, unlike Schön, Sharples discusses more particular individual differences in approach, characterising them in terms of those who are driven by reflection, with its emphasis on planning and explicit forms of knowing and thinking, and those who are driven by tacit engagement with the production of text. Sharples does not deal solely with the equivalent of 'design-by-drawing', working with models of the finished artefact. His writers are more akin to designer-makers, taking the writing from initial ideas to finished text. It is interesting, therefore, to compare his model of different approaches to writing with Louridas' contrast between 'literal' and 'metaphorical' design: the same process but at different levels.

Sharples concludes that this type of examination of the writing process needs to be extended:

> *"Accounts of writing as a cognitive process have been almost exclusively concerned with the writer's mental states and processes. There needs to be a corresponding study of external representations. It should provide an understanding of the type of marks and signs that the writer makes on paper or screen, the techniques for working with them, and the function that these external representations perform in recording, structuring and mediating cognition"*

Sharples himself makes a more extensive examination of the model of writing as creative design in How We Write: Writing as Creative Design [Sharples 1999]. In particular, he explores the relationship between the cycle of reflection and engagement (what he refers to as "the cognitive engine of writing"), the main activities of writing (planning, composing and revising), and the role of external representations. He also examines different composing strategies used by writers (as distinct from the Planner and Discoverer approaches or orientations towards writing); these are discussed further in Chapter 9, ***Discussion***.

Chandler

In The Act of Writing, his phenomenological study of writing, Chandler "highlights major processes of mediation involved in writing, including the writer's engagement with media such as language, the written word and writing tools". (The ideas and quotations in this section come from this publication [Chandler 1995].) He describes two quite distinct approaches to writing, like Sharples: 'planners' and 'discoverers'.

> *"Some writers (in my terms Planners) seem to regard thought as quite separate from the words they use in writing about their ideas. Planners write primarily to record or communicate what is already clear in their mind." "For Discoverers, the act of writing does not simply involve a transcription of ideas which are already clear in their minds: writing is a way of thinking."*

Chandler describes a number of more specific composing strategies used by writers (see Chapter 9, ***Discussion***), but he concludes that writers have an underlying orientation towards 'goals' or 'discovery':

> *"…it seems that the ways in which many writers habitually describe their experiences of the process of composition do focus either on* discovery *or on* goals. *Such terms of reference may be interpreted as polar extremes relating to a basic long term orientation towards the experience of composition."*

These different approaches can broadly be expressed through different metaphors of engagement with the medium of language:

> *"Those for whom language is experienced primarily as a tool which they use I will characterize here as Planners... those who tend to experience language as a medium which acts upon them I will refer to as Discoverers"*

Like Turkle & Papert's 'hard' and 'soft' approaches, Chandler's two orientations to writing are quite distinct 'ideal types', characterised by clusters of attributes concerning different aspects of the writing process, and which differ along similar lines to those observed in the studies of programmers.

A *planner*'s approach to writing is characterised by control and conscious purpose. They focus on explicit goals, and the form of the work is preplanned before writing commences. They emphasise 'product': writing is viewed as a tool, a means to an end. A *planner*'s relationship with language is objective: a *planner* acts upon the medium of language to express their ideas. Language is experienced as transparent: thought is separate from words; writing is used to communicate what's clear in the mind. Revision is largely an internal, mental process. Chandler quotes William Lutz:

> *"…'Before I write, I write in my mind. The more difficult and complex the writing, the more time I need to think before I write. Ideas incubate in my mind. While I talk, drive, swim and exercise I am thinking, planning, writing. I think about the introduction, what examples to use, how to develop the main idea, what kind of conclusion to use. I write, revise, agonize, despair, give up, only to start all over again, and all of this before I ever begin to put words on paper… Writing is not a process of discovery for me… the writing process takes place in my mind. Once that process is complete, the product emerges. Often I can write pages without pause and with very little, if any, revision or even minor changes'..."*

In contrast, a *discoverer*'s approach is characterised by discovery and an openness to experience. *Discoverers* have tacit aims which allow the form of work to emerge through playing with ideas, finding a pattern and shape within the writing.

> *"For John Cheever, there was a painterly sense of 'shape': knowing when a story was right was 'a question, I guess, of trying to get it to correspond to a vision. There is a shape, a proportion, and one knows when something that happens is wrong… I suppose that [with] anyone who has written for as long as I have, it's probably what you'd call instinct. When a line falls wrong, it simply isn't right'."*

Discoverers emphasise process: writing is viewed as a way of thinking and a "way of knowing". A *discoverer*'s relationship with language is subjective; they engage with the medium of language to find ideas, and have a sense of being 'acted upon' by the medium.

> *"[Quoting Russel Hoban] 'I'm not in the business of making clockwork novels which go from A to B when you wind them up. I'm at the service of the material that enters me. It takes me where it wants to go, and I might not know why I'm going there'… Evidently there is amongst some literary writers a sense of* being used *by language. Writers sometimes feel that the ideas for what they finally write have existed in their entirety prior to their conscious awareness of them, awaiting discovery… It is understandable that such accounts smack of mysticism to those whose experience of writing is quite different."*

(In his book, On Writing [King 2001], Stephen King describes his similar belief:

> *"…stories are found things, like fossils in the ground… Stories are relics, part of an undiscovered pre-existing world. The writer's job is to use the tools in his or her toolbox to get as much of each one out of the ground intact as possible."*)

Language is experienced as concrete and material, with externalisation and physical revision critical to the writing process.

> *"For Discoverers, visible, physical revision is of central importance, and writing is a way of thinking. Theirs is, to borrow W.B. Yeats' phrase, the 'thinking of the body': thought in spatio-temporal action. Such bodily thinking is often associated with art, but since Maurice Merleau-Ponty, phenomenological writers have emphasized the primacy of the body in everyday life, in clear contrast to the rationalistic emphasis on the mind. Whether or not thinking is sensed as a 'bodily knowing', revision is a* physical act *for Discoverers."*

Chandler concludes:

> *"…it is possible that Planners also 'revise' extensively, having interiorized writing to such an extent that such revision is largely mental rather than physical, making them less dependent on the visible word than Discoverers. Stephen Witte, an evident Planner, argues that Planners perform mental revisions on 'pre-texts'. Suggesting that Planners revise in their minds may seem to reduce the usefulness of any descriptive distinction between Planners and Discoverers. However, the need of Discoverers for physical revision may be the difference that makes the difference. Discoverers seem to need to play with their ideas and words as textual objects. Since they experience externalisation and spatialization as an integral part of their thinking they may be more sensitive than Planners to the characteristics of various writing tools and media."*

While his metaphors of language as tool-medium-environment may give insight into elements of my design-then-make, design-through-make and make-as-design categorisations, in terms of individual designers' relationships to their materials what is most significant is his assertion that

> *"descriptions in terms of Planning or Discovery are not simply different ways of describing the same experience: they represent quite different experiences reflecting basic orientations"*

As can be seen from these descriptions, the two approaches Chandler identifies have strong similarities to the two approaches observed by Turkle & Papert in their study of programmers. Like Turkle & Papert's distinction between 'planners' and 'bricoleurs', Chandler's distinction between writers who experience language as a tool, a medium or an environment suggests a more fundamental difference between individuals than the models used by Schön, Louridas, Pemberton and Sharples: that for some practitioners, their 'conversational' involvement with artefacts may be more than reflection on external representations, that creation itself happens through engagement with mediating forms. Moreover, it suggests that the extent to which artefacts mediate experience is a factor of

the relationship between the practitioner and the artefact, not an inherent property of the artefact itself.

Conclusions

This chapter has compared different models of dialogue which commentators from various disciplines have used to characterise the relationship between creative practitioners and the medium/artefacts with which they work, and examined the nature of individual differences in approach, if any, discussed by these commentators. This comparative review has identified literature from two quite different disciplines, writing and computer programming/epistemology, which describe fundamental differences between individuals in their approach to creative practice. Moreover, the differences described in each commentary are similar across a number of different levels of practice. Both Chandler and Turkle & Papert contrast two distinct approaches, 'ideal types' encompassing a number of 'dimensions of difference'.

The differences in approach identified by Turkle & Papert and Chandler can broadly be described in terms of the nature and extent of a dialogue between practitioner and medium, although the metaphors used by the two commentators are slightly different: Turkle & Papert describe the 'soft' or 'bricoleur' approach in terms of negotiation with the medium; Chandler's characterisation of the Discoverer-Planner distinction through different metaphors of engagement with the medium suggests an even stronger mediatory role for the medium in some practitioners' practice. Like Turkle & Papert, he stresses that these distinctions between approaches, although not absolute, are nevertheless significant:

> *"The spectrum of media metaphors... is perhaps useful in suggesting that to talk simply in terms of 'using' tools maybe as extreme a position as to talk solely of 'being used' by them: we both act on and are acted on by, transform and are transformed by, the media with which we engage (a phrase which I find more apt that 'use'). In the making of meanings both give and take are involved. Ends and means are not easy to disentangle. The* purposes *of a 'user' (we have no word for 'engager'!) not only shape but are also shaped by the* functions *of a medium. And mediating circumstances shift the locus of control. But noting the give and take of our engagement with media should not undermine the importance of differences which individuals experience in their relationships with media."* [Chandler 1995]

The characteristics of these different approaches appeared to correspond to the observations from my previous research, and the tentative ideas arising from the Artefact Study. This comparative review therefore suggests a model of diversity in design practice where differences exist between individual design practitioners which are more

significant than variation arising from each designer's personal style, unique experience, or working context; rather they represent wholly different approaches to design, elements of which relate to the nature and extent of a dialogue between practitioner and medium. It therefore leads to the second part of the thesis of this research:

> *that individual practitioners experience different relationships with the artefacts they create and work with in their processes, and* ***that elements of these differences can be attributed to the nature and extent of a dialogue between designer and media****.*

A systematic analysis of this literature, described in the following chapter, suggests the formal/concrete axis is an organising principle for differences in approach across disciplines and across a number of levels of practice. This analysis provides the analytical framework for an empirical investigation into whether the differences between practitioners identified in these other fields of practice could also be observed in two groups of 3D design practitioners, one working with digital media, and the other working with physical media.