Industrial designers’ attention to materials and manufacturing processes: analyses at macroscopic and microscopic levels

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FACULTY OF SOCIAL SCIENCES AND HUMANITIES
DEPARTMENT OF DESIGN AND TECHNOLOGY

INDUSTRIAL DESIGNERS' ATTENTION TO MATERIALS AND MANUFACTURING PROCESSES: ANALYSES AT MACROSCOPIC AND MICROSCOPIC LEVELS

BY

OWAIN FRANCIS PEDGLEY B.Sc. (Hons.)

A Doctoral Thesis
submitted in partial fulfilment of the requirements for
the award of

Doctor of Philosophy
of Loughborough University

(13 September 1999)

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Preface

A short preface has been included in this thesis on two accounts. First, research degrees in industrial design are uncommon. Before introducing the main text, it is worth alerting the reader to some of the obstacles that needed to be confronted during the research work. Second, the pursuance of a research degree has been a major personal undertaking for me; I would like to share some of my motivations.

If designing is taken in its widest sense to be a constituent of intentional activity (i.e., of activity intended to have some effect), the opportunities for learning about how different people design are vast. All sorts of human endeavours involve some form of designing. The concern in this current research is with designing in the specific context of industrial design practice. The body of knowledge that describes practising designers decision-making exists, for the most part, in the form of academic papers. There are notably few substantive texts on how skilled designers (from any area of the design field) think and work. As a direct consequence of this, it was necessary in this current work to pull together findings from quite diverse sources, in order to construct a robust framework for the analysis of design activity. The process that this involved was a lengthy one. It is surprising that more has not been done in the past to synthesise the findings of prior art relating to designing both as a basic human capacity and as a constituent of professional practice. The existence of a critical review of this kind would have brought greater efficiency to the literature search process. Even more surprising though was the difficulty of locating well researched, balanced descriptions of what industrial design is and what industrial designers do. It is hoped that future researchers will find the literature reviews contained in this thesis useable as starting points and building blocks for their own work.

The thesis has taken nearly a year longer to complete than I had first anticipated, but with hindsight I have no lasting regrets about this. I started my Doctoral work in October 1995, three months after my Bachelors Degree graduation. Having commenced the research not knowing quite where it would lead and to have covered the ground that I have is, for me, a personal achievement unsurpassed. As I had hoped, the activity of research has made me more appreciative of the scope and impact of industrial design
and of the complexity of designers' decision-making. I am certain too that the incorporation of the guitar project, as a practical component of the research programme, has helped me become a more considerate and thorough designer.

With this thesis I have pleasure in giving back something to design education and design practice, in return for much that my tutors and fellow students have given to me and inspired in me.

Owain Pedgley
Loughborough, September 11 1999
Introduction

Overview
Industrial designers are professionals employed in work known as 'new product development' (NPD) or 'product design'. The essential outcome of NPD is the creation of a new artefact or system in response to identified needs and/or desires. NPD is invariably a team effort calling upon the competencies of a diverse range of specialists, as shown in Figure 1. A NPD team generates and develops ideas in response to a design brief (a formal statement of needs and desires) and eventually completes a single detailed design proposal for manufacture.

The journey from a brief to a final proposal is a highly complex activity for which the designer will draw upon a combination of personal and external resources to succeed. The work in this thesis constitutes an investigation of designing, in the area of industrial design. The work is underpinned by the presumption that, in order to understand how designers think and work, it is essential to uncover precisely the resources that designers employ in the workplace. This is neither a new position nor a controversial one: the examination of the activity of designing has been at the heart of design researchers' aims for decades. Nevertheless the field is still underdeveloped. The need for further descriptive research, in order to build knowledge of what designers actually do when they are designing (and the contexts in which they work), continues to be highlighted [e.g., Hertenstein, Platt & Powell, 1997; Dorst, 1995; Bayazit, 1993]. To conduct such research it is necessary to document and analyse designers going about their everyday work.

Unfortunately, few researchers have taken up the challenge to study designers in their workplaces. A recent addition to the sparse literature has been work by Mitchell [1996], who interviewed leading people working in NPD and covered subjects including product semantics (meaning associated with the design and use of a product), non-designer participation in NPD and methods for strategic thinking. Texts on designing authored by practising industrial designers themselves are rare.
Overall, the picture of research into industrial design decision-making is of a body of knowledge that is comparatively underdeveloped. It is quite a task to find out about the kinds of decision-making involved in central elements of industrial designers' work (e.g., the development of the external shape of a product; the assessment of end-user needs and wants; the incorporation of ergonomic data into emerging ideas). The fact that little of substance has been published on what contemporary industrial design activity actually entails has implications for a number of groups of people.

**Group 1: Tutors and students**
As preparation for entering the design profession, it is vital that graduate students have an appreciation of the contemporary practices of professional designers. In order to better prepare students, tutors need to be conversant with those practices (but are currently not well served by available information). Research therefore needs to be conducted to (a) acquire knowledge of precisely what those practices are, and (b) develop an understanding of how professionals reach their high levels of attainment.

**Group 2: Information providers**
Companies who provide information for use in industrial design (e.g., printed texts, software, internet publications) need to (a) present the right kind of information, and (b)
deliver information in a manner that industrial designers can make ready use of in their work. In order to provide high quality support for industrial design, information providers need to know in detail how designers work and the kinds of resources they make use of and require. Such findings will come from empirical studies of designing.

**Group 3: Practising designers**

Designers can learn from exposure to other designers' work constraints, opportunities and procedures. Designers can bring something of other people's work into their own, contributing to their experiential base and professional development.

The current opportunities for research into industrial design decision-making are varied and wide-ranging. This thesis, however, focuses on what is potentially one of the most significant elements of industrial designers' work: what limits, widens and drives choices of materials and manufacturing processes for product proposals?

**A review of materials, processes and industrial design**

On two accounts, materials and manufacturing processes rank as paramount concerns in the development of any new artefact.

- An artefact is ultimately an assembly of processed material components or a single component of processed material.
- Of a NPD budget, 80% is typically committed (though only 5% spent) prior to the development and detailing of a product. The majority of this commitment originates from the proposing of a particular manufacturing route (i.e., choices of materials, processes and finishing). [Connolly & Watts, 1984:15]

An initial review of literature found that the role, significance, handling and apportioning of materials and processes issues in industrial design were poorly reported subjects and largely unexplored for such an important element of product design. Processed materials have both utilitarian and expressive uses [Flurscheim, 1983:9], but industrial designers' responsibilities for these have never been satisfactorily articulated. In most cases, materials and processes are reported as being important for industrial designers to take into account. However, few examples are given of the approaches that can be taken to decision-making, or the factors that will be shaping the generation of ideas. How much are industrial designers concerned about materials and processes? What actually
happens to make the transition from rough ideas to the final decision that a product will be manufactured from material x by process y?

Fundamental questions about the role of materials and processes in industrial design were raised in November 1996 on the Industrial Design Forum e-mail discussion group [IDForum mailing list, 1996]. The debate included contributions from practitioners and academics and indicated many areas of ambiguity that deserved close inspection; these have been incorporated into the literature reviews of Chapters Two and Three. The Industrial Designers Society of America (IDSA) has recently staked a high profile interest in its members' involvement with materials and processes, shown by a new internet web site [IDSA, 1998]. Members are asked to share their experiences as a powerful learning resource for their colleagues. Basic questions are posed, for example: 'why did you choose a particular material?' and 'why did you opt for a particular process?'. The aim of the IDSA web site is to build a comprehensive information source for practising designers. Its presence serves to underline the need for this current fundamental research.

Design epistemology
One branch of research in which there is a need to make headway is in how designers use different kinds of resources (e.g., knowledge and information). This branch of investigation is referred to as design epistemology. NPD is ultimately carried out in an engineering environment (because final proposals are invariably realised using industrial manufacturing processes), yet industrial design also has historic ties with arts and crafts based designing. There appears to be if not a conflict then a challenge for the industrial designer to confront here: if it is the case that artist-designers and engineers have distinct ways of knowing about (and attending to) materials and processes, how does the industrial designer combine the two (if, indeed, that is what is achieved)?

Incorporation of a practical element
As a graduate industrial designer, the author placed a high priority on including a practical element in the research programme. The author's designing featured as a major component of the enquiry for two reasons. First, as a substantial source of primary data on how designing progresses. Second, as a vehicle for testing and developing data collection methods appropriate to a detailed study of designing. As will be explained in

1 A detailed treatment of different authors' suggestions for what the components of 'resources' should include is given in Chapter Two.
Chapter Five, the difficulties of securing long-term commitment from other designers compounded the case for making the author's designing a central element in the research programme.

A project brief was set to design and prototype a polymer (plastic) acoustic guitar. The project is explained in full in Chapter Eight. A successful instrument has been produced and evaluated and is now an important addition to the author's design portfolio. Loughborough University has been granted a U.K. patent application\(^2\) and U.K. registered design rights\(^3\) for the instrument. With commercial exploitation, the University could recover much of its investment.

The nature of practice-based doctorate work in design is a topic of much current debate [e.g., Buchanan et al., 1999; Frayling, 1998; DRS (Design Research Society) mailing list, October 1997; Frayling, 1997]. A key topic in these discussions has been the role doctoral candidates' own designing can take in Ph.D. submissions. It is a secondary aim of this thesis to demonstrate one way of incorporating one's own designing into a doctoral degree programme. Although the designing spanned over two years as an intermittent component of the research project, this thesis is not a study of (or presented as a contribution to) guitar design. To be so, the reported work would need to reach beyond the limited bounds of materials and manufacturing processes.

Documenting design activity: macroscopic and microscopic views

The majority of empirical studies of designing commence with the capture of designers' actions and thoughts and progress to the analysis of the gathered data, in order to understand what designers do and how and why they do it. A common misconception is that the design professions involve work practices that are somehow mysterious and inaccessible and thereby inherently barred from detailed research study [Newbury, 1996]. This stance is understandable given that much reasoning is hidden away in a designer's mind, there generally being no need to make it public. Thought-through ideas can emerge on paper or as a physical artefact seemingly from nowhere. Despite these apparent hurdles, much headway has been made by researchers involved in capturing and analysing design activity (some of the results of which are reported in the literature reviews of Chapters One, Two, Three and Five).

The kinds of descriptions of designing that are advanced from analyses of empirical data fall into two categories, macroscopic and microscopic, referring to descriptions at contrasting levels of proximity to the observed activity.

---

2 UK patent application number GB99 199 22.6, filed 24 August 1999.
3 UK registered design right certificates 2074916 and 2074917, filed 23 May 1998.
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 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.

Empirical studies of designing tend to draw upon data from either short, controlled design exercises or, more rarely, from documentaries of less contrived designing. For the purpose of this thesis, a documentary of designers' decision-making is a longitudinal study based on data collected in parallel with, and in direct relation to, the carrying out of a designated design project. The majority of documentaries of designing have been made in areas other than industrial design (e.g., engineering, architecture, software) and almost wholly concentrate on analyses at microscopic levels. Fewer than a handful of documentaries have included analyses at a macroscopic level [Lee & Radcliffe, 1990; Radcliffe & Lee, 1989; Waldron & Waldron, 1988; Bucciarelli, 1984]. Of these, only the 1990 study is concerned with industrial design.

It is worth noting that past studies have not focused on any discrete element of a designer's work (e.g., attention to ergonomics, electro-mechanics, costing, styling) but rather have sought to describe decision-making processes independent of any particular element. This point is coupled with the goal of many researchers which has been to contribute to understanding of designing as a basic human capacity, separated from any particular profession (or at least any particular area of the design field).

A data collection and microscopic analysis method called 'protocol analysis' is dominant in past empirical research into designers' thinking. The method originates from psychology research of the 1920s. In protocol analysis, a video camera pointed at the designer's workplace records audio and visual data whilst the designer works and 'thinks aloud'. This thinking aloud is termed 'concurrent verbalisation'. The audio and visual data are later transcribed into a 'protocol' that becomes the subject of analysis. Protocol analyses have tended to be laboratory-based to make them workable (rather than conducted in naturalistic, real-world settings). The studied design activity has also
needed to be constrained in duration and scope and, therefore, has featured only a small fraction of what would be included in a full length project. These constrictions are probably acceptable to the researcher who wishes to capture only small segments of designing in order to make microscopic analyses.

The bias towards laboratory studies continues today, across different areas of the design field, presumably (in part) because in practice they are easier to manage than naturalistic studies. The most ambitious protocol analysis study of industrial design activity to date was made in 1994 at Delft University, Netherlands. The results were published in April 1995 as a special edition of Design Studies and, later, more comprehensively as a book [Cross, Christiaans & Dorst, 1996]. The imbalance away from macroscopic views and naturalistic settings is something which this study in part seeks to rectify, since better understanding of how designers work cannot be formed from microscopic views and laboratory-based designing alone [Dorst, op. cit.]. Macroscopic analyses have the potential to reveal the constraints and opportunities that shape designers' work.

The diary of designing

Protocol analysis is by no means a benchmark method for use in all studies of designing [Cross, Christiaans & Dorst, op. cit.]. There continues to be calls for the use of alternative, complementary techniques [Oxman, 1995; Kuffner & Ullman, 1991]. One of the key lines of work in this Ph.D. has been an evaluation of data collection techniques appropriate to a naturalistic, long-term study of real-world designing. High priority was placed on finding a data collection method that interfered as little as possible with normal design activity and that allowed for data to be collected on very focused elements of designers' work.

A lasting impression of past documentaries of designing is that they have not made enough use of sketch sheets and models (produced in the course of designing) or reported-back on what designers have to say about their own work methods. The latter is vital if one is seeking an accurate account of designing from the perspective of the designer (see Pedgley [1997b] for the author's intermediate work on this). Two data collection methods were finally selected for use in this study: (i) a 'diary of designing' study, used to collate documentary evidence of attention to materials and processes (especially in relation to sketch sheets and physical models); and (ii) semi-structured interviews.

An important point to note is that the diary was developed as a data collection instrument that the author would find workable over a couple of years on the guitar
project. One of the functions of the author's designing was to test early versions of the diary, before committing other designers to use it. This hands-on approach to developing the diary was used because it was not possible to say, in advance of first trials, what format of diary would provide rich data for the study; there was no precedent to follow. The diary of designing provides autobiographical, documentary evidence of designing contained in a combination of narrative and drawings. The diary is devised such that it can be stored as an archive prior to analysis.

**Scope of the enquiry and level of generalisation**

The overriding need in the enquiry was to identify the issues at the heart of industrial designers' involvement with materials and processes; to explore the scope and boundaries of the subjects. Surveys of practices (to yield statistics) were not appropriate for two reasons. First, the right kinds of questions need to be asked if surveys are to be successful. At the commencement of the enquiry, the body of knowledge relating materials, processes and industrial design was too underdeveloped for these questions to be formulated. Second, data collected through semi-structured interviews and case accounts yield far richer descriptions of designing than can be gained by general surveys. Surveys might be attempted when the underlying interactions of materials, processes and industrial design are better understood.

The chosen approach has been to limit the primary data collection to a small number of cases, spanning professional, graduate and undergraduate practices. Research based on a few cases is well known to be useful when (a) the investigator has little control over events (designing is a complex real-world activity); (b) the area under investigation is poorly represented in literature; and (c) the aim is to provide insight rather than general rules [Allison et al., 1996; Yin, 1994; Eisenhardt, 1989].

As a step towards a model of industrial designers' attention to materials and processes, cross-case comparisons have been made. Owing to the small number of cases involved in the study, conclusions stop short of making forthright claims for practices in general. For the same reason, the chief research questions (Chapter Four) have been stated as 'questions to be investigated' rather than hypotheses to be confirmed or refuted.

**Summary**

The Ph.D. programme comprises research about, through and for the purposes of designing [Archer, 1995]. It is research about designing because that is where the heart of the enquiry is based; finding out how designers work. It is research through designing
because a proportion of the primary data are derived from the author’s own practical design work. Finally it is research for the purposes of designing because the conclusions have a direct bearing on how one might approach designing a product.

The following primary data sources were used.

- A diary study of the author's guitar project. As far as the author is aware, this is the first substantial documentary of industrial design decision-making.
- Diary studies of two finalist design students' skydiving helmet projects (with accompanying post-diary interviews).
- Nine semi-structured interviews with professional industrial designers from consultancies and companies.
- Postings to the internet mailing lists IDForum [op. cit.] and DRS [op. cit.].
- Semi-structured interviews with a mechanical engineer and an artist-designer.
- Semi-structured interviews with two second year undergraduate designers.

All of the diarists and interviewees were male. Various literature reviews were undertaken to support the study, as below.

- The nature of research and Ph.D. degrees in design.
- The nature of decision-making in NPD and industrial design.
- Methods of capturing and analysing design activity.
- Materials, manufacturing processes and industrial design.
- The use of personal and external resources in design activity.

The thesis makes contributions to knowledge and understanding under the following headings.

**Materials and processes in industrial design (at a macroscopic level)**

The work culminates in a diagrammatic framework of the constraints and opportunities that shape industrial designers' decisions on the manufacturing route for product ideas. The nature of creativity with respect to materials and processes is identified.
Materials and processes in industrial design (at a microscopic level)
The work culminates in descriptions of the experiential base designers possess for
creativity with materials and processes, the kinds of information sources that are
consulted and the nature of 'mind's eye', 2D and 3D modelling.

Methods of capturing design activity
The work culminates in the implementation and evaluation of a novel 'diary of designing'
as an instrument for capturing design activity.

The implications of the findings of the research for industrial design education and
providers of design information are discussed. A summary of the research programme is
shown in diagrammatic form in Figure 2.

* These terms are explained in Chapter One.
The nature of research and PhD degrees in design

The nature of decision-making in NPD and industrial design

Methods of capturing and analysing design activity

Materials, manufacturing processes and industrial design

The use of personal and external resources in design activity

Laying the groundwork for the study and devising the programme

Pilot interviews with two second year undergraduates and crafts/engineering designers

Data collection methods tested, evaluated and developed

Polymer acoustic guitar design & development

Interviews with nine professional industrial designers

Generation of a diary of designing

Support diary studies of two final year undergraduates working on a skydiving helmet

ANALYSSES OF DESIGN ACTIVITY

Preparation of final thesis chapters, including discussion and conclusions at macroscopic and microscopic levels

Figure 2: The research programme
SECTION ONE

A framework for analysing designers' attention to materials and manufacturing processes
CHAPTER ONE

Industrial design in context

Introduction
This first chapter, and Chapter Two, have two principal purposes. First, to define the terminology used throughout the thesis. Second, to identify some underlying concepts of designing presented in literature that have helped researchers to explain the ways in which designers work. This first chapter commences with a section on industrial designers' responsibilities in NPD, in order to state the author's position in relation to these.

Industrial designers' responsibilities in NPD
The term 'industrial design' originates from a period predominantly in the early twentieth century, when art school trained designers and craftspeople (sometimes referred to as artist-designers) were asked to divert their skills to products made by manufacturing industry. Today's industrial designers are, typically, members of NPD teams, working on products that are usually physical artefacts to be produced in large volumes by industrial manufacturing processes. Industrial designers are employed in consultancies and manufacturing companies (where they work as 'in house' staff designers). A few choose to work freelance as self-employed designers.

A NPD team consists of a number of specialists with competencies that complement those of colleagues. Wood & Ullman [1996:202] describe the composition of a typical plastics product design team (overleaf). Their observations act as a good starting point for describing industrial designers' responsibilities in product design.
Industrial designers, experts in human factors engineering, ergonomics and aesthetics, develop features that directly interact with the customer and provide overall form. Mechanical design engineers develop the components that make up the product. These components fulfil the functions that the customers specify. Tool designers add and modify features necessary for component manufacture. Plastics process engineers also affect the design and the features to ensure that the plastic material will flow and cool as needed by the tool designer.

One primary task undertaken by industrial designers (although not exclusively) is the determination of a product's functions, which may notionally be subdivided into:

- those providing utility (i.e., usefulness; included for practical gain);
- those providing expression (i.e., bringing character and meaning to a product with no enhancement of utility).

These subdivisions can rarely be attributed exclusively to any given component of a product; those components that interact with end users, in particular, are likely to have a degree of both utilitarian and expressive function. For example, the front panel of a loudspeaker needs to provide, amongst other things, the structure to which a speaker cone can be fastened (utility) but also needs to look attractive and fit into an intended environment (expressive).

A tentative description of an industrial designer's specialism within NPD is as follows. Industrial designers configure a product so that utilitarian and expressive functions fit the human anatomy, "astonish the human senses" [Pankhurst, 1998] and are suited for use in an intended environment. The latter is intentionally vague because it can differ markedly between products (e.g., providing water protection for a diver's watch; striving to make a park bench look in keeping with its surroundings; attempting to make a security camera inconspicuous; ensuring that a broom can do a good job of sweeping leaves on a lawn).

Fits and sensations to the human body come primarily through contact with the outside surfaces of a product and so control of a product's external, three dimensional form (e.g., shapes, patterns, textures, colours, layout of controls) is a prerogative of the industrial designer. The outside surfaces of a product can be an assembly of casings that shroud internal electromechanical components (as with, for example, a laptop computer, a coffee grinder and a camera lens) or the surfaces can in themselves provide the majority of a product's utility (as with, for example, a pair of scissors, a camera tripod and a Frisbee). Since the outside of a product is often what a customer is first confronted with (before making any assessment of utility), industrial design is crucial to making a favourable impression [Hollins & Pugh, 1990:91].
The external form of a product is not determined arbitrarily. Good reasons exist for the form that products take, driven by many technical, marketing, physiological, psychological, social and cultural factors, coming from the work of all sections of the design team as well as the industrial designer's own concerns. A popular belief is still held, however, that industrial designers do little more than styling and that they are not informed on technical considerations. Most recently this belief was expressed to the author by a number of delegates at the Fifteenth Conference of the Irish Manufacturing Committee (IMC-15), held at the University of Ulster in 1998.

The level of technical aptitude required of a designer (and the kinds of final outcomes to be expected from a project) differs between briefs [Bates & Pedgley, 1998]. A designer's technical proficiency will be a reflection of both formal training and on-the-job experience. In the U.K., Industrial Design degrees differ quite widely in their technical content [Myerson, 1991] but overall, engineers are widely regarded as technically more astute than industrial designers [Pace, 1997]. Nonetheless, one Australian product development engineer has commented on a recent decreasing polarity between what these two representatives of a NPD team actually do [Heller, 1997].

Increasingly [engineering and industrial design] ... are 'professions of one' where each one of us brings our own particular mixed bag of tricks to the party hoping we can get past the doorman to where the action is. The skills in this bag will cross the traditional professional boundaries to form what is required to be a 'Sony' Designer or 'Philips' Designer or 'Whatever Company You Want To Work For' Designer.

One way of distinguishing any given area of the professional design field is to identify the kinds of tangible outcomes that are normally generated. Areas such as furniture design and software design are self-explanatory but in this respect 'industrial design' is not a helpful term. The range of products from manufacturing industry is enormous, from, for example, state-of-the-art electro-mechanical devices such as components for a microwave oven, through to simple structures such as shelving and cutlery. It is a hopeless (and in some ways misleading) task to seek a watertight boundary for the kinds of products that are suited to industrial design input, but some trends are apparent.

Input into the design of internal working parts of products is less relevant to industrial designers because, in use, these parts have little or no intended contact with people [Ulrich & Eppinger, 1995]. In addition, the design of internal working parts will often require a level of engineering expertise that is beyond the competency of an industrial designer. These parts do have user interaction at other times however (e.g., during assembly, installation or repair) and could therefore benefit from an industrial designer's input. One group of products for which industrial design input is particularly on show is 'consumer goods' [Blaich, 1995]. These are marketed products for which designing for
the needs and wants of a target population is very important (Figure 3). It can be said that the upshot for industrial designers is that their efforts should result in a memorable experience for the users of their products [Pankhurst, op. cit.; Stoddard, 1997].

Figure 3: An example of a 'consumer good', the Nokia 232 mobile telephone  Reproduced with permission of Nokia Mobile Phones Ltd

Sir Terence Conran has expressed this view too, seeing the best of industrial designers' work as "...objects of desire which are a pleasure to own, a pleasure to use and a pleasure to behold..." [quoted in de Noblet, 1993:8].
In conclusion, it is inaccurate to speak of 'industrial design aspects of NPD' because this gives an impression that industrial design can be 'tacked on' during a product's development (see Black [1964] for a discussion of this). Industrial design is closer to an individual approach to designing: a "methodical creative procedure that can be applied to all problems of conception." [French designer Roger Tallon, 1961, quoted in de Noblet, op. cit.;242] Roger Tallon was perhaps being too vague and far-fetched there, but his vision fulfils the task of freeing industrial design from the bounds of any particular class of product.

**Design problems and problem-solving**

Everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state. [Simon, 1981:129]

This quotation from Simon underlines a fact that designing is far from the exclusive preserve of the professional designer. Besides being prominent in many people's employed work, design activity is more or less a constituent of most everyday tasks (e.g., devising a shopping route around a town; composing a letter). Taken in its broadest sense, designing is a basic human capacity, put to use when engaged in intentional activity: that is, when intending to have some effect. It is characterised by (although not limited to) the use of forethought, imagining the future and lessening the need for trial-and-error decision-making. This is a fitting description of the work practices of many professions. An account from Buttermore [1998] explains more.

Having been both [a meteorologist and an industrial designer] I can say that they are not really so different at all, at least not in my case. Both fields analyze various data and (...) project outcomes into the future. Weather forecasts and design 'solutions' are both future scenarios that only have some reasonable degree of probability of occurring as we envision them. Only the data, tools, and presentation materials are really different. The other differences are of a more personal nature (style, background, opinions, influences, etc.) and vary between individual designers as much as with those in other fields.

Turning attention to industrial design, a characteristic of many design problems (especially as presented formally in a brief) is that they contain a complex of missing information, inexplicit requirements and conflicting demands. Problems in environmental
planning have many similarities to design problems. Rittel & Webber [1974] characterised planning problems as 'ill-defined' or 'wicked' problems, which, in fact, offers a high-level characterisation of design problems in general. When tackling a product design project, therefore, it is as necessary to define and understand the problem(s) as it is to propose resolutions [Pedgley, 1996; Simon, op. cit.]. The process of 'getting to know' a project can lead to the boundaries of underlying problems and point towards information, not made explicit in the brief, that may be relevant.

It is often not the case that a design problem can be fully understood prior to the generation of resolutions. In the process of designing, one learns more about the issues that are important to a project [Norman, 1997; Cross & Cross, 1995; Schön & Wiggins, 1992; Jones 1992; Cross & Nathenson, 1981]. One's conception of what a project requires and one's capability to piece together disparate information improves over time [Walz, Elam & Curtis, 1993]. Ideas for how a product might look and be configured will change as a result of the learning, as will ideas for how to proceed for the remainder of the design work. Hence, at the commencement of a project, the work that will be covered later can be only partially envisaged. At BIB, a leading U.K. design consultancy, a period of learning is set aside on a project before 'designing proper' is embarked upon.

The success of any project depends on the clear definition of the aims and objectives right from the start. It is vital therefore to establish the project's parameters with our clients before any work is initiated.

[BIB Design Consultants, 1997:17]

Whilst the inherent open-ended nature of industrial design problems demands that the designer exercises judgement on project priorities and direction, it does mean that there can be no point at which designing is truly exhausted or an ultimate end is reached. "Individual designers can form their own, possibly idiosyncratic understanding of the problem." [Cross & Cross, op. cit.:144] One designer's goals for a project might be quite different to another's tackling the same brief. Translated to NPD, many alternatives to the eventual final proposal (and alternative ways of designing) will probably be considered in the course of the work. Had these alternatives been pursued, the resulting end product would probably have been different. The net result is that it is not meaningful to evaluate a given end product as a 'correct' or 'incorrect' resolution of the original design problem(s). Instead, a degree of 'success' should be established. The most objective measure of that success is against the quantitative and qualitative demands that were contained in the original brief and product design specification (PDS)\[^5\]. End users do not

\[^5\] The PDS is a working document used by designers to quantify and qualify the various performance targets and specifications that a new product needs to meet.
have these documents and so their evaluation is more vague and made against some personal criteria which may or may not be duplicated in the PDS.

**How can design decision-making be described?**

It was stated in the introduction to this thesis that many studies of decision-making have been made in the design field but that industrial design was poorly represented among these. In order to establish basic concepts that underlie decision-making in industrial design it is therefore necessary to look mostly to other areas of the design field for advice. Many authors have put forward concepts that are applicable to professional design activity in general and it is to these references that the next sections will refer. By combining the findings and ideas of researchers in different areas of the design field, it is intended that a balanced view of designing is presented.

In the following sections, design activity is split into views at macroscopic and microscopic levels. With this approach it is first necessary to issue a note of caution. Whilst the distinction is very useful for categorising design activity, it would be unwise to consider the two views, from the designer's perspective, as mutually exclusive. Switches between macroscopic and microscopic levels of attention are likely to be in evidence during a project, and attention at one level will probably feed off of the other.

**Design activity viewed at a macroscopic level**

The primary phases of NPD, from a 'mission statement' (or brief) through to a 'product launch' are shown in Figure 4. Although far from a comprehensive description, Figure 4 succeeds in showing an initial deliberate divergence of design possibilities (in which ideas are generated and explored) through to a gradual deliberate convergence of possibilities towards a single, final product. The process of convergence towards a final proposal is an iterative one, where designing progresses as a gradual resolution and improvement upon earlier work [e.g., Gebala & Eppinger, 1991; Akin, 1979]. Figure 4 fails to show some of the feedback loops that are now in place between 'production ramp-up' and 'system-level design' in contemporary NPD. These loops serve to reduce the number of shortfalls that are picked up during each phase of NPD (that would otherwise be larger if a solely linear process were followed) [Pankhurst, op. cit.].
The kinds of work typically involved in the different phases of NPD are as follows.

- **Concept development.** Formulation of a combination of embryonic ideas and feasible proposals (concepts), probably covering several different perspectives on the brief.
- **System-level design.** Refinement of a chosen concept into a feasible product proposal (in engineering traditions this is often referred to as the 'embodiment' phase).
- **Detail design.** Determination of engineering details for the manufacture of each component of the product proposal.
- **Testing and refinement.** Construction and evaluation of pre-competitive prototype versions of the product.
- **Production ramp-up.** Manufacture of the product using the intended production processes.

A launched product is nearly always subject to modification, so even though the bulk of development work may be completed in the phases described in Figure 4, development does not really come to an end until the product has ceased to be manufactured [Design Business Association, 1992:8]. In fact it is doubtful that design activity ever comes to an end. A product might have ceased to be in production but, over time, it would be difficult to resist revisiting the design of that product in one's mind, even though it is too late to implement changes.
Within the transition from a brief to a final proposal, there is no particular way that one should go about designing [see, for example, Jones, op. cit.]. In the author's experience, undergraduate designers tend to follow their own ad hoc methods, driven by a unique set of priorities laid down partially by the student and partially by the demands of an individual project. In any given project there are likely to be episodes of work calling for structured analyses and others calling for imaginative approaches to their resolution. Some authors have attempted detailed macroscopic descriptions of designing, notably through the use of flow diagrams. A problem with these is that they are usually more prescriptive than descriptive and provide little information of what designers actually take into consideration. The results are generally too simplistic (e.g., Figure 5) or, occasionally, too complex (e.g., Figure 6) to be satisfactory macroscopic descriptions of design activity.
Figure 5: A basic flow chart of a design process (for product material selection)
Reproduced from Connolly & Watts [1984] with permission of the IEE
Figure 6: A complex flow chart of a design process. Reproduced from Asimow [1962] with permission of Prentice-Hall
Design activity viewed at a microscopic level

The description of designing presented at the start of this chapter, applying forethought before practical action, becomes less robust if one takes a microscopic view of the activity. A case in point relating to pottery was described by Professor Martin Woolley [1998] in his Inaugural Address at Goldsmiths' College, University of London. He observed that clay on the hands of the potter alternates between being part of the potter, part of the process of designing a product, and part of the end product itself. Thus designing, especially when coupled with practical action, can happen quickly (if not spontaneously) in a process that is more likely to rely on reaction and feedback than forethought. Serendipitous designing has its place in such a context.

Two quite different explanations for how designing progresses on a microscopic scale have been nurtured by researchers, from the original ideas of Herbert Simon and Donald Schön. For Simon [op. cit.; 1973], designing is a process of rational problem-solving, where order is imposed on data and progress is made in a planned, structured manner. Simon's description has found limited favour with researchers. This position is unsurprising given the wide acknowledgement that designing involves much learning along the way and that, without first engaging in the activity, one can have only a partial understanding of a design problem.

Schön [1983] sees designing more as an intimate, personal and less predirected process, where a conversation between the designer and the designer's ideas is necessary to reach an outcome. Decision-making in design is "...a process in which, interactively, we name the things to which we will attend and frame the context in which we will attend to them..."; a move is then said to have been made once the attention is given [ibid.:40]. The resultant adjusted state of affairs is then reflected upon. This reflection can be either "on" or "in" the activity of designing [ibid:55] and will direct the designer to subsequent areas in need of attention.

Work is currently underway at Delft University to see how good a fit Schön's 'reflective practice' description is to the work of engineering design students [Dorst & Valkenburg, 1998]. As part of this work, a tidy diagram of the mechanism of reflective practice has been developed (Figure 7). One feature of this diagram that is currently missing is a second feedback loop from the reflection, directed into other frames or initiating new names.
Reflection works by the designer looking back on actions and asking, for example: 'What features do I notice when I recognise this thing?'; 'What are the criteria by which I make this judgement?'; 'How am I framing the problem that I am trying to solve?' [Schön, op. cit.:50]. Schön notes that a reflective conversation can be considered as "...the 'art' by which practitioners sometimes deal well with situations of uncertainty, instability, uniqueness and value conflict." [ibid.:50] A reflective conversation relating to choices of materials and processes for a product (in this case an ice axe) might conceivably work as follows.

1. The designer sketches cross-sections for a new ice axe.
2. "Ah ha! I need to design the shaft so that the user’s hand will not slip down it." (The shaft is NAMED and ‘the prevention of hand slippage’ is FRAMED).
3. An ergonomic shape may be developed to create a comfortable non-slip grip. (A MOVE is made).
4. "What material would this be made from then?" (REFLECTION is given on the result of the MOVE, perhaps initiating thoughts on non-slip materials or non-slip textures that could be applied to the shaft).

Other authors have identified a ‘move’ as a fundamental unit of designing [e.g., Goldschmidt, 1995], and some have likened it to a mode of enquiry consisting of a conjecture ('what if...?') followed by a query of confirmation ('has it...?') [Kuffner & Ullman, op. cit.; Hillier, Musgrove & Sullivan, 1972]. The identification of 'moves' was a common feature of many of the microscopic analyses of design activity made as part of the large Delft University study [Cross, Christiaans & Dorst, 1996]. A move may be considered as the action taken to adjust a current state of a design idea into some other
(desired) state. The action will be triggered from a starting point determined\(^6\) by the designer, termed the 'primary generator' [Darke, 1979]. Hillier, Musgrove & Sullivan [op. cit.:255] have discussed the nature of this starting point.

...conjectures do not, on the whole, arise out of the information [in front of the designer] although it may contribute heuristically. By and large they come from pre-existing cognitive capability- knowledge of instrumental sets, solution types, and informal codes, and occasionally right outside- an analogy perhaps, or a metaphor, or simply what is called inspiration.

Embedded in this quotation are two further key concepts in design activity, those of modelling (a process by which designers explore ideas) and seeing (i.e., how, with imagination, something will be construed as beyond what is obvious to the naked eye).

**Modelling**

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 usefully be 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).

\(^6\) In practice, the starting point might be the result of a tacit knowing as much as a verbally expressible decision. Chapter Two deals with this in detail.
Although they can be considered as categories in their own right, 2D and 3D modelling can also be considered as external manifestations of cognitive modelling. For example, in the case of the ice axe design mentioned earlier, the designer might have envisaged a hand pressing down on the drawing of the ice axe shaft, anticipating what problems there would be with the design as it stood (cognitive modelling), and drawing the alternative designs that come to mind (2D modelling). Cognitive modelling is a remarkable human capacity. Everyone is familiar with images 'in the mind's eye', with the possible exception of people who do not dream [Ferguson, 1992]. The 'mind's eye' is often thought of as a visual organ but the modelling capacity (of the mind) can operate with eyes closed and provide sensations of sound, touch, smell and taste too [McKim, 1980; Archer & Roberts, 1979].

The mind's eye, spontaneously active in dreaming, can also be considerably directed. Unlike the sensory eye, which is bound to the here-and-now, the mind's eye can travel in space and time to the there-and-then, can entertain fantasy, can form, probe, and manipulate structures and abstract ideas, can obtain insight into realities that have not yet been seen, and can foresee consequences of present plans. [McKim, op. cit.:87]

Given McKim's observations, the importance of cognitive modelling in designing is plain to see. Even so, the structure of designers' modelling is not a well understood subject; little can presently be said beyond anecdotes. McKim talks of 'visual thinkers'. Designers, with their use of modelling, fit very well into this category, as illustrated by the following passage.

Visual thinkers utilize seeing, imagining and drawing in a fluid and dynamic way, moving from one kind of imagery to another (...) ...prepared with a visual understanding of the problem, they imagine alternative solutions. Rather than trust to memory, they draw a few quick sketches, which they can later evaluate and compare. Cycling between perceptual, inner and graphic images, they continue until the problem is solved. [ibid.:9]

Seeing and imagining, as cognitive abilities associated with modelling, have been presented as fundamental to how designing progresses [Schön & Wiggins, op. cit.]. They are discussed in more detail in Chapter Two.
Design synthesis

This is the final underlying concept of design activity to be included in this chapter and involves, in the face of conflicting requirements, the pursuit of a well-balanced final outcome. Any given line of work has its sets of considerations to be made and options to be sorted. In design practice, the juggling of considerations and options is a dominant and defining task central to the pursuit of a well-balanced final outcome. Success in the task is often referred to as having reached integration or design synthesis [Mayall, 1979] and can be a very satisfying experience. Synthesis is more likely to be achieved if one knows what works in opposition to what, and what works in harmony. Components for synthesis in NPD can include: findings of market analyses, user assessments and ergonomics evaluations; ideas for product-user, product-environment and product-product interactions; proposals for mechanical, electronic and electro-mechanical layouts and proposals for manufacturing routes and assembly.

Summary

This chapter has identified and discussed a number of key concepts defining design activity, with particular reference to NPD and industrial design.

- The responsibilities of the industrial designer within a NPD team have been indicated and the scope of the work discussed. The industrial designer's essential specialism has been identified as the control of a product's external, three-dimensional form, comprising shapes, patterns, textures, colours and layouts.
- The capacity for designing can be regarded as a basic human capacity.
- Industrial design problems are ill-defined; their resolution benefits from an element of learning during the design activity. Resolutions should be regarded as more or less successful rather than correct or incorrect.
- A macroscopic view of industrial design activity shows: (a) an initial divergence of ideas followed by a trend of convergence towards a single end proposal; and (b) that designers are not bound to follow any specific route or methods.
- A microscopic view of industrial design activity shows: (a) that the activity can be regarded as a process of 'rational problem solving' or 'reflective practice'; and (b) that a 'move' can be regarded as a fundamental unit of designing, initiated from a starting point termed the 'primary generator'.

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- A note of caution was issued stating that macroscopic and microscopic levels of attention are likely to be intertwined.
- Cognitive, 3D and 2D modelling are central concepts in design activity.
- The pursuit of a well-balanced final outcome is a dominant and defining task in design and its achievement is referred to as 'design synthesis'.
CHAPTER TWO

The use of personal and external resources in NPD

Introduction

Every object made by man is the embodiment of what is at once thinkable and possible. (...) Every object made by man is situated at an intersection of lines of development of thought (models, cultural structures, forms of knowledge) with lines of technological development (availability of materials, transformation techniques, forecasting and control systems). This interaction between what is thinkable and what is possible, which we refer to as design, is neither simple nor straightforward.
[Manzini, 1986:17]

The industrial designer is a new phenomenon- he is interdisciplinary- he has to use the knowledge belonging to many disciplines but in an entirely new way.
[Arthur Pulos, then Professor in Charge of the Industrial Design programme, Syracuse University, USA, quoted in Black, 1964:12]

These two quotations set the scene for this chapter. The second of the quotations comes from a discussion of the nature of industrial design and the character of the designer, made thirty five years ago. It is now well established that industrial design requires competency in a wide range of technical subjects [e.g., Myerson, 1991], but what exactly is meant by a 'new way' (or, perhaps more accurately, a distinct way) of using knowledge from different disciplines? The fact that industrial design emerged partly from the combining of arts, crafts and engineering traditions leads one to the reasonable assumption that something of each of these remains in contemporary practice. But what?

Also, what is meant by 'using knowledge' when designing?

To answer these questions, this chapter presents insights from reading in the area of epistemology. Epistemology is a wide-ranging subject that is often accompanied with discussion on matters of psychology and physiology. These matters have been purposefully avoided in this current work. The focus is instead on the establishment of
the conceptual framework and terminology needed to collect and analyse empirical data on design activity. Even within this context, epistemology is not a simple subject.

Given that little has been written on industrial design epistemology, one must assume that the findings of research and anecdotes from other areas of the design field are (at least partially) applicable to industrial design. Either way, without empirical evidence of industrial designers' particular use of resources, one is restricted to theory and speculation. The focus of the chapter is on designers' attention to materials and manufacturing processes, although the ideas contained in the text have relevance beyond just that element of designers' work. The chapter culminates in a comparison of artist-designers' and engineers' ways of attending to materials and manufacturing processes. Findings from interviews with a ceramics designer and a mechanical engineer are considered as part of this final section.

What is a resource?
Resources are defined in the Cassell Concise English Dictionary [1994:1142] as "a means of aid, support" and the "capacity for finding or devising means". If one reviews published work that makes reference to designers' resources, a variety of terms can be collected (Table 1). Resources can be considered as either (a) personal (i.e., residing privately in an individual person) or (b) external (i.e., recorded "external to a human mind" [Rodgers & Clarkson, 1998:253]).

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Table 1: Terms used in literature to refer to designers' resources
Each of the terms listed in Table 1 will be discussed in this chapter, but with avoidance of learning theory (i.e., how an individual generates or acquires knowledge). The primary concern throughout the chapter is to establish workable distinctions between the various personal and external resources that designers use in their day to day work practices.

Definitions of external resources

For the purpose of this thesis, all external resources are classed as sources of information. Information can be split into: (a) that which is received but not sought (e.g., when literature is 'happened across' or when a colleague volunteers advice) and (b) that which is actively consulted (e.g., where one makes a purposeful effort to find something out). Marsh [1997] provides exemplary coverage of the kinds of information that engineers use, and identifies the most frequent source as contact with colleagues (i.e., other people's personal or external resources). In a similar study, Court, Culley & McMahon [1995] observed that for twenty engineering projects, the most frequently accessed information sources were colleagues, employees, internal reports, drawings and supplier catalogues. Powell & Nichols [1982] reported that of thirty interviewed architectural designers, twenty eight had a private library of information sources with which they had become thoroughly familiar. The findings of research into designers' use (and rejection) of particular sources of information (and perhaps, by implication, particular formats of information) are valuable to companies involved in supporting designers' work practices.

It has been an aim of some design researchers to distinguish 'data' from 'information' [e.g., Andersen, 1998; Rodgers & Clarkson, op. cit.] but the workaday differences, as confirmed by dictionary definitions, are not clear-cut. 'Data' are defined as "facts or information from which other things may be deduced" and 'information' is defined as "intelligence communicated; notice, knowledge acquired; facts, data" [Cassell Concise English Dictionary, op. cit.:329&701]. For the purpose of analysing design activity, it is probably more beneficial to describe the form in which information is presented or represented (e.g., diagrams in an instruction leaflet, a telephone conversation, a stream of numbers, a colour), rather than dwell on whether it is data, rather than information, that has been consulted.

Information use can be regarded as a key step in designers' acquisition of new knowledge. As such, information sources and information use are revisited throughout this chapter.

Definitions of personal resources

It is widely reported that designers rely heavily on memory (i.e., personal resources) and infrequently make a concerted effort to consult information [in architecture: Lera, Cooper
& Powell, 1984; Mackinder & Marvin, 1982; in engineering: Marsh, op. cit.; Court, Culley & McMahon, op. cit.; in industrial design: Cross & Cross, 1995; in designing generally: Lawson, 1990]. Personal experience is immediately accessible and judged by designers to be reliable and more "palatable" than comparable printed information [Mackinder & Marvin, op. cit.:10]. Newland [1990] made a thorough investigation of architects' avoidance of information. He concluded that much of the behaviour could be traced to an individual's learning style and colleagues' readiness to share experiences. But what exactly is 'experience'? When it has been necessary to describe a designer's competency, researchers have used the terms 'ability', 'capability' and 'experience' more or less interchangeably. These terms are, however, quite vague. They seem to blanket more precise terms that have, at some time, been offered as more fundamental components of a person's design competence. These components will now be examined.

**Operational competence**

Knowledge might rightly be seen as the cornerstone of experience, coupled with understanding (in the sense of comprehending the significance of what one knows). But what do industrial designers know (or need to know) to practise industrial design? A distinction in NPD can be made between 'product-centred knowledge' (one's knowledge of, for example, products, components, manufacturing processes, materials, environments, people, and market places that could, potentially, direct the final specifications of a design proposal) and 'procedural knowledge' (one's knowledge of how one goes about designing a product, or how one could go about designing a product). The two classes of knowledge are not mutually exclusive: by applying one's procedural knowledge, one may derive new product-centred knowledge and modify one's procedural knowledge. An industrial designer's operational competence can be said to draw upon both procedural and product-centred knowledge. Consider the following as examples of an industrial designer's product-centred and procedural knowledge.

**Product-centred knowledge**

- The modulus of elasticity (E) of brass is 106 GPa.
- Swimming pools are a wet, noisy and humid environment.
- The vogue colour for products in the year 2000 is brilliant orange.

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\(^{1}\) The term is used here in a loose sense to encompass meta-activities in NPD (e.g., planning, investigating, making, promoting, evaluating).

\(^{2}\) This is simply a restatement of the learning element that is a feature of designing, as introduced in Chapter One.
• Sony Trinitron computer monitors have screens almost as flat as a liquid crystal display.
• People over sixty years old are ten times as likely to wear slippers around the home as people under twenty five.
• Two dissimilar metals in direct contact can cause bi-metallic corrosion.
• Jumpers do not sell well in the summer.
• Korg's Prophecy synthesizer has a 'good feel' about it.

Procedural knowledge
• The critical load for a mechanical member in compression is given by the Euler equation.
• To appreciate the environment that a product will be used in, it is worth experiencing that environment first-hand.
• Colour swatches laid next to a foam model help in the decision-making for the final colour scheme of a product.
• Competitors' products can be partially evaluated by examining promotional brochures.
• All sorts of general information can be potentially useful in designing a product: one needs to keep a keen eye out at all times.
• Products should be designed so that they can be easily disassembled for repair.
• One can use one's 'common sense'.
• If one examines and handles a competitor's product, one can 'get a feel' for it.

Procedural knowledge can act as an alert (that there is something to be considered in the first instance) and product-centred knowledge can provide a stock of past ideas and resolutions on which to base new designs [Rusch, 1970]. In design research literature, existent knowledge used in this way is referred to as 'heuristics'. Heuristics serve to provide apt (and often empirically-grounded) suggestions for how a product is, or is to be, designed. Heuristics are applied with more or less success and accuracy.

Aside from possessing knowledge, what is it that predisposes an individual to apply knowledge? Pring states that something learnt can be "impersonally packaged" and has to become "personally significant" [1995:156]. He proposes that knowledge requires "...a range of qualities and propensities which involve practical know-how and capability..." [ibid.]. Practical know-how will be discussed later, but the idea of qualities and propensities affecting knowledge is something suited to the current discussion. The term in common use for such qualities and propensities is 'values'. When exercised in decision-
Values and value judgements

Values can be technical, economic, aesthetic, moral or hedonic in nature [Archer & Roberts, 1979], and can be particular to an individual or common amongst a group of people. A value judgement is a "subjective and personal estimate of merit in a particular respect" [Cassell Concise English Dictionary, op. cit.:1453]. Value judgements can be made through the exercising of, for example, one's preferences, priorities, opinions, convictions and emotions. In design decision-making, a marked effect of values is to direct and reduce the various avenues of enquiry a designer explores. Consider the following as example value judgements relating to industrial design, materials and manufacturing processes.

- 'Our new range of music synthesizers have metal casings for durability, even though plastic alternatives are cheaper for us to use'. A preference for one material over another, made on the basis of technical and economic values.
- 'Reaching a balance of form and a harmony of materials is what designing a product is all about for me'. An implicit statement of priority to focus thoughts on the determination of a product's form and materials rather than some other product feature. Reasons for holding this as a priority might well be difficult to articulate in words but nevertheless is present, real and clearly brings satisfaction to this designer.
- 'I think shiny plastic looks terrible'. An opinion which may sway the designer in this case away from the use of shiny plastic in a new product.
- 'I believe MDF (medium density fibreboard) is a suitable replacement for English Oak'. A conviction based, perhaps, on working with MDF and finding it capable of forming the same shapes as those found on English Oak products. But does the conviction take account of people's general acceptance of MDF products and, hence, MDF as a suitable substitute material for products traditionally made from English Oak? For the designer there is clearly an element of risk involved here, as expressed to the author by

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* The idea of something being difficult (or impossible) to articulate in words will be discussed shortly.
one industrial designer, [Hearn, 1997]: "We [industrial designers] believe as denizens of good taste that we also know what others will or should like. This is of course a dangerous notion."

- 'I have a passion for creating products in which materials provide people with a tactile response'. An emotional state driving this designer's approach to product design.

In the next sections of this chapter, discussion focuses on the application of the following aspects of epistemology to the practice of industrial design. Each of the aspects has a common thread: to further describe designers' knowledge and values, both as entities in themselves and as entities put to use in the context of practice.

1. Ways of knowing
2. Relationships between tacit knowing and skill
3. The qualitative status of knowledge
4. Classes of decision-making
5. Competence in modelling

Ways of knowing

One of the most important epistemological concepts to grasp when preparing to document and analyse design activity is whether or not a designer is able to make explicit\(^{10}\) what they know. An inability to do so may be because a designer is inarticulate but, more fundamentally, it may be because what is known is not susceptible to expression by way of words\(^{11}\). A knowing of this kind is referred to as a 'tacit knowing' [Polanyi, 1967]. To describe tacit knowing, Polanyi uses an example of people's ability to recognise one face from another, coining 'proximal' and 'distal' terms as the functional structure of tacit knowing.

We are attending from the features [of the face, proximal term] to the face [as a whole, distal term]. It is the proximal term... of which we have a knowledge that we may not be able to tell. (...) We are attending from... elementary movements to the achievement of their purpose, and hence we are usually unable to specify these elementary acts. [ibid.:10]

\(^{10}\) Make explicit here refers to the act of writing or speaking.

\(^{11}\) Even though it may not be possible to express in words precisely what is known, it may be possible to provide explicit pointers to what is known.
Daley [op. cit.:300] has alerted attention to the presence of a tacit dimension in designers' capabilities.

The way designers work may be inexplicable, not for some romantic or mystical reason, but simply because these processes lie outside the bounds of verbal discourse; they are literally indescribable in linguistic terms.

Designers may be incapable of explaining, for example, what it is that they do when they 'come up' with design ideas, or what it is that they find satisfying about a product's shape. In this way, a tacit knowing can relate both to a designer's procedural knowledge and product-centred knowledge\(^\text{12}\). In order to explore ways of knowing in more detail, it is helpful at this stage to pay some small attention to the subject of learning. Ryle [1963] wrote of the philosophy that we can know that or know how.

The primary source of knowing that is from reading or being told (i.e., knowledge derived by way of words). Knowledge so derived is, assuming it has not been forgotten, able to be communicated verbally\(^\text{13}\). For example, one can learn about a particular music synthesizer by reading a press release: learning that the instrument has sixty-one keys; that the action of the keys is 'responsive'; that the mass of the instrument is twenty-five kilograms; that the sounds it produces are 'breathtaking' and that the instrument's colour is an attractive shade of blue. But from all this, one still does not really know the product, only of it. In another example of knowing that, an industrial designer might be instructed that, in order to create a quality spray paint finish on an MDF model, the paint must be built up in a series of thin layers. But possession of this knowledge is no guarantee that the designer will be able to achieve a high-quality finish on a model.

To possess more than a knowing that, one must acquaint oneself with more than a verbal description. In the case of a product, photographs (or other analogues) will help, but better still is first-hand acquaintance with the product. In the case of a practical procedure, graphical descriptions may help but they are a poor substitute for first-hand involvement in that procedure. Complementary to a knowing that, designers can, for example, observe or study the natural and material world, make artefacts or, indeed, design a product. It is through these activities that a knowing can be derived. That is to say, a knowing how can be derived only from acquaintance, not by reading or being told. An important point to note is that some of what is known by acquaintance can

\(^{12}\) Reference is made back to p.49, where examples of product-centred knowledge and procedural knowledge are listed. Clearly the listings are explicit statements, but that is not to rule out a tacit dimension within them (that cannot, by definition, be explicitly stated).

\(^{13}\) Even in a case where knowing that has become 'internalised' (e.g., in the performance of a rule-based procedure 'off by heart') it would be inaccurate to describe that knowing as tacit (inexpressible) since, at some time, the rules of the task must have been described verbally. Instead, a knowing that can be memorised. The idea that something can be performed 'off by heart' is close to what is recognised as skilled behaviour; this will be revisited later in the chapter.
indeed be a knowing that (because it can be made explicit) but, critically, the totality of knowing something by acquaintance is beyond expression in words. To discuss this further, it is convenient to return to the examples of the synthesizer and spraypainting.

**Handling and playing a synthesizer**

'Observation of the instrument shows it to have a keyboard of sixty one keys'. Stated like this (explicitly), one's knowing from acquaintance inevitably appears reduced to nothing more than a knowing that the instrument has sixty one keys. Critically, however, the statement represents only a small portion of what can be known from acquaintance. In the process of becoming acquainted with a product, one cannot help but observe and experience many features in succession. Some of the knowledge thus derived may have a tacit dimension relating to how the product is configured and how the product performs. In the case of the synthesizer:

- playing the keys, one can discern not just that they are responsive but how they are responsive (though be unable to express that responsiveness verbally);
- picking the instrument up, one can experience its weight and describe that the mass is concentrated in given areas, and that it is heavy, but be unable to explicitly state how heavy (only estimate that the mass is twenty five kilograms);
- listening to the instrument, one can describe that the sounds provoke images in the 'mind's eye' (but be unable to express how the sounds achieve that end);
- looking at the instrument, one can state explicitly that it is an attractive shade of blue (but not how that blue is attractive).

A tacit knowing is not, however, completely beyond expression. For example, designers can attempt to express the visual elements of their tacit knowledge by drawing, sketching or finding a suitable colour swatch (a case of 'a picture speaks a thousand (imprecise) words'). Tactile elements might be expressed through making an analogue of a texture for somebody to feel; aural elements might be expressed by reproducing, as best as can be done, a sound for somebody to hear; elements relating to smell and taste might be expressed by identifying something that smells and tastes very similar to the object that has been experienced.
Spraypainting

Knowing that a quality finish will be achieved by building-up a series of thin layers of paint is different from knowing how to achieve a quality finish. Knowing that provides insufficient description of what it is like to perform practical tasks. If one acts-out spray painting 'in the mind's eye' solely on the basis of knowing that, the experience will not be an accurate representation of what it is like to actually engage in spray painting. To know how to create a quality spray paint finish on a block model, one must experience first hand, for example, the problems that blind corners and concave surfaces present, and in so doing, develop a mastery of directing the spray can nozzle so as not to over coat areas of the model's surface14. But in this practical activity, exactly how one's hands react and what one does in these actions is not possible to describe in words [Manzini, op. cit.:52; Polanyi, 1983:49].

The presence of tacit knowing raises an important point for researchers engaged in analysing design activity: even if designers' activities draw predominantly on knowledge that is able to the expressed explicitly, the presence of a tacit dimension has the effect that the overall decision-making cannot be reduced to theory [Pring, op. cit.]. Such theory is needed to construct AI (artificially intelligent) computers that design in the same way that people do.

Relationships between tacit knowing and skill

What should the tacit element in designers' knowledge be called? The simple answer is 'tacit knowledge' or 'a tacit knowing' but, to complicate issues, various other terms have been used in design literature: 'know-how'; 'practical knowledge'; 'knowledge of the senses'; 'knowledge of familiarity', 'connoisseurship' and 'skill' [Dormer, 1994]. In design literature, know-how is most often used to refer to a tacit knowing of procedure (and in particular, a practical procedure such as making something) and not, for example, to a tacit knowing of a product's qualities (as recently described for the synthesizer). Tacit knowing has also been implicated with 'craft knowledge' [ibid.], although this is a little misleading too since a tacit dimension can be identified in the knowledge of designers from outside of the crafts tradition, such as those working in engineering [Ferguson, 1992]. Late nineteenth century engineers, in particular, have been described as "mechanical craftsmen" who relied as much on "mechanical aptitude" and "invent'ive genius" as on reading and being told [Black, 1970:200].

But whatever one chooses to call tacit knowing, the qualities of it remain unaltered.

14 As with performing something 'off by heart', to have a mastery of an activity is also recognised as having skill.
The constitutive rules of a craft are only learned by actually doing the activity. Indeed, they are the activity. This is a fundamental point about craft [tacit] knowledge. You cannot understand it or know it until you can do it [are acquainted with it]. Reading about it is not the same as understanding it. [Dormer, op. cit.: 42]

Know-how (in the sense of tacit procedural knowledge) and skill are closely related concepts and are now compared. If we take the example of spray painting, engagement in the activity can be said to draw upon: (a) knowledge that the principles of high quality spray painting are such-and-such; (b) tacit knowledge (e.g., know-how) of the intricacies and intimacies of painting; and (c) values to direct the activity in the specific circumstances (e.g., to take account of a need to be economical with paint). This is of course a simplified example of the interaction of knowing that, know-how and values, but it illustrates the principles.

So in practice, how can one identify know-how if it cannot be expressed verbally? Schön [1983:51] explains, using two different examples, that to an outside observer, an individual’s know-how is expressed in the practical action of that individual.

...a tight-rope walker’s know-how, for example, lies in, and is revealed by, the way he takes his trip across the wire (...) ...a big-league pitcher’s know-how is in his way of pitching to a batter’s weakness, changing his pace, or distributing his energies over the course of a game.

It would be more accurate to say that what an observer sees in an individual’s practical action is not solely know-how but, rather, skill, of which know-how might be one element (but, as illustrated in the case of spray painting, not necessarily the only element). For example, skill can be observed in pen-on-paper solving of mathematical problems. From this standpoint, skill must logically be present (though not observable) in mental tasks for which no outward activity arises (e.g., solving mathematical problems or constructing prose ‘in one’s mind’).

15 The Cassell Concise English Dictionary defines skill as an “expertness, ability, practical mastery of a craft, trade, sport etc., often attained by training” (op. cit.: 1255).
16 A comment based on the condition that mathematical problems are solved (at least in part) with a knowing that (i.e., explicit rules of algebra, transformation etc. must be followed).
17 Colloquially this is more likely to be classed as ‘being clever’ rather than ‘skilled’.
So what are the qualitative differences between know-how and skill? The most obvious difference is revealed by examining how the words are used. Whereas know-how can be said to exist in one's mind at all times (as tacit knowledge), the same cannot be said of skill. Skill exists only during the performance of an activity; if one is not engaged in an activity then one has no need for (and cannot exhibit) skill. Moreover, skill has no meaning or place outside of the context of intentional activity, since syntactically one cannot be skilled in aimless movements. People who are 'skilled' at activities are self-evidently able to do those activities well. They possess high degrees of mastery (which may be called skills), which are in turn indicative of the content of those people's existent knowledge and values: "...each action shows that we are what we know." [Dormer, op. cit.: 64] In addition to indicating existent knowledge and values, skills are also indicative of one's ability to generate knowledge and values; to react to the particulars of a situation, especially those particulars that are transitional, as summarised by Ryle [op. cit.:29].

A person's performance is described as careful or skillful, if in his operations he is ready to detect and correct lapses, to repeat and improve upon successes, to profit from the examples of others and so forth. He applies criteria in performing critically, that is, in trying to get things right.

In short, skill can be considered an ability, the existence of which is restricted to the performance of intentional mental tasks or practical activities\(^{18}\). Know-how can also be considered an ability, but its existence is not tied to the performance of any action. Skill is action-based; know-how is knowledge based.

Skill can manifest as a state in which one's senses are trained to such a high level that incoming 'sense data' [Russell, 1929] can be discerned and fine qualitative judgements can be made. This state has been termed 'connoisseurship' [Dormer, op. cit.:21]. Connoisseurship is acquired in specialised subjects and can refer to, for example, a person's ability to attribute an approximate manufacturing date to a product or a person's ability to evaluate the quality of a product from its appearance. Dormer [ibid.] gives examples of connoisseurship for sensations of sound and touch: "The way an engine sounds or the way a mechanism responds to the touch are revealing to the knowledgeable engineer." With highly developed skill, there exists an ability to perform activities as 'second nature'; without standing back and pondering beforehand; without a double operation of first considering and then executing [Schön, op. cit.; Ryle, op. cit.].

\(^{18}\) It is acknowledged that whilst an activity can certainly be carried out wholly in one's mind (e.g., mental arithmetic, envisaging how a product will break) it may be inaccurate to talk of a wholly practical activity. That is to say, all practical activities might draw upon some degree of mental activity. This is a matter for psychologists to debate.
One reason for this ability has been recognised already in the chapter: memorised knowing that. For knowing how, the ability may be considered the inevitable end of learning something by acquaintance. That is to say, one will inevitably need to concentrate less on an activity as one gets more practised (acquainted) with it. Dormer [op. cit.:82] has noted that experts "...do not reflect about rules- they push forward with the certainty of rules acquired, reflected upon, embedded and 'forgotten'."

The qualitative status of knowledge

There exist qualitatively different ways in which something can be known, dependant on the content of the information from which that knowledge has been derived. That is to say, one's knowledge can be, for instance: up-to-date or outdated; comprehensive or sketchy; trustworthy or untrustworthy; statistical or anecdotal; personal or shared; and well-founded or misguided. However, from the perspective of the practitioner, the idea of information and knowledge having qualitative status is only as important as practitioners choose to make it. What does the status of information or knowledge matter, so long as, in the end, a satisfactory product proposal is reached? Must sources of information be consulted; or will experience suffice? The answer to these questions is twofold. First, the use of particular knowledge and sources of information might directly benefit the final design of a product (e.g., in the design of garden shears for the U.K. market, the use of statistical information on the British public's arm strength; in the design of packaging for popular music, letting one's imagination run riot). Second, the use of particular sources of information (and perhaps more fundamentally, use of particular formats of information) might be more suited to industrial designers' cerebral processes than others. Observance of any correlation might stand oneself in a position to produce a better product proposal than non-observance. For now though, until investigated empirically, this idea remains as speculation. It is possible though, through accounts in the literature, to identify knowledge of different status that designers could use in their decision-making:

- knowledge attributed to 'common sense';
- knowledge derived from casual observations and acquaintances;
- knowledge derived from experiments.

Knowledge attributed to common sense

Common sense refers to "sound practical judgement; the general feeling of mankind" [Cassell Concise English Dictionary, op. cit.:263]. Pring [op. cit.:144] points out that:
What characterises common sense is not so much what is believed but the way it is believed—unquestioningly, without reference to reasons, as self-evident and uncontroversial, shared with the group with whom one identifies.

The use of common sense in NPD became a topic of small discussion on the IDForum mailing list after an industrial designer wrote "...more people are cut by dull knives than sharp ones." [Buttermore, 1997] In reply, David Durling (Vice Chair of the Design Research Society) points out a need to be cautious when making decisions founded on common sense.

Trouble is, common sense may be common, but is often inaccurate. I would rarely design from this vague standpoint, at least not with products that rise above fashion. When it can be judged to be correct, I value statistical information. Such information can then be used alongside our (common) intuition19.

[Durling, 1997]

In contrast, the late Misha Black, a Royal Designer for Industry, expressed wariness towards the use of formal procedures, research and analysis in design activity: "...these sophisticated techniques are too often applied to minor design problems which ordinary common sense and experience could easily and rapidly solve." [Black, 1965:32] This leaves us with no firm case for or against the use of common sense in designing, but it at least alerts us to its presence. What it does do, implicitly, is suggest that designers would be wise to be alert to any serious misgivings over particular ways of knowing things.

Knowledge derived from casual observations and acquaintances
Knowledge can be derived through one's casual observations of, and acquaintances with, the particulars of the world: through contact with the type of information that is received in an unplanned sense. Such knowledge could in fact be construed as the empirical counterpart of one's common sense. That is, common sense which has, from the individual's perspective, been empirically confirmed and made "personally significant" [Pring, op. cit.:156]. Taking the example of the sharp knife mentioned a short while ago, one's knowledge of sharp knives is reliable enough, empirically speaking, without benefit of statistics. One could, therefore, make reference to one's personal experiences of knives (more or less successfully) in the design of new knives or products that interact with knives.

19 David Durling uses the term 'common intuition' here, interchangeably with 'common sense'. Intuition, which is experienced as a class of decision-making rather than a way of knowing, is discussed later in this chapter.
Knowledge derived from experiments

The word 'experiment' is used here to refer to "an act, operation or process designed to discover some unknown truth, principle or effect, or to test a hypothesis" [Cassell Concise English Dictionary, op. cit.:464]; it is used in the sense of a deliberate effort to generate empirical evidence. Designers might find it useful to generate product-centred knowledge through experiments (e.g., to investigate whether in fact more people are cut by dull knives than sharp ones; to investigate people's preferences for product colour schemes or materials; to evaluate one material against another; to establish whether people understand the semantics of icons on a product). The conclusions from such experiments will be subject to some of the same considerations as academic research (e.g., sample size, reliability, degree of generalisation that can be reached) but the full academic approach (i.e., placement of the new work into the context of an existing body of knowledge) is not necessary. If only for reasons of cost and time, it could be supposed that most of what a designer knows (and therefore applies) is not derived from this kind of experiment.

Classes of decision-making

Designers use a number of different classes of decision-making in their work including, for instance, rules-of-thumb, intuition and analysis [Saaty, 1994]. Attempts have been made to categorise these classes by asserting that they are more or less 'deep' or 'shallow' [e.g., Rodgers & Clarkson, op. cit.] but this approach has problems. For instance, a rule-of-thumb might appear, on the surface, to be rather simplistic and shallow (in contrast to analytical, deductive reasoning). However, a rule of thumb might equally be seen as the culmination of significant learning or a lifetime's experience that is, operationally, just as successful as analytical, deductive reasoning. From a pragmatic perspective, the defining difference between classes of decision-making is the degree of deliberation that precedes a decision, something that is irrespective of any judgements of quality.

Analytical decision-making

Analytical decision-making refers to a process of making decisions based on analysis; that is, based on a process of "separation into constituent elements" of the particulars of a situation [Cassell Concise English Dictionary, op. cit.:42]. In design, analytical decision-making is often referred to as a priori and, as such, is associated with a process of deliberation and deduction. Some forms of analytical decision-making involve the following of a written procedure; some require the consultation of information (e.g., the use of material selection charts).
**Intuitive decision-making**

Intuition refers to a spontaneous and impulsive knowing sometimes referred to as a person's 'sixth sense'. Intuition is experienced as a 'hunch', a 'gut feeling' or an 'automatic' knowing that directs a person to make a judgement (decision). Simon [1981:105] notes that "...most intuitive leaps are acts of recognition." Intuition has meaning only in the context of decision-making; it is distinct from simply rapid recital of memory and, as will become apparent, rapid reasoning. The Cassell Concise English Dictionary describes intuition as "immediate perception by the mind without reasoning; instinctive knowledge" [op. cit.:718]. By definition, therefore, an intuition cannot be preceded by deliberation; it is neither deductive nor inductive [Magill, 1963:xxiii]. Instead, an intuition resolves the constituent elements of an uncertain situation in a single, spontaneous operation. A central feature of intuition is that it can lead a designer to make rapid procedural or product-centred decisions. As with skilled activity, a tacit dimension is present in intuitive decision-making: it is probable that one is unable to describe the knowledge on which one's intuition is based, and one is unable to explain what it is that one does when an intuitive decision is taken.

Some people may associate intuition directly with a high level of skill. Certainly if intuitive decisions are consistently accurate and helpful then it can be said that a mastery of decision-making has been reached. But if one's intuitive decisions are often inaccurate and unhelpful, the same cannot be said. Perhaps in this case the decision-making is really based on a guess masquerading as an intuition? It could be said that for genuine intuition, one needs to be highly skilled.

The following three quotations taken from the IDForum mailing list describe vividly some of the everyday occurrences of intuition in industrial design decision-making. The quotations do not amount to a case for or against the use of intuition, and their content is anecdotal, but they do provide rare and genuine discourse on the subject.

We came up with a product proposal which shouted 'CNC sheet steel' to the designers and the client [i.e., sheet steel formed by computer-numerically controlled (CNC) machines]. We then brought in two very clever engineers who insisted that it was not rational to work on such a hunch. It took them two months of patient analytical work to come up with the answer that CNC sheet steel was the only way. What they ignored was that the 'experienced intuitive' method had brought together the different functional, marketing and manufacturing issues and all the complex interlocks far more effectively than analysis. Who can afford two months in today's environment? [Rust, 1996, Senior Industrial Design Lecturer, Sheffield Hallam University]

In response, Nina Warburton, then Project Manager at the Centre for Industrial Design, University of Northumbria, made the following comments.
We had a client who told us flat out and with a straight face that we couldn't possibly just use 'gut reaction' to know that a cross section of an injection moulding was strong enough. He said that the only way to decide this was to do a 'design calculation' (whatever that is) and work it out mathematically. Lo and behold he came up with the same answer we had had all along, using our ever so faulty 'gut reaction' or as I would rather call it 'empirical knowledge'.

[Warburton, 1996]

Matt Dutton, a practising industrial designer in New Zealand, responded to both of these postings.

It's all very well using empirical knowledge to avoid re-inventing the wheel. If it informs all your design, however, you run the risk of repeating the mistakes of the past (...). I think your client (...) had a point. The answer 'because we say so' just isn't good enough for some people. It may be a pain in the ass to have to dot all the i's and cross all the t's all the time, but the alternative is the risk of a faulty product. There are software solutions for these problems. If you don't trust computers you can always get an engineer's analysis of your component. I've often been told by engineers that 'if it looks right it usually is'. The eye-ometer can be quite accurate. How far do you trust it?

[Dutton, 1996a]

Dutton's last comments are provocative and well observed: whether or not intuition is sufficient for design decision-making is a matter for individual designers and firms to decide. In some circumstances it would certainly be prudent and useful to take an analytical, documented approach to design decision-making. For example, in instances where mechanical failure of a product might have potentially disastrous human consequences. Under such circumstances, critical decisions need to be recorded in order to be verified.

Cross & Cross [op. cit.], as part of the Delft protocol analysis study, found that intuitive decision-making was present mostly within early phases of designing (e.g., idea generation). Mackinder & Marvin [op. cit.:9] found that their group of architects consulted printed information (and, by implication, used analytical decision-making) far more at the back end of a project than at the start. In a similar conclusion, Rodgers & Clarkson [op. cit.] have proposed that as development and detailing become important in NPD, analytical reasoning becomes dominant. This seems a fair supposition given that a final design, in an industrial context, needs to be unreservedly suited to a particular manufacturing process. Intuition is probably an insufficient basis for decisions in an environment where mistakes can be financially costly.
Chapter Two: The use of personal and external resources in NPD

Competence in modelling

Chapter One introduced modelling as a means of stimulating thinking. In this section, an examination is made of 'seeing', an important cognitive ability that directs (and enhances) designers' modelling. Schön & Wiggins [1992:135] have described the nature of seeing in design decision-making.

In all this 'seeing', the designer not only visually registers information but also constructs its meaning - identifies patterns and gives them meanings beyond themselves. Words like 'recognize', 'detect', 'discover' and 'appreciate' denote variants of seeing, as do such terms as 'seeing that', 'seeing as' and 'seeing in'.

Harrison [1978:192] writes about a young child making something from building blocks, where the child develops a feeling that what is being created will, or will not, meet expectations.

He stands back from it to see how it looks, to see if it is going right, what it is turning into, how it is failing to develop one way or another, how it may be emerging as something of which he can be proud or persist in disappointing him by falling down just as it is about to be [metaphorically or literally] something.

In industrial design, an example of seeing is when a designer construes an ill-formed 3D foam model as something more than just that: as a final product which can be manipulated, tested and evaluated through cognitive modelling. The designer will perceive details on the model 'in the mind's eye' which do not exist on the physical object. In this way, imagination, we say, will help a designer to see. For instance, in picturing a tent in the 'mind's eye', one can soon have thoughts that relate to the whole subject of tents and camping [Yan, 1993; Mayall, 1979]: tents are pitched outdoors; tents are for sleeping in; tents need to be portable; tents can be camouflaged; tents can be of a ridged or geodesic structure. Similar thoughts can be initiated from seeing a real tent, or coming into contact with printed images of a tent. Having an abundance of thoughts around an initial object in this way, which can be considered as evidence of a capability to see, holds obvious benefits for a designer: Ideas for a product's functions (and features for achieving those functions) can be entertained in the mind. Supporting this, Muller & Pasman [1996:113] talk of designers' abilities to "...generalize a unique design situation through typification of knowledge, that has been acquired in experience with existing designs and previous situations." Schön & Wiggins [op. cit.:155] point to similar abilities.

We speculate that designers are able to store the discoveries that result from past projects, carrying them over to new situations that trigger them, on the basis of features perceived as similar.
These comments again refer to the importance of knowledge acting as heuristics during the design act. One's capability to see rests on one's existent knowledge and values: "a knowledgeable observer sees more than a less knowledgeable companion because he or she has a richer stock of memories with which to match incoming visual sensations.” [McKim, 1980:49]

**Graphicacy**

In the same way that capability to compute, read and write are linked to numeracy and literacy, so there exists a capacity of mind enabling one to deal competently with visual/spatial information. This capacity of mind is termed 'graphicacy' [Balchin, 1972]. It can be asserted that a high level of graphicacy will contribute positively to designers' cognitive modelling abilities^20.

**Summary (Part 1 of 2)**

- Resources can be classed as either 'external' (information) or 'personal' (knowledge and values).
- Operational competence in designing draws upon both procedural knowledge (one's knowledge of how one goes about designing a product, or how one could go about designing a product) and product-centred knowledge (one's knowledge of, for example, products, components, manufacturing processes, materials, environments, people and marketplaces that could, potentially, direct the final specifications of a design proposal).
- 'Values' can be considered as a collective term for one's disposition to think one way rather than another. Values 'shape' what one knows. Value judgements are judgements made on the basis of one's values. Designers' value judgements can be based on, for example, preferences, priorities, opinions, convictions and emotions. The effect of values in decision-making is to direct that decision-making.

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^20 Balchin [ibid.] gives an example of people's ability to relate the geography of a landscape to the printed markings on a map, and vice versa, to illustrate the role of graphicacy. Clearly parallels to this can be made for designed artefacts (or physical models thereof), drawings, and images held in the 'mind's eye'.
• Some of what designers know can be expected to be tacit (not explicitly expressible by way of words). 'Something' can be known that and 'something' can be known how. The former refers primarily to knowledge derived from reading or being told; the latter refers to knowledge derived only by acquaintance and inevitably contains a tacit element. For practical action, a knowing how is invariably required for skilled performance.

• The tacit element in designers' knowledge is often termed 'know-how', although the knowledge referred to extends beyond procedural knowledge (i.e., knowledge of the intricacies and intimacies of performance for a given practical activity) to include, for example, designers' product-centred knowledge and designers' values.

• Skill is considered to be the operational culmination of designers' knowledge and values. From a pragmatic perspective, skill is the ability of an individual to perform an intentional mental task or practical activity. One can have a high or low level of skill. 'Skills' refer to designers' abilities to perform different tasks (rather than entities which are qualitatively similar and additional to knowledge and values). Since some elements of a designers' knowledge and values are tacit, so a feature of skill is that it has a corresponding tacit dimension. Skilful performance is sometimes observable in the execution of a task and is indicative of the content of one's existent knowledge and values. Moreover, skills are indicative of one's ability to generate knowledge and values.

• There exist qualitatively different ways in which something can be known, dependant on the content of the information from which that knowledge has been derived. Knowledge can be (a) attributed to common sense; (b) derived from casual observations and acquaintances; and (c) derived from experiments.

• Designers' decision-making can be classed by whether or not deliberation precedes a decision. Two common classes can be identified: (a) 'analytical' (requiring deliberation) and (b) 'intuitive' (automatic; made without deliberation and containing a tacit dimension).

• 'Seeing' is an important cognitive ability that directs (and enhances) designers' cognitive modelling. Variants of seeing include seeing that, seeing as and seeing in. Central to designers' capacity to model is the capacity of mind enabling one to deal competently with visual/spatial information; this capacity of mind is termed 'graphicity'.

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Comparisons between artist-designers' and engineers' attentions to materials and manufacturing processes

...materials and processes are directly linked to the creation of form and, hence, to the designer's primary goal. Artists and engineers also learn and know about materials, and there is (...) therefore, the potential for epistemological comparisons. (...) 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...
[Norman, 1997:2&6]

...architects are used to handling timber at a different scale and in a different context [than a furniture designer] and thus have already developed a 'timber language' with a distinctly architectural accent.
[Lawson, op. cit.:38]

Designers make use of a variety of kinds of knowledge- from scientific knowledge of the properties of materials to the in-effable craft knowledge (derived from apprenticeship, experience, trial and error etc.) which enables a skilled practitioner to say that a given design situation 'feels' right (or wrong).
[Cross, Naughton & Walker, 1981:24]

Industrial design, as a component of NPD, is ultimately carried out in an engineering environment because final proposals are invariably realised using industrial manufacturing processes. But some of the roots of industrial design lie in arts and crafts based designing. Both artist-designers21 and engineers22 specify the use of materials, processes and finishes for a given design. If it is the case that artist-designers and engineers have distinct ways of knowing about (and attending to) materials and processes, what of each are now present in contemporary industrial design? This appears to be a question at the heart of industrial designers' involvement with materials and manufacturing processes. To help gain insight into the essence of artist-designers' and engineers' involvement with materials and manufacturing processes, in 1997 two interviews were conducted with designers based at Loughborough University. The findings are reported on the next few pages.

21 The term 'artist-designer' is used here to refer to the kind of craftsman who makes products with clear utility, e.g., ceramic jugs, glass tableware, furniture, stringed musical instruments. Such a craftsman is sometimes called a studio-based designer-maker.
22 The term 'engineer' is used here in an industrial context and not in the context of a domestic workshop.
The last section of this chapter comprises a side-by-side summary of artist-designers' and engineers' ways of knowing about, and attending to, materials and processes. The summary is intended as a useful step towards discussion on what constitutes industrial designers' distinct way of knowing about, and using, materials and processes.

A mechanical engineer's perspective
The notes here are based on responses given in an interview with Dr. Ian Wright, then Director of the Engineering Design Institute (EDI) at Loughborough University (now Head of Department, Mechanical Engineering). The comments made by Dr. Wright are made in many instances in relation to the EDI's industrial consultancy work.

What considerations are made?
An engineer's first concern is to devise schemes that will satisfy mechanical, electrical and electronic functions desired of a product. The final shape of any given product component will be determined by the combining of related schemes. A comment was made that engineers rarely consider how materials and processes can be used in expressive ways. The utility of materials is important in the design of components. Engineers will consider, for example: the ability of a material to withstand different loading conditions (e.g., shear stress and fatigue), stress concentration factors, and the ability of a material to perform in harsh environmental conditions (e.g., temperature, humidity, acidity). The properties of materials that provide utility are, in general, quantifiable (e.g., yield stress, elastic modulus, coefficient of linear thermal expansion, Poisson's ratio).

When is attention given?
Dr. Wright took the view that engineers 'probably' attend to materials choices later in a project than industrial designers. Choices of materials for a component tend to be looked at once schemes for satisfying utilitarian functions have been proposed. There are exceptions though. In the aeronautical industry, for instance, candidate materials must be considered early on because designing for low weight is important. Undergraduate mechanical engineers at Loughborough are advised to consider manufacturing processes from the outset of a design project.

What range of materials is used?
Dr. Wright noted that the availability of materials and processes creates a significant constraint on what designers at the EDI can and cannot specify. Stereolithography rapid prototyping is not available at the EDI and so plastic products are rarely designed. In
general, products are designed in engineering metals (rather than other engineering materials\textsuperscript{23}) because the fabrication and machining tools needed to prototype metal components are readily available. For some products though, metals are a poor choice of material. An example was given of a staple gun for use in surgeries (as a replacement for stitching wounds by hand). One component of the staple gun needed to be a very thin tube with stiff walls and, at the same time, needed to meet criteria for sterilisation and toxicity. To achieve these specifications, it was decided that a thermoplastic was required.

Information sources to aid the selection of materials and processes
Printed charts (e.g., those from the Fulmer Materials Optimiser) are used to compare quantitative information on the performance of different materials and processing combinations. Staff at the EDI make use of experts and facilities across the University campus, including, for example, materials selection databases held by the Institute of Polymer Technology and Materials Engineering (IPTME). When specifying the final material(s) for a component, reference is given to British (BS) and International (ISO) standard classifications of metals.

An artist-designer's perspective
The notes here are based on responses given in an interview with David Scott, a practising artist-designer and Course Leader for the B.A. (Hons.) 3D Design (Ceramics) degree at Loughborough University's School of Art and Design (LUSAD)\textsuperscript{24}. The course is intended to develop students' capability to design and make:

- sculptures from ceramic materials (i.e., clays);
- one-off (craft) pottery using a potter's wheel;
- tableware and pottery for industrial production (for companies such as Wedgwood, Royal Doulton and Denby).

\textsuperscript{23} The term 'engineering materials' refers to a selection of ferrous and non-ferrous metals, thermoplastic and thermoset polymers and ceramics commonly specified by engineers.

\textsuperscript{24} Formerly Loughborough College of Art and Design (when the interview was conducted).
What considerations are made?
When students arrive on the course, most want to make "wobbly pots" and create eccentric forms (i.e., they express a preference towards the craft and sculpture lines of work). Over the duration of the course, some students develop a strong interest in the production of industrial tableware.

When is attention given?
Materials are considered early in the development of a new product and predominantly through 3D modelling. The prevalent approach to designing is to generate and develop ideas by experimenting with the end-material or a modelling material (e.g., plaster). Clay is a malleable material that can be moulded, dust-pressed or cast, using hand or industrial processes. Surface decoration and finishing can be applied to the outside surfaces of clay products. 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.

It is rare that a design is developed solely on paper before committing to making. After examining students' development work, it was evident that paper-based designing was used predominantly for working-up ideas for decorations, paintings, illustrations and finishes (i.e., those elements of a product which are placed onto a clay shape).

What range of materials is used?
The ceramics designer can make use of two classes of clay.

- White earthenware (a relatively cheap and unrefined clay);
- Bone china (an expensive, high quality clay that has translucency similar to porcelain and is suited to mass-manufacturing processes. Once in abundance in Stoke on Trent, U.K., it is considered a very English material and when fired it is stronger than white earthenware).

Because of the high cost of bone china, students' design work is prototyped in white earthenware (even though final designs may be intended for manufacture in bone china).

A recent development in the Ceramics department has been the use of a Silicon Graphics computer workstation running Deskartes CAD (computer aided design) software. This technology has opened a number of opportunities for designers. The pottery industry adheres to many traditions of product shape and form and so when creating a new product range, a designer will often simply apply a new pattern, ornament or finish to a 'standard' tableware shape. The CAD software can be used to visualise subtly new
product shapes and to render 'standard' shapes in a number of decorations and finishes, before committing to 3D modelling.

Summary (Part 2 of 2)

Artist-designers' and engineers' ways of knowing and attending to materials and processes are now summarised side by side in Table 2. In addition to the findings from the two interviews already described, reference was made to the following sources when compiling the Table: Bolton [1996]; Kusuma [1996]; Lesko [1996]; Black [1994]; Dormer [op. cit.]; Ashby [1992]; Ferguson [op. cit.]; Fulton [1992]; Cross [1990]; Dormer [1990]; Charles [1989]; Manzini [op. cit.]; McAlhone [1985]; Cross [1982]; Pye [1978]; Eggleston [1974] and Black [1970].
Table 2: Comparisons between artist-designers' and engineers' attentions to materials and manufacturing processes (4 pages)

<table>
<thead>
<tr>
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<th>Artist-designers</th>
<th>Engineers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Popular antithesis</td>
<td>Materials, manufacturing processes and finishes provide a product with character (expressive function).</td>
<td>Materials, manufacturing processes and finishes are selected on the basis that they can contribute positively to the utility of a product.</td>
</tr>
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</table>
| Whose needs and/or desires are satisfied by the end product? | Sometimes those of a client; sometimes those of the artist-designer themselves:  
<pre><code>                  | ...the starting point is with the creative fulfilment and self-expression of the individual craftsperson... [Dormer, 1990:142] | Those of a client or the employing company.                                   |
</code></pre>
<p>|                      | From this perspective, it is clear that artist-designers have opportunity to exercise hedonic values. |                                                                            |
|                      | [For artist-designers] ...the natural tendency, in the absence of any outside subject matter or purpose, has been to make art about themselves. Sometimes this self-reflexive art has taken the form of abstract or figurative expressionism in which the intention is to leave a deeply personal mark for the world to see. [Dormer, 1994:74] |                                                                            |</p>
<table>
<thead>
<tr>
<th>Artist-designers</th>
<th>Engineers</th>
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<tbody>
<tr>
<td><strong>Satisfaction of the senses</strong></td>
<td>Artist-designers' choices of materials, processes and finishes are strongly directed towards the satisfaction of people's senses of sight, touch, sound, smell and/or taste.</td>
</tr>
<tr>
<td><strong>Range of materials used</strong></td>
<td>Expertise in a select few materials (e.g., different types of clay, metals, woods). The materials that artist-designers use are sometimes inherently non-homogeneous (e.g., wood). Anomalies in the structure of a material are used to enhance the character of a product.</td>
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<th>Artist-designers</th>
<th>Engineers</th>
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<tbody>
<tr>
<td><strong>Level of personal involvement in the manufacturing process</strong></td>
<td>A high level of involvement. Artist-designers' undertake the making and finishing of a product until it is complete. Because the artist-designer is also the manufacturer of a product, there is no requirement for an explicit plan of manufacture to be produced. Indeed, decisions on the final specifications of a product are not necessarily made ahead of making that product (i.e., an element of designing-whilst-making is possible).</td>
<td>A low level of involvement. Production is the responsibility of a manufacturer. Hence, the final specifications of a product need to be fixed and made explicit ahead of manufacture so that production can be planned and tools can be commissioned. The specifications of a product are communicated in, for example, BS308 GA (general assembly) and detail (part) drawings, showing, for example, dimensions, tolerances, surface finishes, manufacturing processes, materials and methods of assembly.</td>
</tr>
<tr>
<td><strong>Consistency of end products</strong></td>
<td>When uniformity of shape and finish is desired (e.g., in the batch production of a jug design), this is not always completely achievable owing to the nuances of manufacture that are inherent in hand production. However, part of the appeal of crafts-based products is that they are unique.</td>
<td>Product consistency (i.e., the production of exact copies as defined by a plan of manufacture) is paramount.</td>
</tr>
<tr>
<td>Nature of knowing and modelling</td>
<td>Artist-designers</td>
<td>Engineers</td>
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<tr>
<td>A material is known when the designer has formed a &quot;personal relationship with raw materials&quot;. [Black, 1970:202]</td>
<td>To an engineer, a material is known when its properties are known, which is to say, codified in a numerical form. [Manzini, 1986:53]</td>
<td></td>
</tr>
<tr>
<td>By way of hands-on contact with end materials, the artist-designer develops know-how of the resistance and acceptance of a material to working, finishing and construction. The generation of this know-how may be directed by a master teaching an apprentice the methods of construction and finishing that have, over the years, been found the most profitable.</td>
<td>Engineers' attention to materials and processes is predominantly made not through hands-on contact with end materials, but through the use of quantifiable material and process properties. That is to say, by way of mathematics, draughting and computer-based work.</td>
<td></td>
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CHAPTER THREE

Materials, manufacturing processes and industrial design

Introduction
In the introduction to the thesis it was stated that attention to materials and processes is a paramount concern in NPD but that the apportioning of that attention to industrial designers was unclear. Engineers have levelled criticism at industrial designers, accusing them of "...poor awareness of production feasibility and a 'precious' attitude of their ideas." [Connolly & Watts, 1984:56] The harshness of this criticism may not be justifiable. Paul Pankhurst [1998], speaking at an international conference, presented a very modern perspective of how materials and processes, in the sense of defining these for a production artefact, interact with industrial designers' work. Consumers are increasingly demanding 'product exclusivity' (subtle modifications to a product to suit a particular user group). In a modern manufacturing environment this can be achieved by employing what is called 'lean manufacturing' and 'just in time' production techniques. With these approaches to manufacture, products are not produced in large batches and stored for long periods in a warehouse prior to distribution. Products are instead manufactured as required, allowing for industrial designers' suggestions for alternative materials and finishes to be implemented and marketed as within-range modifications. Surely in such an environment, industrial designers are unable to work effectively if their knowledge of production feasibility is poor?

Arguments can be put forward for more or less involvement with materials and processes by industrial designers. For example, a high level of involvement might be seen as essential for producing feasible ideas or, in contrast, any involvement at all might be seen as detrimental to the production of creative ideas. Without supporting evidence, however, neither of these positions is convincing. This chapter reports the results of a literature review focused on uncovering what is currently known about the role and significance of materials and processes in industrial designers' work. The primary
purpose of the literature review was to identify gaps in current knowledge and understanding. The review was split into two phases. The first phase was aimed at exploring the breadth of the subjects involved but was unable to identify pragmatic statements on just what industrial designers' involvement and specialities relating to materials and processes are. Jeremy Myerson [1991], in his report on technological change and industrial design education, provided some hints though. He reports that industrial designers are involved with two broad kinds of interaction with materials and processes, as below.

- "Materials", "processes" and "manufacturing", concerned with specifying materials and processes for a production artefact.
- "Workshop practice", where hands-on experience of some materials and processes are put to use in model-making and prototyping.

Other findings of the first phase of the review were presented at a seminar [Pedgley, 1997a] at which invited staff of the University were encouraged to identify the more pressing and elusive subjects to investigate. Subsequent to the seminar, a decision was made to focus the second phase of the literature review on five key areas of investigation, split between predominantly macroscopic and predominantly microscopic subjects. Combined, these subjects would provide pointers for the role and significance of materials and processes in industrial designers' decision-making.

**Predominantly macroscopic subjects**

- When, during a project, attention is given to materials and processes.
- The level of attention given to materials and processes.
- Constraints on the range of materials and processes that designers can specify.
- The challenges of exploiting utilitarian and expressive functions of processed materials.

**Predominantly microscopic subjects**

- The use of resources and modelling to reach decisions on the materials and processes that will be used in a product.
The pilot study of student practice: the injection moulding project

It was imperative that before commitment was made to a long-term study of designing, some groundwork was established for the different ways in which designers worked with materials and processes. The literature review provided some insights but microscopic descriptions of the interactions between materials, processes and designing were notably absent. To provide some initial findings at a microscopic level, semi-structured interviews were conducted with two students in their second year of the Industrial Design and Technology B.A. course at Loughborough University. Both students were male and of a high 2:1 calibre. They are referred to for the purposes of this thesis as Adam and Vince.

The interviews were titled 'A pilot study of the consideration of manufacturing processes and properties of materials by year 2 injection moulding students'. Appendix I is a copy of the working document used for this pilot study. The wording of the document reflects partially-formed ideas and perspectives that were held at the time of its authorship. The students were briefed prior to the interviews on the general subject area that would be covered.

The Injection Moulding project is a long established 'design and make' project in which students design a small plastic product and its associated tool for injection moulding (Figure 8). Students proceed to manufacture the mould tool, often using CNC (Computer Numerically Controlled) milling machines and, using in-house injection moulding machines to produce their products, complete a professional quality display. Unlike a final year project, the conduct of the Injection Moulding project is largely predefined and dictates that students must pay attention to materials and injection mould tool design. The handling of materials and processes issues was therefore sure to be apparent in Adam's and Vince's work, and it was this that interviews concentrated on revealing. The interviews were held with each student once a week for three weeks. By the end of the third week, the students were expected to be ready to finalise their mould tool design. In the interviews, the students were encouraged to 'talk through' their attention to materials and processes by referring to their sketch sheets. The interviews were videotaped and some parts of the discussion were transcribed.
Aside from recording conversation, the videotapes captured the students pointing to drawings on their sketch sheets as they gave explanations of their designing. An encouraging finding of the pilot study was that both students could describe when materials and processes were attended to, and could provide an account of the nature of the attention given. The pilot study also helped in the development of the diary method of capturing designers' thinking, by pinpointing practical issues such as the kinds of responses that are given to questions (and, hence, allowing an assessment of whether it was worth asking those questions in a future study)\textsuperscript{25}.

The findings of the literature review and pilot study are now presented under each of the five key subject headings, as a final step to defining the precise research questions that will be probed in this thesis.

**Subject 1: When, during a project, attention is given to materials and processes**

If we look at when attention is paid to materials and processes, we can develop an understanding of the priorities industrial designers place on their work: whether materials and processes are peripheral or central concerns.

Cornish [1987:6] reports that the selection of materials is "...one of the earliest" decisions in NPD and Cramer [1996c] states that early consideration is of benefit to NPD. The Design Business Association suggest that in the earliest stages of NPD, a design

\textsuperscript{25} The development of the diary of designing is described in detail in Chapter Five.
consultancy should be allowed to "...familiarise themselves thoroughly with the technical background to the product to be designed..." and that discussion with the commissioning company's in-house production personnel should be encouraged [Design Business Association, 1992:5]. Reasons for such early involvement are not stated though. Mackenzie [1991:73] calls on all designers to consider material choices "...at the earliest stage" because decisions will have a direct bearing on: (a) energy consumption during manufacture; (b) the suitability of the product for reclamation; and (c) the environmental impact of the product when it is eventually disposed of. Bolton [1996:147] provides a summary (not specifically for industrial design) of "...stages involved in arriving at possible materials and processing requirements for a product...", reproduced below.

1. Define the functions required of the product.
2. Consider a tentative design, taking into account any codes of practice, national or international standards.
3. Define the properties required of the materials.
4. Identify possible materials, taking into account availability in the required forms.
5. Identify possible processes that would enable the design to be realised.
6. Consider the possible materials and possible processes and arrive at a proposal for both. If not feasible, reconsider the design and go back through the cycle.
7. Consider how the product will behave during its service life.

In this sequence, Bolton shows clearly that the generation of ideas ("a tentative design") should come before attention is first paid to materials and processes. A similar approach, specifically for industrial design, is suggested by Tjalve [1979:106]: arrive at ideas first and then choose materials and processes "as far as possible simultaneously". A similar approach again is echoed by Rust [1996] who will "...integrate material and process [sic] from the concept stage and use understanding of material [sic] and processes to unlock problems." In all of these sequences, materials and processes are considered only after product ideas have been suggested and end applications have been defined. From then on, materials and processes feature strongly in the development of product ideas.

From quite an opposing viewpoint, Kusuma [1996:22], a senior designer at Bayer Corporation, asserts that "...material specifications are almost an afterthought or 'someone else's task', in part because [industrial designers] prefer to work on the intangible qualities of a product." The same might be said for designers who are involved in future-looking 'speculative' products, not intended to be marketed. One practising
industrial designer based in New Zealand has shared similar thoughts on the timing of materials and processes attention through the IDForum mailing list. Over time though, his experience with materials and processes has grown and allowed him to place their consideration at the heart of his work.

The first job I got (in a very down-to-earth manufacturing situation), my boss made it quite clear that he wanted me to go for ideas first and worry about practical considerations second. As I grew more aware of manufacturing constraints, so my method changed to accommodate them. Since all of my designs required approval by people more experienced in manufacturing, the company got the best of both worlds, I hope. Now I have lots more experience with materials and technology, they play a much larger part in my design process.

[Dutton, 1996c]

The first of the injection-moulding students interviewed, Adam, stated that in the very early stages of designing, he concentrated on establishing the function of his widget prior to examining manufacture. His statement revealed an approach to designing consistent with those put forward by Bolton [op. cit.] and Tjalve [op. cit.]. In contrast though, the second injection-moulding student, Vince, thought very early on about how his widget would assemble to a periphery component. He considered the use of different interference and nodule fits as he worked on relatively undeveloped ideas. For both students, the transition of attention to materials and processes (from general to detailed) was evidently not a linear one. Occasional decisions of detail were made quite early on and both students toyed with the manufacturability of different designs early in their projects. Adam was working on a widget through which guitar strings could be passed to form part of a hung shelving system. He considered two methods for creating the channel through which the strings would pass: mould tool inserts and drilling.

In practice then, there would appear to be definable factors, of which some relate to the knowledge, skills and values of the designer, and others to the work practices of the employing company, that dictate whether a large or small amount of time is spent generating ideas with little or no regard for manufacturability. The reasons for the timing and evolution of materials and processes considerations, on a macroscopic level, needs further investigation.

Subject 2: The level of attention given to materials and processes

To better understand industrial designers' particular expertise in relation to materials and processes, we can examine the level of detail to which the subjects are attended to.
Published literature provides some generalisations but contradiction and ambiguity are commonplace, as the following six quotations illustrate.

(i) Sources suggesting detailed involvement.

Industrial designers [...] maintain a practical concern for technical processes and requirements for manufacture. They work to ensure that design recommendations use materials and technology effectively, and comply with all legal and regulatory requirements.
[IDS A (Industrial Designers Society of America), 1997]

A product design consultancy is very different from a graphics retail company. It has to operate from a much stronger technological base. A product is never rendered in the medium it is conceived in. To think in plastics, for example, you have to work in an environment exposed to the needs of engineering development (we lunch with the guys that operate the machine tools). It is only too easy to create a wonderful drawing or model, and a terrible product. But if you understand how a product is going to be made, you will produce simpler, more elegant solutions.
[Gus Desbarats of Random Design Consultancy, quoted in Pipes, 1990:57]

A design problem has been identified. A solution has been conceptualised. Now that solution must be refined, tested, developed and prepared for production. At the heart of implementing the design is the selection of the most effective materials and manufacturing processes. Industrial designers, from the beginning of their education to the end of their professional career, will be intimately involved in the properties of materials and the methods of their use and fabrication.

(ii) Sources suggesting less detailed involvement.

Manufacturing should be attended to in detail by production engineers "in close consultation" with the designer.
[Design Business Association, op. cit.:6]

In practice the majority of [industrial] designers concentrate their efforts on the shape and form of a component without considering the economics of manufacture.
[Connolly & Watts, 1984:39]

A product designer need not have a detailed knowledge but instead hold an understanding of general limitations and possibilities of a wide range of materials and processes.
[Ashford, 1955:137]

It is worth at this stage taking a closer look at what is meant by 'detailed' and 'less detailed' involvement. Notionally we can consider attention to materials and processes in
Chapter Three: Materials, manufacturing processes and industrial design

NPD as split into a hierarchy of levels (Table 3), running from level 1 (least detailed) to level 4 (most detailed).

### Materials

<table>
<thead>
<tr>
<th>Level</th>
<th>Sub-set</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Family</td>
<td>e.g., polymers, metals, woods</td>
</tr>
<tr>
<td>2</td>
<td>Sub-set A</td>
<td>e.g., thermoplastics, non-ferrous metals, softwoods</td>
</tr>
<tr>
<td>3</td>
<td>Sub-set B</td>
<td>e.g., polymethylmethacrylate, copper, pine</td>
</tr>
<tr>
<td>4</td>
<td>Sub-set C</td>
<td>e.g., GE Lexan (trade names, specific grades, flow properties, particular suppliers)</td>
</tr>
</tbody>
</table>

### Manufacturing processes

<table>
<thead>
<tr>
<th>Level</th>
<th>Modification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic</td>
<td>e.g., injection moulding, die casting, vacuum forming</td>
</tr>
<tr>
<td>2</td>
<td>Modification A</td>
<td>e.g., assess the need for inserts, multiple cavities, 3-way parting tools</td>
</tr>
<tr>
<td>3</td>
<td>Modification B</td>
<td>e.g., detail design of the product to suit the process and avoid processing pitfalls (DFMA²⁶)</td>
</tr>
<tr>
<td>4</td>
<td>Modification C</td>
<td>e.g., final mould tool design and associated mould flow calculations (DFMA); testing prior to ramp-up</td>
</tr>
</tbody>
</table>

Table 3: A hierarchy of levels of attention to materials and manufacturing processes

So at some stage in NPD:

- the exact material(s) to be used will be chosen, including the particular grade (e.g., 20% talc-fill acrylonitrile-butadiene-styrene);
- all manufacturing processes will be planned for (e.g., the production of engineering drawings appropriate for a thermoplastic extrusion tool);
- all finishing processes will be planned for (e.g., a tool produced for pad printing).

²⁶ When the planning of manufacturing processes starts in earnest this is referred to as DFMA (design for manufacture and assembly) or just DFM. With injection-moulded polymers, a combination of good DFMA, tool design and high-quality processing can result in an elegant underside of a product casing (e.g., Nokia mobile telephones).
Ulrich & Eppinger [1995:15] tie levels of attention to successive phases of NPD. Note that the described tasks are for product design generally; industrial designers may or may not be involved.

**Concept Development**
Investigate feasibility of product concepts; estimate manufacturing cost; assess production feasibility.

**System-Level Design**
Identify suppliers for key components; perform make-buy analysis; define final assembly scheme.

**Detail Design**
Define part geometry; choose materials; define piece-part production processes; design tooling; define quality assurance processes; begin procurement of long-lead tooling.

**Testing & Refining**
Do reliability testing, life testing and performance testing; obtain regulatory approvals; refine fabrication and assembly processes; refine quality assurance processes.

**Production Ramp-Up**
Place early production with key customers; evaluate early production output; begin operation of entire production system.

One particularly intriguing question is whether in practice industrial designers are involved in detailed part design or if their efforts are rarely applied beyond system-level design. Industrial designers do not have the expertise of production engineers and tool makers, so where do the limits of industrial designers' involvement with materials and processes lie? Evidence to answer this question directly is sparse. Ulrich & Eppinger [ibid.:165] report that industrial designers (in the U.S.) conclude their development work with the preparation of "control drawings" of a final proposal. These drawings define the "...functionality, features, sizes, colors, surface finishes and key dimensions" of a product and, although not detailed part drawings, "...can be used to fabricate the final design models and other prototypes. Typically, these drawings are given to the detailed part designers for completion." [ibid.] In relation to industrial design in the U.K., the Design
Business Association [op. cit.:7] mention the creation of "modelmaking" or "general arrangement" drawings which include "draw angles, mould breaks, and assembly details" but omit engineering details (e.g., tolerances and surface roughness values) and so provide insufficient information for a toolmaker.

Modelmaking and control drawings appear to be similar. Both types of drawing indicate that, in relation to a hierarchy of considerations (e.g., Table 3), industrial designers exhibit a moderate level of attention to materials and processes but do not prepare a proposal for tooling. One industrial designer recently underlined his distance from such work, stating somewhat cheekily that stress calculations and strength testing are engineers' jobs because "...that's what engineers (bless 'em) are for..." [Dutton, 1996a]. Given this position it is conceivable (though in need of investigation) that contemporary industrial designers are occupied almost wholly by the generation of product ideas and that, in this scenario, high demand is not placed on defining manufacturing details. However, the effects of poor design decisions at concept phases will have repercussions later in NPD. Ulrich & Eppinger [op. cit.:191] give examples of how ignorance of the capabilities and constraints of manufacturing processes can lead designers to specify features which are difficult to achieve and expensive (and sometimes unnecessary for the intended utility of a component).

...a designer may specify a small internal corner radius on a machined part without realizing that physically creating such a feature requires an expensive electro-discharge machining (EDM) operation. A designer may specify dimensions with excessively tight tolerances, without understanding the difficulty of achieving such accuracy in production.

It would therefore appear foolhardy to sideline serious consideration of materials and processes during concept phases of NPD.

Subject 3: Constraints on the range of materials and processes that designers can specify

In books showcasing industrial designers' work [e.g., Blaich, 1995], products made from a diverse range of processed materials are presented. Plastics and other non-metals dominate industrial designers' work (Figure 9) but metals are sometimes used too (Figure 10). But whilst the fruits of industrial designers' work are highly visible and accessible in the showcase books, the decision-making to reach the end product is not. This third subject is concerned with identifying the constraints that limit the range of materials and processes a designer is able to make use of. That is, to identify factors that act to restrict
what can be specified, rather than what could be specified given availability to all processes and all materials.

Rownes [1988] examined the design of computer monitors at ICL (International Computers Ltd) and found that for casing design, the company worked with a small number of materials and manufacturing processes. The materials list was as follows, comprised wholly of plastics.

- ABS (Acrylonitrile-butadiene-styrene) (for injection-moulded parts)
- Polyphenylene oxide (for foamed parts)
- Polycarbonate (for injection-moulded parts)
- PMMA (Polymethylmethacrylate) (for injection-moulded parts)

Is it common for in-house designers to work with a short list of materials such as this? Do consultancies work with similar lists of preferred materials? Some insights into these questions were given on IDForum but the questions warrant further investigation: how free are industrial designers to propose new and alternative materials?

Unless one is working in (...) simple concept work, the assumption is that the client's resources are a given and thus one of the first considerations in the design process. (If the client is tooled to work in plastics, it would be inappropriate to design for wood materials and woodworking tools). If new methods and materials are available to -but presently not part of- the client's extant technology, it is up to the designer's research abilities to discover such and suggest their implementation along with preparing a list of pros and cons vis-à-vis their adoption.

[Metcalfe, 1996, industrial designer]

Safety laws and British Standards work to ensure that materials appropriate to the job are used in a product (e.g., for food hygiene, electrical safety). In the Injection Moulding project, the range of materials that could be specified was automatically reduced by the demands of the brief: those polymers that can be injection moulded. Moreover, the limitations of the processing equipment were a factor too. Adam and Vince concluded that some of their design ideas were too curved and required too complex a mould tool to be manufactured with the Department's facilities.
Figure 9: Examples of products for which external surfaces are manufactured predominantly from plastics and other non-metals. Clockwise from top: Bang & Olufsen Beosound Century Sound System (Reproduced with permission of Bang & Olufsen a/s); Caimi Export S.p.A Dondolo Chair (Reproduced with permission of Verner Panton); Philips Philishave HS483 shaver (Reproduced from product packaging, © Philips); Dexixa Joystick (Reproduced with permission of Montgomery Pfeiffer).
Figure 10: Examples of products for which external surfaces are manufactured predominantly from metals. Clockwise from top: Technische Industrie Tacx BV Cyclestand (Reproduced with permission of NPK Industrial Design); Tsubame Shinko Industrial Co. Ltd Stainless Dinnerware (Reproduced with permission of Igarashi Studio); Black & Decker Powershot™ Heavy Duty Staplegun (Reproduced with permission of Worktools Inc.); Lamy Spirit Ballpoint Pen and Mechanical Pencil (Reproduced with permission of C.Josef Lamy GmbH)
One constraint that seems likely to have a strong influence is the 'green design' movement. Issues such as product disposability and recyclability, 'design for disassembly' and the use of recycled materials have steadily become more high profile since the mid 1980s [Mackenzie, op. cit.]. Figure 11 shows an example of Eaglebrook Street Furniture, which makes extensive use of Durawood recycled material. The principles of green design are weighty subjects in themselves and there is no intention to discuss them at length in this thesis, suffice to say that they could be a significant factor in industrial designers' decisions on materials and processes.

![Eaglebrook Street Furniture](Reproduced with permission of Fahnstrom/McCoy)

Designers might sometimes have opportunity to specify unusual materials in their products. John Bloxidge, then president and managing director of Wilkinson Sword Consumer Products Group, spoke of the range of materials that his designers worked with at a seminar organised by what is now the Chartered Society of Designers.

...at Wilkinson we rely on our design director to inspire our product programme and give his young team an opportunity to work with silver, teak, brass and leather as well as microchips, polypropylene and steel.

[Bloxidge quoted in McAlhone, 1985:15]

One area in which designers might pay close attention is advances in materials and processing technology. Not only is the range of off-the-shelf materials vast but it is
becoming more frequent that materials are designed for a product, rather than existing materials being made to fit [Sweet, 1999; Manzini, 1986]. Despite advances in materials technology, there is evidence that, in practice, designers tend not to make extensive use of that new technology.

In Japan, the material a product is made from changes on average every seven years. In the UK a change of material typically happens every thirteen years. In neither case does this pace of change reflect the true pace of progress in materials development. [de Noblet, 1993:271]

Nevertheless, over thirteen years, the expressive qualities of products (provided in part by different surface finishes) have changed dramatically. The evolution of the personal stereo is a good example of this. Of what importance are surface finishes to industrial designers?

Subject 4: The challenges of exploiting utilitarian and expressive functions of processed materials

Creativity and attention to materials and processes

In the Injection Moulding project, Adam made a comment that "...there's no point in making it nice if it's not going to be functional." This point leads to the question: what is the nature of creativity with respect to decisions on materials and processes? Are industrial designers routinely encouraged, as in a newly developed design competition [Core77, 1999], to "...think and design beyond the scope of available manufacturing and technology"? It can be proposed that avoidance of materials and processes issues might relieve the designer of "...the restrictive prerequisite of extensive technical knowledge." [Lee & Radcliffe, 1990:97] Whitefield & Warren [1989:180] observed that "the practicality and originality of designs are negatively correlated." On the IDForum mailing list, industrial designer Matt Dutton put a very different perspective on the issue of creativity when responding to Dow Plastics researcher Robert Cramer's statement that "...the challenge is to balance the creativity of concept with the practicality of manufacturing." [1996b]

Why should practicality be a barrier to creativity? An unrealisable concept is useless except as a brainstorming device. Since it can never be realised, it isn't really creative at all, IMHO [in my humble opinion]. With the challenge of manufacture comes the opportunity to put your ideas to the test. I think it's fun. [Dutton, 1996b]
Cramer then provided a defence.

Malt, I agree—practicality shouldn't be a barrier to creativity. Unfortunately, it appears to be for some [people]. In true brainstorming (...) ideas or concepts are generated without any evaluation [i.e., without manufacturability being assessed]. That's okay because you want to 'open the box' in a risk-free environment. However, you must still choose from all these ideas and a degree of practicality be considered. The balance is achieving just enough reality to separate the wheat from the chaff, but not so much as to get bogged down in details. My experience is that some very 'creative' people either don't want to continue the process (I've done my job) or strenuously resist any modifications or evaluation of their original concept. On the other hand, the 'practical' people have a tendency to want to get to details too quickly. Obviously, these are broad generalisations but my experience has been that the most successful product development programs have been those who have been able to achieve that balance of creativity/practicality very early in the development cycle. 

[Cramer, 1996a]

Creativity in this area is clearly related to balancing utilitarian and expressive functions of materials. For these two functions, are there properties of processed materials that are of particular interest to industrial designers? Ulrich & Eppinger [op. cit.:158] give some hints for expressive functions whilst introducing the idea of an 'industrial design manufacturing cost', described below.

Surface finishes, stylized shapes, rich colors, and many other design details [created through industrial design] can increase tooling cost and/or production cost.

**Utilitarian functions**

British designer Geoff Hollington finds modest yet functional improvements where none might be thought possible. His cherrywood and nickel-plated candlestick has a flexible rubber flange at the top; flex it, and accumulated wax flakes off. Industrial designers around the world are engaged in the constant process of making small, incremental improvements to the performance of the things we use every day—adding small safety features and ergonomic and practical refinements.

[de Noblet, op. cit.:277]

Designers will sometimes adopt replacement materials when a product or product family (and that of its competitors) has become static or obsolete, so as to boost performance in some way [Cornish, op. cit.]. The advantage of using a replacement material might come from "...reducing cost, lowering weight, improving the temperature range, improving strength, reducing corrosion and improving the production." [Hollins & Pugh, 1990:121]
Expressive functions

Simple changes in material, process or finish can make marked differences to a product and can be applied to improve marketability without altering the basic concept [Hollins & Pugh, op. cit.; Christensen, 1992; Cornish, op. cit.]. Questions may be asked of a processed material such as: 'For this product, does it look good?'; 'Does it portray the right kinds of message?' and 'Does it have a surface texture that feels right?'

Subject 5: The use of resources and modelling to reach decisions on the materials and processes that will be used in a product

This last subject focuses on how designers make use of resources and modelling when attending to materials and processes. The uses are not specific to (or necessarily used by) industrial designers; this is something to be investigated. Some of the uses are close to the practices of design engineers; others are closer to those of artist-designers.

1. Scrutinise the use of a product

An emerging product proposal might be broken down into constituent components and, for each component in turn, utilitarian and expressive requirements of materials, processes and finishes might be determined.

2. Use of a concept screening matrix

A rigid and explicit approach to designing could be adopted, making use of an 'analytical hierarchical process' [Saaty, 1994]. For example, the manufacturability of a potential proposal might be determined by a criterion such as "ease of manufacture" [Ulrich & Eppinger, op. cit.:114]. This criterion will probably be incorporated into a 'concept screening matrix' or 'House of Quality' (a form of 'quality function deployment' (QFD), a technique with roots in production engineering for explicit, analytical designing). With such designing, 'scores' for design proposals making use of different materials, processes and finishes are determined.

3. Application of new materials and processes technology

A designer might evaluate the properties of new materials and processes with an eye to updating existing products or creating new products.

4. Assessment of environmental performance

Where 'green issues' are a high priority, an assessment will need to be made of the environmental impact of a design proposal.
5. Use of computers
Computers have the potential to support decisions on materials and processes in a number of ways.

- Design-based databases [e.g., Granta Design Ltd, 1999; Boothroyd Dewhurst, 1999; Puttré, 1991].
- Material property databases [e.g., MATWEB, 1999; Derzko, 1998].
- Stress calculation, mould flow and other technical analyses.
- Rendering of CAD models in different materials and surface finishes to visualise product possibilities (Figure 12).

6. Rules for DFMA & detailing
Design for manufacture and assembly (DFMA) was introduced earlier in this chapter. DFMA is performed by applying guidelines that have been demonstrated to improve the performance, quality and reliability (and reduce costs) for any given manufacturing process [Cornish, op. cit.; Bralla, 1986; Connolly & Watts, op. cit.]. Table 4 contains example DFMA guidelines taken from Bralla [op. cit.]. Cocker [1997] describes some of the problems that are encountered (and solutions adopted) in detailing injection-moulded parts at Hoechst Technical Polymers (Table 5).

Summary
Five key areas for investigation relating materials and manufacturing processes to industrial design activity have been identified in this chapter.

- Timing and sequence
- Level of detail
- Constraints
- Creativity in combining utilitarian and expressive functions
- Use of resources and modelling

In Chapter Four these areas will be included in a series of research questions that the remainder of this thesis will seek to address.
Figure 12: CAD models rendered in different materials and surface finishes. From the top: Fishing reels (Reproduced with permission of Mark Evans); Salt and pepper cellars (Reproduced with permission of Mark Evans); Excella telephone (Reproduced with permission of Dean Bates)
### Sand casting (metals)

Reduce the number of reinforcing ribs which intersect at one point so as to reduce the necessary thickness of the intersection. This helps to prevent voids at the intersection.

[Bralla, 1986:5.11]

### Injection moulding (polymers)

...shrinkage of plastic material causes various irregularities and warpage in the molded part. The most common defect is the sink mark, or surface depression, opposite heavy sections.

[ibid.:6.20]

To rectify this, several changes in design can be made. Material can be removed to create a pattern and lessen the weight of the section. Surface textures can be added to disguise any imperfections. The design of the reinforcing ribs can be modified, as below.

Reinforcing ribs should be thinner than the wall they are reinforcing to prevent sink marks in the wall. A good rule of thumb is to keep rib width to one-half or less of wall thickness.

[ibid.:6.24]

| Table 4: Example DFMA guidelines |
### Problems

<table>
<thead>
<tr>
<th>Problems</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weldlines [part-lines where different parts of a mould join] in areas of the moulding which experience high stress or are visually important.</td>
<td>• Careful part design with use of flow leaders and restrictors as necessary.</td>
</tr>
<tr>
<td></td>
<td>• Thoughtful gate location to offset weldline positions from critical areas.</td>
</tr>
<tr>
<td></td>
<td>• The use of valve gates for tools with multiple gates to control the position and quality of weldlines.</td>
</tr>
<tr>
<td></td>
<td>• Use of materials with good weldline properties and / or lower filler content.</td>
</tr>
<tr>
<td></td>
<td>• The use of overflow wells off the weldline area to maximise weldline quality.</td>
</tr>
<tr>
<td>Overheating and material degradation or premature freezing of polymer.</td>
<td>• Thicker or thinner sections and carefully controlled injection pressures.</td>
</tr>
<tr>
<td></td>
<td>• Better cooling system in a tool.</td>
</tr>
<tr>
<td></td>
<td>• Careful runner and gate design for minimum flow length and shear.</td>
</tr>
<tr>
<td>Unbalanced runner systems in multi-cavity tools resulting in a tool that simply will not fill or that over packs or under packs cavities.</td>
<td>• Profiled runner and gate sizes.</td>
</tr>
<tr>
<td></td>
<td>• Sensible arrangement of parts in the tool according to the comparative part weights.</td>
</tr>
<tr>
<td></td>
<td>• The avoidance of family tools.</td>
</tr>
<tr>
<td>Warpage and shrinkage</td>
<td>• Careful positioning of the gate, especially in fibre filled materials with anisotropic shrinkage.</td>
</tr>
<tr>
<td></td>
<td>• The use of glass bead or mineral filled materials.</td>
</tr>
<tr>
<td></td>
<td>• The use of uniform wall sections.</td>
</tr>
<tr>
<td></td>
<td>• Proper packing of the cavity.</td>
</tr>
<tr>
<td></td>
<td>• Strategic design of the components to give the correct shape as a direct result of predicted shrinkage and warpage.</td>
</tr>
</tbody>
</table>

Table 5: Detail design for injection moulding at Hoechst Technical Polymers
CHAPTER FOUR

The research questions

Introduction
Section One of this thesis has been concerned with the establishment of a framework for analysing industrial designers' attention to materials and manufacturing processes. The literature reviews and pilot investigations were directed towards the formulation of several research questions that addressed weaknesses in current knowledge and understanding.

Chief questions
The chief research questions are as follows.

1. What role and significance do materials and processes have in industrial designers' decision-making?
2. Can industrial designers' 'distinct way' of expressing and generating materials and processes knowledge and values be identified and described?
3. What implications do (1) and (2) have for industrial design educators and information providers?

Chapter Three identified five key areas for investigation, split between predominantly macroscopic and predominantly microscopic subjects. It is under these headings that supporting questions, to provide evidence for answering the chief questions, are now listed.
Supporting questions (predominantly macroscopic)

When, during a design project, attention is given to materials and processes

- Are there similarities between practices for the timing and sequence of attention? What do these reveal about the importance of materials and processes as elements of industrial designers' work? (peripheral? central?)
- Sometimes industrial designers are involved in future-looking 'speculative' products, not intended to be marketed. Is attention to materials and processes different for these products?

The level of attention given to materials and processes

- To what level of detail does attention commonly reach?

Constraints on the range of materials and processes that designers can specify

- What are the constraints and from where do they originate? Hence, how wide is the range of materials and processes that industrial designers are able to specify?
- As a 'snapshot' of current practice, what bearing do the constraints of 'green design' have? (e.g., the specification of recycled materials; design for disassembly; design for recyclability)

The challenges of exploiting utilitarian and expressive functions of processed materials

- What is the nature of creativity in this area?
- What opportunities do materials and processes offer industrial designers? Do industrial designers look for particular functions to be achieved from materials and processes (as compared to other design team members)?

Supporting questions (predominantly microscopic)

The use of resources and modelling to reach decisions on the materials and processes that will be used in a product

- What sources of information are used to help in decision-making? How is information used?
- How are computers used to support decision-making?
- How are knowledge and values expressed in decision-making? What components of industrial designers' attention to materials and processes are characteristic of engineers and of artist-designers?
- What is the nature of cognitive, 2D and 3D modelling in this area?
SECTION TWO

Methods of capturing and analysing
design activity
CHAPTER FIVE

Data collection methods

Introduction

The introduction to the thesis provided an overview of the approaches researchers take to the task of documenting design activity. This chapter explores in depth the issues that arise from the pursuit of this task. It reports the development of a methodology for recording designers' thinking over the duration of a design project. Foremost on the list of requirements for the methodology was to take into account the author's designing, this having been planned as a substantial source of primary data. The chapter includes discussion on how the author's designing has acted as a vehicle for the testing and refinement of a novel 'diary of designing' data collection instrument.

In addition to data from the author's designing, it was anticipated that data from studies of five professional designers would be collected using a diary. The findings from these additional studies would be used to examine professional practices and would help in the evaluation of the diary method of capturing designers' thoughts. In the event, it proved impractical to make longitudinal studies of professionals at work and so interviews were conducted with nine designers employed across different sized consultancies and in in-house design departments. To help evaluate the diary, two industrial design students were asked to produce diaries to accompany their final year major project.

The need to uncover designers' thoughts

Thinking is one of the most intractable parts of psychology since the thought process is not easily observed. It need not be started by, nor concerned with, current events in the environment, and moreover it need not conclude with any communication to the outside world. [Lawson, 1990:96]
As a cerebral activity, designing is private and (as explained in Chapter Two) not necessarily explicable. However, most designers do not resemble "...Rodin's 'Thinker' who sits in solitary meditation." [ibid.] 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 (and also the 'deliverables' of NPD, such as final presentation models and formal project reports) can be considered external manifestations of cognitive activity. These products would therefore seem to be very valuable to researchers intending to reveal decision-making processes [Schön & Wiggins, 1992:154; Zimmerman & Weider, 1977:487]. Often though, the products of 2D and 3D modelling are intelligible only to the originator and have no purpose beyond use by that person. The products can be seen as rather like an index to a book, in this case pointing to discussion held not on paper or on a computer screen but in the designer's mind. From the researcher's perspective, the stand-alone value of the products is questionable. For example, if a designer has sketched a curve for a plastic component, his or her accompanying thoughts may have been to do with form in an aesthetic sense or they may have been to do with making sure the component could come out of a mould tool. For some designers, these thoughts may occur simultaneously. Simply by looking at the sketch it will not be possible to tell what was thought.

The principle that designers' thinking is hidden in the markings on sketch sheets was illustrated in the interviews held with the two Injection Moulding students. Much of the students' thinking in relation to materials and processes was insufficiently externalised on sketch sheets for an outsider to gain a clear understanding of the decision-making that took place. Some episodes of designing made no use at all of 2D or 3D modelling. For example, Vince stated that a lot of his ideas were "worked through" in his head (to determine whether they would work or not) and that unworkable ideas, in particular, were not externalised. Examples of the Injection Moulding students' 'hidden thinking' in relation to materials and processes are now presented for illustrative purposes. The figures are taken from the students' sketch sheets.

Adam's 'hidden thinking'

Adam designed a widget as part of a modular hung shelving system based around the reuse of guitar strings. His thinking behind Figure 13 was that the strings passing through the widget would act like a cheese wire and tear the widget material; this utilitarian consideration is not evident from the drawing.
In another sketch, Figure 14, a great deal of thinking about the visual properties of materials is concealed. The drawing is of a red widget but Adam thought that this "might look dire" in comparison to the products that would be perched on the hanging system, so in his 'mind's eye' he considered a black version imposed on the drawing of the red widget. Another possibility was a marbled effect, which he also imagined imposed on the drawing. To an outsider, the drawing looks like nothing more than a rather simple visualisation of an idea, but for Adam its function was greater than this.

Vince's 'hidden thinking'
Vince looked at reclaiming old or used products by designing a widget to connect them together to give them a new lease of life or a completely new use. He started by looking
at translucent cigarette lighters and developed ideas for a lamp in which the coloured lighter cases would be illuminated by a bulb. An injection moulded widget would fasten the lighters together. Figure 15 holds the thinking in relation to this period, but regard for the expressive functions of the lighter material is not obvious from the artwork.

Figure 15: Design work holding attention to expressive qualities of materials

In a different widget idea, Figure 16, Vince looked at re-using 35mm film canisters by replacing the standard lid with a modified version. Some of the thinking behind this drawing was based on a concern that the material needed to be sufficiently flexible to extend around (and clip onto) the lip of the main canister body. To achieve this, the lid would be "made from LDPE" (low density polyethylene), but no note of this is made on the artwork.
As the work by the Injection Moulding students shows, it would be unwise to assume that (a) products of 2D and 3D modelling represent a complete description of designing, and (b) a lack of visual or verbal evidence indicates a lack of underlying cerebral activity. Because some of designers' thinking is embedded (and inaccessible) in the products of 2D and 3D modelling, in order to extract that thinking (and therefore go beyond mere inferences) it is necessary to ask designers to make that thinking explicit\(^\text{27}\). A call to this effect was made some time ago by Darke [1979], in order to understand designing from designers' perspectives. Verbal accounts of designing can be requested to be given in direct relation to episodes of 2D and 3D modelling. In exceptional cases, conscientious designers will accompany their everyday designing with such a log of reasoning [Jones, 1992:xxvi].

**Data collection requirements for a longitudinal study of designing**

Marsh [1997] provides a succinct introduction to several of the key factors of influence when devising a descriptive study of designing (environment; nature of the study; individual subjects or teams; problem complexity; number of cases; time constraints; duration; data collection methods). Other useful texts in this area are: Lera [1983], Yeomans [1982] and Bessant [1979] (for advice on studying designing generally) and Stauffer, Dietman & Hyde [1991], Stauffer & Ullman [1988] and Magee [1987] (for advice on studying designing in engineering).

\(^{27}\) It is acknowledged that thinking will remain elusive if the underlying knowing is tacit.
Bayazit [1993] was concerned with describing the nature of designers' knowledge and suggested a three-stage process for documenting and analysing design activity.

1. Knowledge elicitation. Collect data on designers' thinking and archive this in an unstructured and unanalysed form.
2. Interpretation of knowledge. Analyse data by a hierarchical procedure.
3. Structuring of knowledge. Present findings and discuss their wider validity and implications.

It is this structured approach that has been adopted for this enquiry. The methods of data analysis that were adopted are described in detail in Chapter Six.

The environment and the nature of the designing to be studied

The majority of published analyses of professional designing (across all areas of the design field) have been performed on tasks that were "...shorter, less complex and did not require the extensive integration of knowledge" that is characteristic of a full project [Walz, Elam & Curtis, 1993:63]. In these studies, the design environment is purposefully stripped down to what amounts to laboratory conditions. This is not necessarily a problem for researchers interested in examining designing at a microscopic level. Their objectives can often be met by studying short episodes of designing that do not come from a naturalistic, longitudinal study. However, where it is the intention of the researcher to reveal current practices across the length of NPD, the activities under study need to be authentic. A fact that needs to be confronted by researchers is that designing is "...pursued through action in and on the real world, in all its complexity." [Archer, 1995 paper 5:4] Any moves to artificially control either the design environment (e.g., the duration of the designing) or the decision-making processes (e.g., access to information and tools; denying 3D modelling) would undermine the authenticity of the design act and, hence, instil doubts over the validity of the collected data. A high priority was therefore placed on taking a naturalistic approach to data collection. The studied designing would be carried out in real-world circumstances (i.e., in a normal working environment), with all inherent complexities and long time-scales intact. Under such conditions, events such as client meetings, feedback on ideas from users and consultation with specialists would occur normally. Prospective data collection methods therefore needed to be workable within a naturalistic setting.
Interference with designing

Data can be collected either concurrently (at the time of designing) or retrospectively (at some point after the event). It is desirable to collect data close to the activity under study in order to reduce the likelihood of unintentional misreporting. Recollections made some time after the event have a tendency to be smoothed-out versions of what actually happened [Lawson, op. cit.]. However, the leaving of a gap between designing and reporting back might be seen as beneficial. By allowing for a period of reflection, a designer will have opportunity to assess how worthwhile an episode of designing has been, something which is difficult to determine at the time of designing. A major drawback of gathering data very close to the activity under study is the risk of disruption to that activity. This last point will be discussed later in relation to (a) concurrent verbalisation and (b) a diary produced concurrently with designing.

Limitations of data collection methods

A study of designing, in which the designer is the main focus of attention, is close to a study of people at work generally. The same problems to do with revealing what people are thinking apply. Data are normally evaluated against three criteria.

- Reliability. Would the same results be obtained if data collection were repeated under identical situations?
- Validity. Can the authenticity and accuracy of data be corroborated?
- Effectiveness. Has what was set out to be captured actually been captured?

These three criteria are now examined in relation to designers giving accounts of their decision-making.

Reliability

People are not machines; they are not able to report on every detail of their activities. Details come and go. Thus it must be expected that, on another occasion, the depth and complexity of an account (but hopefully not the essential message) might be slightly different. An element of learning is also present in the process of making explicit design decision-making (where that process is not normally carried out). A designer's ability to give a thorough account can be expected to improve over time.

Validity

Only the designer knows what he or she is thinking, so there can be no independent verification of the authenticity or accuracy of the accounts of designing thereby given.
Validity therefore hinges on acceptance of the honesty of designers' accounts. However, honesty will be compromised in situations where the designer under study deliberately (and perhaps out of character) makes great effort to be seen in a good light [Robson, 1993:254]. This characteristic is termed 'reflexivity'. The most common method of verification of somebody's account of events is, where possible, to 'triangulate' what is said against other sources of evidence. For industrial design, this would include the existence of, for example, sketch sheets, models and notes from meetings, as well as confirmation from colleagues that reported work was indeed carried out. With such checks, dishonest accounts "show up as inconsistencies" [Bourque & Back, 1982:93].

**Effectiveness**

Effectiveness refers to how useable collected data are for answering research questions. This may be determined, to a degree, prior to data analysis but is probably better left until afterwards, when a fuller examination can be made.

**A review of prospective data collection methods**

The following data collection methods were unsuitable for this current research because by themselves they could not reveal designers' thoughts:

- observation by a research worker;
- video recordings of designing made without audio\(^{28}\).

**Concurrent verbalisation and protocol analysis**

A development on video recording is the method known as protocol analysis, as described in the introduction to the thesis. Table 6 overleaf is a review of some recent protocol analysis studies in design. The 'engineering' category includes mechanical, electrical and electronic engineering. A typical protocol includes the following columns of data:

- absolute time (to the nearest second);
- a verbatim transcript of concurrent verbalisation;
- notes on any parallel motor activity (e.g., drawing, examining).

\(^{28}\) The value of video recording a designer at work was assessed during the development of the diary of designing. More details are given later in this chapter.
Very short stretches of a protocol (spanning minutes) tend to be examined and hence the descriptions of design activity that are developed tend to be at a microscopic level. As an example, the analysis method used by Dorst & Dijkhuis [op. cit.] was to split the protocol into fifteen second periods and for each period assign a five figure word (it was found that the studied designers rarely deviated from a single topic within a fifteen second time period). The five figure word (e.g., 03102051351001) provides a coded description of the categories of activity that were engaged in at the time. Researchers are free to define their own categories in order to meet their specific research objectives. Protocol analysis requires extensive effort in capturing and transcribing data and for this reason alone is practicably suited only to short design exercises that can be controlled in a specially allocated room.

Some people find concurrent verbalisation easy to cope with [Davies, 1995]. Others (this author included29) find it unnerving and intrusive [Waldron & Waldron, 1988]. In order to capture trains of thought, concurrent verbalisation requires that the designer 'talks aloud thoughts' rather than 'talks aloud thoughts on a particular subject'. In this way, for NPD, data relating to materials and processes will not necessarily be collected and, in any event, such data will be mixed with data on other subjects. Hence protocol

29 The author set himself a short design exercise to see how he responded to concurrent verbalisation.

Table 6: Some recent protocol analysis studies in design

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Area of the design field</th>
<th>Area of investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>Gero &amp; McNeill</td>
<td>Engineering</td>
<td>Discussion and implementation of methods for analysing protocols.</td>
</tr>
<tr>
<td>1995</td>
<td>Akin &amp; Lin</td>
<td>Industrial</td>
<td>Modelling and the arrival at 'novel design decisions'.</td>
</tr>
<tr>
<td>1995</td>
<td>Dorst &amp; Dijkhuis</td>
<td>Industrial</td>
<td>The applicability of Simon’s and Schön’s descriptions of designing.</td>
</tr>
<tr>
<td>1995</td>
<td>Goldschmidt</td>
<td>Industrial</td>
<td>‘Productivity’ in designing and relationships with design ‘moves’.</td>
</tr>
<tr>
<td>1995</td>
<td>Lloyd, Lawson &amp; Scott</td>
<td>Industrial</td>
<td>The significance of periods of silent thinking.</td>
</tr>
<tr>
<td>1995</td>
<td>Vissel</td>
<td>Industrial</td>
<td>Use (and re-use) of knowledge during a project.</td>
</tr>
<tr>
<td>1994</td>
<td>Lloyd &amp; Scott</td>
<td>Engineering</td>
<td>Decision-making viewed at a microscopic level.</td>
</tr>
<tr>
<td>1992</td>
<td>McGinnis &amp; Ullman</td>
<td>Engineering</td>
<td>The build-up of constraints during a project.</td>
</tr>
<tr>
<td>1991</td>
<td>Tunncliffe &amp; Scrivener</td>
<td>Graphic</td>
<td>Analysis of knowledge for artificial intelligence (AI) computer support.</td>
</tr>
<tr>
<td>1989</td>
<td>Radcliffe &amp; Lee</td>
<td>Engineering</td>
<td>Decision-making viewed at microscopic and macroscopic levels.</td>
</tr>
<tr>
<td>1989</td>
<td>Whitefield &amp; Warren</td>
<td>Engineering</td>
<td>Analysis of knowledge for artificial intelligence (AI) computer support.</td>
</tr>
<tr>
<td>1988</td>
<td>Eckersley</td>
<td>Interior</td>
<td>Decision-making viewed at a microscopic level.</td>
</tr>
</tbody>
</table>
analysis will not be an efficient method of gathering data solely on attention to materials and processes. Additional reservations about the usefulness of protocol analysis have been identified in separate studies.

- Concurrent verbalisation can simply contain 'echoes' of actions already captured by the video camera [Davies, op. cit.].
- There is doubt that 'thought aloud' words accurately reflect underlying cognitive activities involved in designing [Dorst, 1995; Oxman, 1995; Lloyd, Lawson & Scott, op. cit.]. The doubts are raised against a backdrop that tacit knowing and intuition are present in designers' decision-making.

Given the stated reservations, concurrent verbalisation (and, hence, protocol analysis) was not seen as a suitable data collection method for a longitudinal study of designing. Other data collection methods that could be used to provide documentary evidence were considered.

**Interviews**

Interviews could be organised, say, every day between the designer and researcher on the subject of materials and processes. Any more frequent than this and the interviews would be prone to becoming intrusive. If the designer did not object, an alternative approach would be for a researcher to ask questions and note responses whilst 'shadowing' the designer at work. As a method of data collection for the author's designing, interviews would not work because they required somebody else to formulate and ask suitable questions, and nobody was in a position to do this.

**Questionnaires**

Cooper & Cooper [1984] used questionnaires to record designers' opinions towards, and uses of, design guidelines. It seemed that some kind of self-administered report, similar to a questionnaire, might work as a methodical and suitable way of documenting designing for this current research. Questionnaires can be filled-in as and when required and can collect very simple or very detailed descriptions of a person's work practices, from a 'tick the box' format to a request to 'write about...'. If used on a regular basis, questionnaires (particularly requests to 'write about') resemble diaries.

A diary appeared on first inspection to be a suitable method for recording longitudinal design activity from the designer's perspective. Efforts were therefore directed to the
Development of a format of diary that the author could use to document his own designing.

Development of a diary of designing

Overview
A diary was proposed as workable so long as not too much was asked of the diarist. For this current research, accounts of designing were required only in relation to materials and processes. The potentially vast content of a diary was thereby quickly limited by this requirement. A diary that asked for accounts of designing on a range of subjects would take a great deal of time to complete and would be prone to very selective reporting, although it has been attempted: Mackinder & Marvin [1982:51] exhibit diaries written by architects giving accounts of intended and actual activities over one week (though the diary entries were little more than summaries). Ball [1990] also made use of diaries, produced on a weekly basis by seven final year electronic and electrical engineering design students in response to specific questions on project work.

A search of the ASLIB Thesis Index [1998] showed that diaries have played central roles in Ph.D. studies across academic fields (e.g., to collect data in human sciences, medicine, education and agriculture). Some researchers have analysed other people's 'life diaries', whereas others have generated primary data by writing their own diaries. Activity diaries, rather like checklist questionnaires, have been used to generate data. Diaries have been where people report on their perceived roles, thoughts upon, and feelings towards circumstances, especially in studies of teamwork or other social interaction. In this way, diarists serve as "...adjunct ethnographers of their own circumstances." [Zimmerman & Weider, op. cit.:484]

Brett [1987] has collected a fascinating and entertaining selection of writings from approximately one hundred diarists who wrote meticulous accounts of their everyday lives. He explains the kinds of entries that are made.

A diary very rarely has the polish of professional writing, although some diarists clearly wrote with enormous care and with a view to publication. But the occasional roughness is part of the charm. A diary entry should glow with the immediacy of reaction (even if the diarist subsequently revises his opinion of what he has written).

[ibid.:viii]

Brett points out that diaries can have a variety of slants in their content, reflecting the character of the diarist and revealing something of the importance of events in their life, both through inclusion (and notable omission) of subject matter.
A diary can also be a conscience, as Rev. W.J. Temple observed on 29 February 1796: 'Strange that I have not begun my Papers. A Journal is certainly of use: at least it lets us see how little we do, and how difficult it is to carry good resolutions into effect. Every week, for some time past, I have intended to begin upon these Papers, yet have not.' [ibid.: xi]

In the context of research, descriptive (and less introspective) data are generally sought. Diarists are often asked to respond to specific (but relatively open-ended) questions as they write their entries [Bourque & Back, op. cit.; Zimmerman & Weider, op. cit.]. This was the approach adopted in this current research.

Table 7 lists recent documentaries of designing that fall into a category termed 'retrospective reviews'. These documentaries have a common element of post-designing commentary (or a 'review') of a spotlighted longitudinal design project. On occasions, the commentaries make direct reference to the products of 2D and 3D modelling. A diary could also easily do this, so that the use of modelling could be tracked through a project.

### Table 7: Some recent retrospective reviews of design activity

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Area of the design field</th>
<th>Data collection method</th>
<th>Area of investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>Roy</td>
<td>Industrial</td>
<td>Post-designing narrative</td>
<td>The role of creativity in industrial design.</td>
</tr>
<tr>
<td>1992</td>
<td>Galle &amp; Kovács</td>
<td>Architecture</td>
<td>Post-designing narrative</td>
<td>The role of sketching in architectural design.</td>
</tr>
<tr>
<td>1990</td>
<td>Lee &amp; Radcliffe</td>
<td>Engineering &amp; Industrial</td>
<td>Post-designing questionnaire</td>
<td>Comparisons between the work approaches of industrial design and mechanical engineering students.</td>
</tr>
<tr>
<td>1988</td>
<td>Waldron &amp; Waldron</td>
<td>Engineering</td>
<td>Post-designing narrative</td>
<td>The nature of the conceptual phase of NPD.</td>
</tr>
<tr>
<td>1984</td>
<td>Bucciarelli</td>
<td>Engineering</td>
<td>Participant observation (and subsequent narrative)</td>
<td>The nature of real-world engineering design.</td>
</tr>
<tr>
<td>1982</td>
<td>Mackinder &amp; Marvin</td>
<td>Architecture</td>
<td>Time sheets (describing activities engaged in)</td>
<td>The role of information and experience in architectural design.</td>
</tr>
</tbody>
</table>

**Designing a diary**

At the outset of this current research, the use of diaries for documenting designing was limited to less than a handful of reported studies, so consequently there was much to be investigated. A first report on the author's development of a diary of designing was presented at an international conference [Pedgley, 1997b], where it was met with interest and enthusiasm. The next sections of this chapter comprise a more comprehensive
version of that paper. First person tense has been used to help convey clearly the work covered.

Different diary formats were conceived, tested and refined by me working on a trial project approximately seven months into the research programme to design a pair of sports sunglasses. The different formats were also considered as if they had been used on my final year undergraduate projects. Because of the pressures of time, some of the changes to the format had to be made once the longitudinal design project, the design of a polymer acoustic guitar, had commenced.

I used my designing to trigger in my own mind the kinds of questions that I would want a diarist or interviewee to tell me about the roles of materials and processes in their work. In this way, the development of the diary and the formulation of the research questions interacted with one other and my on-going literature reviews. It was a period of action research, "...calculated to generate or test new, or newly imported, information, ideas, forms or procedures..." [Archer, 1995 paper 3:2]. Action research is characterised by intervention in the situation under study by the researcher for the purpose of reaching some goal; the researcher is participant (or active) in the situation under study and systematically performs some kind of action [Stringer, 1996]. In this case, the action was the testing of different formats of diary, especially important before asking other designers to become diarists. The periods of learning that resulted were valuable for bridging the gap between what I would have liked to have captured and what was available to be captured.

Zimmerman & Weider [op. cit.:491] provide a good summary of what it was like to be involved in the period of action research.

Our experience with the diary (...) recapitulates the basic structure of most ethnography: the ethnographer only partially knows the particulars of conduct he is looking for before they are encountered, but upon seeing them, he or she knows that they are what have been sought 'all along'.

I took stock of the kinds of entries I was making into the diary, asking myself: 'How can I change the format and questions so that I record this data rather than that?'. A notebook was kept at the time to record my changing ideas for the format. Over time, the questions I had set myself to answer in the diary became memorised.

In parallel to writing a diary, all the products of my 2D and 3D modelling were attached with a label for confidentiality and intellectual property rights (IPR) purposes, as shown in Figure 17.
The © symbol formally declared copyright of the design work to the author and the 'all rights reserved' statement provided IPR cover for countries that are not signed-up to the international copyright convention. The date was added so that the work could later be sorted into chronological order and the label was signed to verify authenticity. In addition, sketch sheets and log book pages were assigned unique codes to aid sorting and referencing at the analysis stage. For example, 'DS20' referred to design sheet 20; 'LB1:22' referred to log book 1, page 22.

The concurrent format diary

...asking a designer to externalize his or her thinking in writing as it [designing] proceeds... is inconceivable.

[Galle & Kovács, 1996:185]

I wanted to test Galle's & Kovács' claim first hand since it seemed a logical starting point for the first format of diary: to gather accounts of designing as close as could be got to events happening. Whenever my designing touched upon the subject of 'technical concerns' (later refined to materials and manufacturing processes), I put my designing to one side to make a diary entry. Appendix II consists of an entry timing chart for the concurrent format diary. The mean number of entries made per day was four (the modal daily entry account was one). Entries were made at a mean frequency of approximately one every sixteen minutes (the modal frequency was one every two minutes) and entries took a mean of one and a half minutes to write (the modal duration was one minute).

The pre-formatted stationary used (Appendix III) was devised to be portable so that entries could be made equally as well in a studio or in a workshop. An area on the stationary titled 'what happened today?' was also filled-in so that each day's progress on the project (whether related to materials and processes or not) could be recorded. This information would be used to place attention to materials and processes into a broad context of NPD.
The concurrent diary was used during the early stages of the guitar project, over the first twenty four days (equal to approximately one tenth of the total number of days spent on the project)\(^{31}\). Entries for the concurrent diary typically consisted of a series of annotated sketches or brief lines of text. I used two referencing systems to link the contents of sketch sheets, log books and the like to my entries. Sometimes I would redraw what was on a sketch sheet or log book onto the preformatted stationary and add notes. For more complex artwork, I would mark a drawing on a sketch sheet 'X' and then refer to 'drawing X' in my entry.

Anyone who has been engaged intensively in an on-going activity knows that thoughts can follow oneself around day and night.

[In relation to design work], sketches are made on cocktail napkins and the backs of envelopes, groups work out ideas on chalkboards, realizations are made in the shower and on the way to work, decisions are made on the shop floor in response to unforeseen conflicts or opportunities.

[Kuffner & Ullman, op. cit.:42]

Instances of 'out of hours' designing were reported as retrospective comments in the next day's diary.

**Video recordings**

Video recordings were made in the early stages of the guitar project, in order to assess the worth of moving pictures of a designer at work (and, additionally, to provide data on the frequency and duration of writing concurrent diary entries). Features of designing such as the dynamics of sketching, the consultation of information and the 'twiddling of thumbs' could be examined from video recordings (Figure 18). The thinking at the time was that video recordings might be used to assess the 'productivity' of designing in relation to different information sources, taking a similar line of enquiry to Goldschmidt [op. cit.]. As part of this thinking, the concurrent diary entries were, when appropriate, complemented with a period of reflection at the day's end. The reflection was made in response to the following questions and was written in a different coloured ink to the concurrent entries.

\(^{31}\) Diary entries for the guitar project were made on a total of 227 days. This figure is approximately equal to the number of days for which time was spent on the project (notwithstanding the fact that for some of these days, far less than a whole day’s work was dedicated to the project).
Can key moments in today's work (that have genuinely advanced the design project) be identified?32

Were any information sources used today for considering materials and manufacturing processes that will not appear on the video tape?

Are there any general comments arising from today's designing regarding the consideration of materials and manufacturing processes?

The video recordings provided clear evidence of design work in progress, including the precise sequence of pen-on-paper marks for each sketch sheet. Video recording was later ceased because the focus of the research turned away from the examination of drawing-in-action and the measurement of 'productivity' of designing. For the same reason, the pre-formatted section of the diary marked 'enthusiasm' was removed. It had been a rather naïve attempt to gauge my current persuasion towards the design project.

During its use, a number of minor changes to the concurrent diary format were made and some major changes were considered but not put into practice (Appendix IV). Over time, the concurrent diary became tedious to write and the interruptions (forcing stop-start working) became annoying. Whether or not those interruptions adversely affected the design activity under study is a moot point. On a macroscopic level, one would suspect not, because there is no obvious reason why interruptions should change long-term goals and ideas for how to tackle a project. On a microscopic level, trains of thought are most definitely halted (but not necessarily diverted) by having to pause to make an entry. These aside, the most pressing methodological constraint of the concurrent diary for me was the annoyance of interruptions.

I had come to conclude that what I covered relating to materials and processes on any given day was not vast and that the details of the attention were still fresh in my mind at the day's end. Towards the end of using the concurrent diary, I was thinking how I could make better use of sketch sheets (found in practice to be where most of my thinking in relation to materials and processes was externalised). In response, I decided to develop an 'end-of-the-day' diary format: outside of the activity so that it did not intrude, but close enough for the designing to be fresh in the mind. This new format would also make better use of sketch sheets.

32 This question was posed to replicate Akin's and Lin's [op. cit.] identification of 'novel design decisions' (major advances in a design project). The major advances so identified need not necessarily be related to materials and manufacturing processes.
The end-of-the-day format diary

Three formats of stationary were developed for the end-of-the-day diary, as below. The stationary is contained in Appendix V.

- A 'standard' sheet. This had a large blank area in which a detailed entry could be made. It also had spaces for 'date', 'sheet number' and the 'day's main activity'.
• A 'tracing' sheet. This was a formatted sheet of tracing paper that could be overlaid onto any paper-based design work. Its purpose was to link attention to materials and processes to 2D modelling\textsuperscript{33}. Attention could be circled and described on the tracing sheet. Tracing sheets have an advantage over plain paper in that artwork does not have to be re-drawn. Also included were spaces for 'date', 'sheet number' and the 'day's main activity'. Figure 19 shows the tracing sheet in use.

• A 'no detailed entry' sheet. This acted as a record of the day's main activity when designing was carried out but no materials and processes considerations were made.

![Figure 19: Use of the tracing sheet end-of-the-day diary](image)

When writing the end-of-the-day entry, the day's sketch sheets, log book entries and models acted as tangible reminders of how thoughts evolved. In practice, at least one of the three formats of preformatted stationary was filled in on every day that work was carried out on the guitar project. Similar to the concurrent diary, 'out of hours' thoughts were recorded the next day. The end-of-the-day diary was used for the last 90% of days spent working on the guitar project.

\textsuperscript{33} This was thought to be especially useful if the attention was difficult to put into words.
Diary studies of other designers

Because the initial formats of the diary were intended for no-one other than myself, and because the work was exploratory, there was no real need to write explicit instructions on how to make a diary entry. However, in preparation for securing diary studies by other designers, written instructions were produced once the end-of-the-day format had been finalised (see Appendix VI). These written instructions were devised to uncover both macroscopic and microscopic levels of attention. Following a poster display [Pedgley, 1997c], five design consultancies (Dartnall Design Associates, DCA, IDEO, Jones Garrard and Renfrew Associates) and two in-house design departments (Black & Decker and Berghaus) were contacted to seek their agreement to make a diary study of one of their design projects. None of the consultancies or companies were able to participate. On reflection, it was probably asking too much of these design firms to fit the production of a diary into their already busy schedule, especially given the little direct benefit to them. As an alternative strategy, I secured agreement that two finalist undergraduates, working on the same design-and-prototype project, would produce diaries. The purpose of these additional studies was twofold:

- to secure information on whether or not other people found the diary workable;
- to provide evidence of attention to materials and processes for use in cross-case comparisons.

A briefing was given to the undergraduates to explain the purpose of the diary and how it worked. The students' details were gathered on pre-formatted stationary (Appendix VII).

To investigate professional designers' handling of materials and processes issues, semi-structured interviews with nine practising industrial designers were arranged. Even this did not prove easy. Of forty one firms approaches, 63% did not reply, 15% replied but declined to be interviewed, and 22% agreed to be interviewed. This response to a request for an interview underlined how difficult it would be to secure the far greater commitment that a diary study needed (and, indirectly, provided weight to the argument to take my own designing as a case study).

Effects on the authenticity of the spotlighted designing

The writing of a diary requires a designer to reflect and report on the day's work in a way that is not part of normal design activity. The act of reflection, where reflection is not
normally given, will obviously heighten a designer's awareness of the subjects involved. Schön & Wiggins [op. cit.: 155] have described this phenomenon.

The hard work of making explicit the discoveries gained through designing may help to make them more readily accessible and more subject to conscious control and choice.

Designing will therefore be affected in some way simply by (a) writing a diary in the first place and (b) undertaking parallel academic studies (e.g., literature reviews, interviews). The latter can be classed as nothing more significant than the development of one's experiential base. The former will be examined in an evaluation of the diary method in Chapter Ten.

The undergraduates' post-diary interview

Burgess [1981] and Zimmerman & Weider [op. cit.] report that post-diary interviews work well for assessing the validity of, or expanding upon, diary entries.

While no unimpeachable assurances were available that a given diary was not a work of fiction, the impact of this intensive interrogation [post-diary interview] was presumed to be such that maintaining a pretense would be difficult without falling into glaring inconsistency, especially since the diary writer did not have access to his or her diary after its completion or during the interview.

[Zimmerman & Weider, op. cit.: 491]

Post-diary interviews can also be used to establish the reasons for why a diary may be scant of entries. The diarist may have been unable to commit to the method, may have found it too difficult to articulate their designing in words or may have reported accurately that decisions were taken independent of concerns for materials and processes. Diarists can be asked in post-diary interviews to:

- explain the use of jargon or apparent strange or multiple use of vocabulary in entries;
- elaborate on entries that were unintelligible to the researcher;
- elaborate on episodes of designing that were of principal importance to the research (especially where the diary had captured insufficient evidence);
- provide feedback on how they felt about compiling a diary and how workable it was.
Post-diary semi-structured interviews lasting approximately one hour were conducted with the two finalist students in one of the Department's studios. An open-ended technique was used (e.g., 'talk me through...' and 'how did you approach...?') so that the responsibility was on the student to dictate the content of answers. The precise wording of the questions posed in the interviews therefore differed for the two students. As is normal for such interviewing, a focus or new direction was set when:

- it was timely to do so (e.g., the interview approached a substantive matter but it was probable that, without an interjection, the matter would pass under-discussed);
- the interviewee 'dried up' and needed a prompt or question to continue giving an account of their designing.

A checklist was to hand as a reminder of the key topics (from Chapter Four) to be covered in the interview. At no time did the interviewees see this checklist. Being an excellent stimulus for discussion, the products of 2D and 3D modelling were referred to in the interview. The interviews were audio recorded and, in parallel, notes were made of the sketch sheets and models that the students referred to. The audio recordings were transcribed as a combination of paraphrases and verbatim quotations (Appendix VIII). Comments on the use of the diary were recorded on a questionnaire sheet at the end of the interview (Appendix IX).

**Interviews with professional designers**

Eight one-to-one interviews were given across three distinguishable kinds of practice. One email questionnaire (based on a reduced set of the interview questions) was answered by Pentagram consultancy, London. The interviewed designers were employed at different sized practices, ranging from a solo consultancy (Dartnall Design Associates) through to a giant multinational company (Samsung). With this range, the perspectives of consultancies and in-house design departments could be revealed. The participating firms are listed below.

**U.K. freelance (solo) designers**

Dartnall Design Associates, Belton, Leicestershire
U.K. consultancies
BIB, Whitchurch-on-Thames, Berkshire
Grey Matter, Central London
Johnson Haigh Rogers, Loughborough, Leicestershire
Pentagram, Central London

Manufacturing companies with U.K. in-house design departments
Flymo, Newton Aycliffe, Co. Durham
Kenwood, Bramley, Hampshire
Nokia, Camberley, Surrey
Samsung, Brentford, Middlesex

All of the interviews, except that with Dartnall Design Associates, were conducted at the firms' premises. The interview technique was similar to that of the post-diary interview: semi-structured and conversational. The questions posed related directly to the questions stated in Chapter Four. The interviewees were not aware of the questions prior to the interview. None of the designers objected to audio recordings of the interview being made (to avoid making distracting and incomplete notes during the interview). Verbatim transcripts were produced for each interview (except in the case of BIB, where the recording device failed to work). The transcripts were made soon after the interviews were given so that difficult-to-transcribe periods would benefit from fresh recall of what was said. The interviews each lasted approximately one hour.

Factual questions and attitudinal questions were posed. Prior to the interviews, the questions were reviewed for reflexivity (i.e., whether particular answers might be provoked by the wording of the questions)\(^{34}\). The questions were pre-written but not adhered to rigidly, on the premise that open-ended, flexible questioning would be necessary to penetrate the issues as they were encountered. Responses were negotiated through re-phrasing and clarification. After each interview, consideration was given to how questions could be better phrased for the following interview (and whether questions needed to be added or removed). Eisenhardt [1989] describes this as a sensible way of proceeding if absolute consistency of data collection between cases is not vital. In practice, the changes made to the emphasis and the wording of questions were not major. They were made because (a) interviewees had different professional responsibilities and (b) as an interviewer, one learns to use more precise language. The question list for the last of the interviews, held with Nokia, is contained in Appendix X.

\(^{34}\) It is acknowledged that a bias can also be introduced in the delivery of questions in the interview; at all times the author strove to appear neutral to the responses that were being given (as advised by Stringer [op. cit.:64]).
Summary of the diary of designing

An end-of-the-day diary of designing has been developed as an instrument for capturing long-term designing. A completed diary comprises a chronologically correct running commentary on designing in a narrative / graphical form which can be stored as an archive and subsequently analysed. Reporting at the day's end is a compromise between being too close to the activity (and upsetting it) and too distant from it (when the likelihood of providing misinformation increases). The diary is made in relation to a single element of designers' work and with respect to just one NPD project.

Features of the diary

- It is written by the designer at the day's end.
- It documents the designer's account of working (rather than an outsider's inferences).
- The content is requested not to include elements of design activity that the researcher is not interested in.
- The content is requested to be made against a few guide questions and prompts (so that the final content is focused but not rigidly dictated, allowing for the designer's perspective and writing style to prevail).
- The discipline of day-by-day reporting encourages accuracy in accounts.
- Since diaries require no meticulous transcription, a great deal of time and effort can be avoided at the analysis stage.
- The studied designing can be carried out anywhere the designer chooses since the diary does require the designer to work at a particular location.

Limitations of the diary

- It requires the production of documents which are not normally expected of a designer and which may be considered obtrusive.
- Diaries are subject to the same limitations of reliability and validity as other methods of collecting data on designers' thoughts. The precise content of a diary will be a reflection of the diarist's capability to verbally articulate what they have covered in their work.
- Diaries rely on honesty. For the author's designing, two witnesses have verified that entries were made into the diary at the day's end, as the guitar project progressed (Appendix XI). For the undergraduate studies, a post-diary interview was conducted.
• Once work on the guitar project had commenced, diaries were archived and left unconsulted until the end of the project. Without this strict rule, the diaries were available as a quite abnormal source of information for use in designing.

• The diary, by definition, provides an individual’s account of designing. Team designing could be studied by the individuals in a team each writing a diary, though this might prove very complex to analyse, especially cross-checking. As an alternative, a nominated individual could produce an account of designing, acting as a spokesperson for the team, although a diary completed this way would probably lack sufficient data for analysing trains of thought and cognitive modelling.

An evaluation of the end-of-the-day diary of designing is included in Chapter Ten.
CHAPTER SIX

Data analysis methods

Introduction
The analysis of people's written or spoken reports often commences with the categorisation of the content of those reports [Sapsford & Jupp, 1996:166]. Protocol analysis studies of designing are made in this way too. In the Delft University study, researchers were asked to "...perform the analysis in any form they saw fit." [Cross, Christiaans & Dorst, 1996:4] In practice, researchers assigned categories to the protocol according to their personal objectives.

The analysis procedure for this current research shared the same starting point of data coding. Altogether, four stages were covered in order to systematically construct descriptions and subsequent theory.

- Stage 1: Assignment of codes to the interview transcripts and diary entries.
- Stage 2: Within-case collation of interview transcript and / or diary entry excerpts of the same code.
- Stage 3: Description of each case in relation to the research questions.
- Stage 4: Cross-case comparison and development of model descriptions.

Each stage is now described in turn.
Stage 1: Assignment of codes to the interview transcripts and diary entries

Eighteen words (presented in the first column of Table 8) were used to code the data into categories directly related to the research questions in Chapter Four. Codes were assigned according to the content of sentences or individual passages of narrative. Either (a) no code; (b) a single code; or (c) multiple codes were assigned. Not every code was used in every interview transcript or diary. The analysis relied on the author seeing links between the data and the possible categories. It is acknowledged that the success of the analysis is dependent on "...the experimenter's own knowledge of the process he is observing / analysing." [Cornforth, 1976:134] At all times it was necessary to assess whether in fact none of the predefined categories adequately fitted the data. On five occasions during the coding of the interview transcripts, this was found to be the case, but it was clear that the data would be useful to the enquiry. To cope with this, new emergent categories were defined. The emergent categories were seen as important because they arose from the data and had not been identified in the literature reviews. In other instances, data were rejected on the grounds that its content was not relevant to this current research.

Some of the codes used for the early transcriptions differed slightly from the definitive list in Table 8; the differences were due to more precise use of words in later transcriptions. The discrepancies in the coding are described below.

- 'GROUNDWORK' was a code used to refer to work that a designer might need to cover before attention to materials and processes could be given. Data given this code have been merged with data coded 'WHEN'.
- 'PALATE' was a forerunner code to 'RANGE'.
- 'PROPERTIES' was a forerunner code to 'FUNCTIONS'.
- 'KNOWLEDGE' was a forerunner code to 'KNOW/VALUE'.
- 'APPROACHES' was a code used to refer to a designer's use of knowledge, values and/or information. Data given this code have been merged, as appropriate, with data coded 'INFO', 'COMPUTER', 'KNOW/VALUE', 'COG', '2D' and / or '3D'.

Appendix XII contains, by way of example, the coded transcript for the Samsung interview.

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35 With the exception of the last two words, which emerged in the processes of analysing the interviews with professional designers.
Stage 2: Within-case collation of interview transcript and diary entry excerpts of the same code

For each interview and diary study, passages of narrative assigned the same code were collected and arranged systematically.

<table>
<thead>
<tr>
<th>ROLE</th>
<th>The role and significance of materials and processes in industrial designers' decision-making</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHEN</td>
<td>The timing and sequence of attention</td>
</tr>
<tr>
<td>SPECULATIVE</td>
<td>Speculative product design</td>
</tr>
<tr>
<td>LEVEL</td>
<td>The level of detail reached</td>
</tr>
<tr>
<td>CONSTRAINTS</td>
<td>Constraints</td>
</tr>
<tr>
<td>RANGE</td>
<td>The range of materials and processes that are able to be specified</td>
</tr>
<tr>
<td>GREEN</td>
<td>'Green issues' in practice</td>
</tr>
<tr>
<td>CREATIVITY</td>
<td>The nature of creativity with respect to materials and processes</td>
</tr>
<tr>
<td>OPPORTUNITY</td>
<td>Opportunities offered to industrial designers</td>
</tr>
<tr>
<td>FUNCTIONS</td>
<td>Functions that industrial designers desire materials and processes to satisfy</td>
</tr>
<tr>
<td>INFO</td>
<td>The use of information</td>
</tr>
<tr>
<td>COMPUTER</td>
<td>The use of computers</td>
</tr>
<tr>
<td>KNOW/VALUE</td>
<td>Knowledge and values</td>
</tr>
<tr>
<td>COG</td>
<td>Cognitive modelling</td>
</tr>
<tr>
<td>2D</td>
<td>2D modelling</td>
</tr>
<tr>
<td>3D</td>
<td>3D modelling</td>
</tr>
<tr>
<td>TASK</td>
<td>Tasks (other than modelling) for reaching decisions on materials and processes</td>
</tr>
<tr>
<td>FORMAL</td>
<td>Evidence that rigid design procedures are followed</td>
</tr>
</tbody>
</table>

Table 8: Codes used in the analysis of transcripts and diary entries (all with reference to designers' attention to materials and manufacturing processes)
Stage 3: Description of each case in relation to the research questions

In Section Three of this thesis, the findings of each interview and diary study are initially presented separately, partly to aid analysis and partly to make data presentation clear. This approach is taken on the advice of Allison et al. [1996] and Eisenhardt [1989].

In general, analysis first requires that you familiarise yourself as much as possible with this information, ‘immersing’ yourself in the different interviewees’ accounts. As part of this process you may find it useful to make summaries of each interview, noting major themes or consistent points of reference across the interviews conducted.

[Allison et al., op. cit.:121]

...the overall aim is to become intimately familiar with each case as a stand-alone entity. This process allows the unique patterns of each case to emerge before investigators push to generalize patterns across cases. In addition, it gives investigators a rich familiarity with each case which, in turn, accelerates cross-case comparison.

[Eisenhardt, op. cit.:540]

For each interview transcript and diary, some sentences and passages were used verbatim, some were used paraphrased and for others, additional material such as photographs and the products of modelling were reproduced for illustration. On those occasions when the message conveyed was especially clear, the passages were used verbatim. On other occasions, paraphrases were used to clarify the content of what was said or written. A significant majority of the interview responses and diary entries were clear in their content and meaning. On the few occasions where the content and meaning were ambiguous, a note was provided on the analysed transcript or diary stating whether anything had been inferred (and why). No questioning of the data was made in the sense of asking ‘did they really mean that, or did they mean this?’. For the author’s diary, introspection (analysing the fact that something was reported) has been avoided. The data from each interview and diary were checked for within-case contradiction and, for the undergraduate diary studies, entries were cross-examined against the post-diary interview transcripts. The results of the interviews with professional designers are presented in Chapter Seven, and for the diary studies in Chapters Eight and Nine.
Notes on the analysis of diaries
When examining the diaries, it was important to be aware of two key issues:

- discrepancies between early and later entries (which might reflect a change from novice to skilled diary-writing);
- the meaning of vocabulary changing over time (and of vocabulary being used in both literal and figurative forms).

Stage 4: Cross-case comparison and development of model descriptions
At this stage, a level of transferability was sought between the results from the collective in-house design departments, consultancies, own-practice and undergraduate work, but stopped short of forthright claims for practices in general (since this could not be achieved with confidence from the small number of individual cases studied). The results of the empirical work were compared against the findings of the literature reviews in Section One of the thesis, in order to propose considered model descriptions of designers' practices. The conclusions both at macroscopic and microscopic levels are contained in Chapter Eleven.
SECTION THREE

Results of analyses
CHAPTER SEVEN

Interviews with professional designers

This chapter contains the results of the interviews held with professional designers. The interview technique adopted was described in Chapter Five. The designers responded to the interview questions by providing answers made in relation to (a) one particular brief, (b) a family of products, and / or (c) design briefs and products in general. Cross-case comparisons and discussion of the results in this chapter are contained in Chapter Eleven. The results are presented in the following order as discrete studies.

1. Dartnall Design Associates (freelance consultant)
2. BIB (U.K. consultancy)
3. Grey Matter (U.K. consultancy)
4. Johnson Haigh Rogers (U.K. consultancy)
5. Pentagram (U.K. consultancy)
6. Flymo (manufacturer with a U.K. design department)
7. Kenwood (manufacturer with a U.K. design department)
8. Nokia (manufacturer with a U.K. design department)
9. Samsung (manufacturer with a U.K. design department)
INTERVIEW ONE

Dartnall Design Associates

Adrian Darfnall works as a self-employed product designer from his office at Belton, Leicestershire. In addition, he is employed by Loughborough University, providing tutorial support for students on the Industrial Design & Technology courses. The interview took place at the University.

The role and significance of materials and processes in industrial designers' decision-making

...if you've produced a design which hasn't taken into consideration manufacturing problems (...) somebody else [working on the product] will do that and they will change your design and they won't do it in the way that you would have done it (...) ...your hair will stand on end when you see it. So, you better do it.

The timing and sequence of attention

Attention should be given very early on, as soon as an idea for a product has been entertained. Mr Dartnall noted that his consideration of candidate materials and processes is not always made particularly consciously: "...but you're doing it right from the word go...".

There is no 'point' at which consideration at a specific level, or consideration at all, starts. Overview and detail decisions are intertwined in NPD. From the designer's perspective, there is a feeling that in order to progress, all the details of a design need to be determined in one go. Mr Dartnall explained this in detail, concentrating on the interdependency and cyclic nature of design decision-making.

Industrial design is an instant thing. [For it to work], the idea has to come all in one go with everything known... which is impossible. (...) The surface textures that you use, the detailing that you use on the surface, can be about hiding sink marks (...) and not purely for decoration and (...) other aesthetic considerations, but it is that as well. [In an injection moulding, for instance], you know where the ribs are, you know where the thicker bits of material are and you know where the bosses are and you say, 'well, now I've got to do something with this surface- I need to break it up, because it's a big flat surface [which is unexciting], I want to lead the eye in so that [something is
made of the surface]. At the same time I've got these damn bosses [which will cause a sink mark on the flat surface] that I want to hide'. (...) If you did it in one go it would be impossible [to get your head around]. So what you do is go round and round (...) fairly quickly. You look at re-jigging and seeing the effect of alterations on the rest of the design; you synthesise the alterations with the design proposal as it stands. You think 'now that works quite nicely, but I've got this problem here, it misses out those ribs'; 'can I move those ribs? would it be sensible to move those ribs, purely because it's surface decoration?'. Maybe you can if it's just a small amount, so you know, these things, round and round.

Lack of time was cited as a major factor for not setting aside at the commencement of a project a period of simply "open-minded thinking" (i.e., designing without assessing the practicalities of a design, as in the technique of brainstorming\(^\text{36}\)). Mr Dartnall thought that an open-minded approach at the start of a project was worthwhile but in practice probably did not happen enough.

If you're working in a big consultancy for big clients who have bigger budgets, then you would expect (...) a certain amount of time to be given to [open-minded thinking]. The reality is, however, that for the majority of middle-to-smaller manufacturers, the time that they actually are prepared to pay for is very, very limited [so the work consequently needs to be tightly structured and speedy]. So it may be three days on a project, or six days. A six-day project is a lot of work and [clients] wince at the price (...) when you've spent six days on something.

One way around the restrictions of time is to have a line of projects ahead. This way, before spending time proper on a project, one can flick through possible ideas, even if just at a cursory level, because it is not costing the client.

You can be out walking on the mountains and you've got these things going around in your mind. And certainly when you come away from those projects and leave them, you do a lot of really good creative thinking about them because you're away from it and pressure of time is not there.

The level of detail reached
In Mr Dartnall's work, the requirements for a product are established first, from which an assessment of potential manufacturing processes and assembly methods can be made, as given in the example overleaf.

\(^{36}\) Brainstorming refers to an activity of quick-fire, open-minded, imaginative and non-evaluative idea generation.
...is this product going to be (...) accessed for batteries? Is it going to need to be accessed for maintenance? Is it something that, once made, is never accessed and is thrown away? What kind of assembly? For example, (...) I did a hand grip system a little while ago, where I was looking for extremely high strength from two injection moulded parts that wanted to be put together permanently; no point in taking them apart, this was a single plastic thing.

A continuous-bead ultrasonic weld was chosen for the assembly of the handrail because the final product needed to be "...like an eggshell (...), a solid thing, no points, no stress transfer." The weld bead shape had consequences for the component shape, so to avoid abortive work it was clearly important to know about the details of different ultrasonic welding techniques.

Mr Dartnall's work frequently includes attention to materials and processes typical of the detailing phases of NPD. The examples given refer to injection moulded plastic components.

Product stiffening and assembly ribs and sink marks

If you're going to put lots of ribs in [a component] and make it of polypropylene you're going to see them all.

Tool design

When an injection moulding comes out of a tool (...) why does it come out? It comes out of the tool because it's pushed out. Why does it stay on that half of the tool and not come away in the other half? It does that because you designed it that way. (...) You know, if you've got ejector pins on one half of the tool but that's not where the moulding is, because when you've opened it it's stayed in the other half of the mould, when it shuts again and you inject again, you just squirt plastic everywhere, you seal the thing together, you weld it all up and you've got a major problem. It has to stay on the right side of the mould and you have to know that it will, and that's design.

Mould flow

Mould flow was seen as something for which industrial experience is necessary (especially of problems) before it can be understood and applied to design ideas. Mr Dartnall thought that recently-graduated designers are unlikely to look at mould flow, unless perhaps if they are working in-house (stated on the premise that in-house designers know their own products in more depth than consultants tend to).

If you're putting a grille on something, where is the feed point going to be relative to the grille? And if you design a grille which has got a series of slots running across the flow of the material, you can expect to get knit lines around the back of it and if you are using certain types of material they will show.
Constraints

Availability of materials and manufacturing processes

...very often you have an established organisation [as a client], who have a very good purchasing department and who already have an established source for a variety of materials, so you have to be careful that you're not specifying materials that are supplier-specific; you're to be very careful that you're specifying materials in a very general way.

If a client currently manufacturers only in ABS (acrylonitrile-butadiene-styrene, a popular impact-resistant thermoplastic) for example, it doesn't necessarily follow that a new product will inevitably be manufactured from ABS, but it makes it more likely.

You certainly get that sort of preference: 'we have a range of products which are in ABS and we want a product in that range; to fit-in with that range', so it helps to have the same material.

If ABS is appropriate for the new product, it makes little sense to force material and manufacturing diversity on the client company by specifying something else.

Budget

Choices of materials and processes need to fall within a price bracket that is appropriate for a product.

Design brief and the client

Working as a self-employed designer, Mr Dartnall is "...one thing to one company and (...) something else to somebody else." The nature of the work that he is commissioned varies accordingly.

Detail preferences of the toolmaker / manufacturer

You talk to manufacturers as early as possible, the people who you will be using, because they have certain techniques that they are good at and that they use a lot and it makes sense to use (...) their experience.

Product precedents

Clients do not specify the use of specific materials. This is instead led partially by the marketplace (i.e., the materials used in competitors' products). "Because there's an established market for [a given product] already, you're already being conditioned, saying we must use polypropylene, polythene...".
Volume of production

Production volume is essential to considering manufacturing processes and materials... You really can't start to think about form until you know what processes you are going to be using (...) and you can't start to think about that until you know how many you are going to be making. And, you know, everything kind of starts with those two pieces of information which you really do need.

The range of materials and processes that are able to be specified

Sometimes design work will hinge around a requirement of a brief to look at new materials and processes. The work in this case resembles a feasibility study, where the client might state 'we want to change this product (for whatever reason); what do you think to this material and what can you come up with?'. To an extent this is part of Mr Dartnall's normal approach to designing, though in this case made explicit: "...you have the freedom to move into other areas and look at other possibilities, and certainly that's part of what I'm doing anyway." In contrast, clients are less likely to suggest manufacturing processes, owing partly to a lack of awareness of what might be appropriate. "New design: they're assuming that it's going to be different. The fact that you've come up with new processes is expected."

And of course you can invent [processes]. I tend to shy away from that with students because they do have an inclination to invent... (...) they should be considering all [currently available methods] first, because if there's an existing technology that does it, and there's a form which is not far dissimilar to what they've already got, or another form that would be equally as nice and equally as good, [it will make NPD cheaper and simpler to make use of those].

'Green issues' in practice

Designing with 'greener' use of materials and processes in mind is:

- pressure-led and often no more than paying "lip service" (rather than a fundamental conviction to say 'what we really ought to be doing is thinking to the future');
- not widespread because of the financial burden of implementing green design practices (higher overheads will result in a lower profit margin if a product is to remain competitive);
- often accomplished by marking plastic components with SPI (Society of the Plastics Industry, U.S.A.) recycling symbols;
- implemented in part as a matter of course on production lines where waste material is re-ground and re-processed as much as is possible before mouldings become degraded.
Manufacturers' experience with re-ground plastic will make them wary about using bought-in third-party post-consumer recycled material.

To say to [manufacturers] 'here's a product which is... [post-consumer] recyclable, you can use this material, you know what [polymer] it is, you can re-grind it can't you?', they'll say 'well yes, theoretically you can, but we already do, as much as we dare, and if we go any higher [on percentage of recycled material in a moulding] we get our clients saying that our customers say, you know, this thing's falling apart in my hands'. As people demand it, as outlets demand it because their customers demand it, so manufacturers will be pushed to [use recycled material more extensively]. But it's no good the designer thinking that he can go along to his client and say 'you really ought to be regrinding more or you ought to be recycling more'- who says? The market isn't saying so yet, therefore the competition isn't doing it therefore I cannot afford to do it.

The nature of creativity with respect to materials and processes

...I don't really think that it's useful to do creative work without the constraints established, because most of your creativity is really directed at solving problems: overcoming difficulties, finding your way around some of the constraints that appear to be there. So if you don't know them, or you haven't really got them lined up in front of you, you don't know what the hurdles are that you're trying to jump. I think student projects, almost by definition, have [the problem of being greatly imaginative but lacking in creativity in the sense just described]. At the end of the day, they can look very creative. They can be very stimulating to look at and think about, but they haven't gone that stage further. And if they did, a lot of what has been done would crumble. And that is the case with just creative thinking for its own sake. It happens in a vacuum; it crumbles when you introduce the real constraints.

To go about designing "without knowing the constraints (...) means you've got to go round again and change it, or somebody else will if you didn't." Mr Dartnall commented that taking the practicalities of manufacturing into account does indeed constrain one's thinking and sometimes opportunities are missed because of a tendency to stick with one's limited knowledge of what can and cannot be achieved: "...there's no easy answer to that; (...) more time, bigger budgets."

Opportunities offered to industrial designers

Advancement of design

What [clients] have said is 'we want to compete'; 'we want to produce a better product than they're producing, using a smaller number of tools and more adaptable parts and therefore a nicer product at the same or lower price'. They certainly don't want to go higher.
Market differentiation

Materials and processes can be used strategically in response to a client's request. For example, "...we're looking for a product in this area and we think we can sell at a higher price at a premium if we have a very high quality product?" or "...we could sell a much higher quality product than [currently exists], we think there's room for it, but wouldn't it be nice if we could sell it cheaper than everybody else is already selling it?"

New technology

New materials and processing technology creates new opportunities for product design. Sometimes materials are invented in order to satisfy particular performance requirements. A designer might propose a product which involves an as-yet-unavailable or unproven (but notionally feasible) material to push design boundaries forward, "...and the materials come along [to do just that job]. Unfortunately they don't come along on a six-day project; maybe for someone working for eighteen months."

Functions that industrial designers desire materials and processes to satisfy

Material and process combinations need to meet the performance requirements (e.g., mechanical, chemical) of a set task.

The use of information

Mr Dartnall tends to consult information if he is making use of a process that has very specific requirements or if he knows that a particular company's equipment and materials will be used in a product, so that he can get the best out of them.

Designed artefacts and the wider world

I think every designer should leave behind a house (or every student designer should leave behind a parental home) full of disassembled products that, you know, are broken. [Products that you cannot] get back together again; parents who are tearing their hair out. I think that is an essential part. And broken is very important too, because breaking things tells you so much about them. Destructive children make good designers.

Liaison with end manufacturers

As well as using printed information, talking to specialists was important too. Close links with end manufacturers are often forged, either through personal contacts from past projects or because a client company has a preferred manufacturer.
Printed sources
Manufacturers’ information gives design tips and recommendations (e.g., processes that work well, product details that work well) but these are often specific to their own materials and not presented as general design information. Mr. Dartnall commented that manufacturers’ information for injection moulding was abundant and that this was especially useful to have to hand.

The use of computers
Computers do not help in the decision-making on the combinations of materials and processes to be adopted in a product. Mr. Dartnall considers mould flow problems for injection moulded components but does not use mould flow simulation computer programs.

Knowledge and values
DFMA knowledge
Mr. Dartnall agreed that knowledge of DFMA is acquired or generated through professional experience of product design.

...you know the general guidelines. For example, wall thickness of ribs should not be more than two-thirds the general wall thickness and they should not be a certain height relative to that wall thickness.

Effects of materials and processes on the creation of form
I know the constraints of process[es] and I know the opportunities of process[es] (…) It’s not just the form, I mean I know what I am trying to achieve, mechanically and in assembly terms, and how many parts I want to get it down to (a minimum number of parts). And so, with all that in mind, I start thinking about shapes. I certainly don’t start thinking about shapes without that in mind because I would have to go back and re-do it.

Volume of production
We all fall into the trap of designing one product, forgetting that 100,000 is entirely different from one. We may be thinking mass production but 10,000; 100,000; 500,000; those are very very different animals and we do tend to forget that and I think it’s not stressed enough in here, in University, quite how different those things are. (…) We do see mixes [of mass and low batch processes] here [in students’ work]. We see people with injection moulded products and hand-welded parts and machined parts, and these processes are in different worlds usually. You have man-hours on a milling machine. Or hand welding; I mean, gas welding you see and gas welding is (…) hardly used in mass-produced products, even where welding is used. And you will see [students] bending tubes and bending metal work and you introduce a weld and [the manufacturer will say] ‘what! what is this?...we don’t want to see that, we want to see this bent out of one piece please’. And if it’s going to be welded, it’s spot welded and it’s all done automatically.
Cognitive modelling

Relationships between the form of a product and the manufacturing techniques that are able to achieve that form were discussed in relation to the design of a desk lamp which was to hand at the interview.

Mr Dartnall: "As you say, here you have a classic... it's probably steel and it's probably a deep drawing. You could spin it, but you couldn't spin it and sell this for eight pounds, which is what this is probably sold for. You could spin it and sell it for forty pounds, maybe fifty pounds, with all the rest of it being equal..."

Owain: "But then you've lost it... you'd be looking at a very high quality, high fashionable lamp..."

Mr Dartnall: "You'd be in an entirely different market. Spinning is generally a hand-made process. It's a clever process, but it's largely hand made. You can spin automatically but it is basically a hand-made process."

Tasks (other than modelling) for reaching decisions on materials and processes

It is important to forge links with manufacturers in circumstances where clients do not have links themselves.
INTERVIEW TWO

BIB

BIB design consultancy was founded by Nick Butler OBE, a Royal Designer for Industry. BIB is one of the UK's most well known consultancies, having developed the Durabeam torch and MB's Connect 4 game.

The recording device for this interview failed to operate and so it was not possible to produce a verbatim transcript. This was frustrating because many of the most probing questions were answered and would have been useful to quote directly. The results contained herein are therefore mostly paraphrases based on recollection less than five hours after the interview having taken place. Recollection was helped by having the original question sheet to hand as a cue. The interview took place on the consultancy's premises with Andy Pidgeon, Head of Design.

The role and significance of materials and processes in industrial designers' decision-making

The great majority of the work at BIB is concerned with the design of products destined to be put into manufacture, so materials and processes are very significant. Mr Pidgeon noted that recently-graduated students of industrial design tend to direct their efforts towards making a product proposal look good, implementing new technologies and adding functionality, but tend less to resolve how a product proposal will be made (i.e., materials and processes related issues). This was stated as a major omission from the skills required for industrial design. When presenting product ideas to a client, one of the first points that a client will raise is "how is this product going to come together on the production line?". Industrial designers have to be able to respond to such questions. The same is true for junior designers at BIB: their work is not limited to purely conceptual, expressive work.

The timing and sequence of attention

Very early on, a designer will have ideas on what materials and processes might be suitable. This is something that is inherent in NPD. Decisions of detail are made when a few appropriate manufacturing routes have been selected for development work. Overall
though, Mr Pidgeon explained that designing does not comprise a string of 'stages' where materials and processes might be looked at, decided upon to a certain level of detail, and then the next area of focus attended to. The activity is more homogenous. Attention to materials and processes is given in conjunction with other considerations, in order to find some middle ground between conflicting requirements. Junior designers do however tend to focus their efforts on idea generation and development (early-to-middle phases of designing) whereas senior designers have the capacity, through their professional experience, to resolve technical problems (whenever they may appear). Put as a summary, attention to materials and processes is given in the following way.

- The basic physical performance and aesthetics required of a product suggest use of certain materials.
- The basic form of a product suggests use of particular manufacturing processes.

Speculative product design
BIB sometimes work on design briefs that demand speculative work (e.g., the investigation of potential future products for a client but where a manufactured product is not, at the time, an aim). Materials and processes issues are not avoided outright in these projects but the level of manufacturing detail reached is lower than for production-bound product design.

The level of detail of attention reached
The nature of attention to materials and processes is tied closely to general phases of NPD. Through these phases (below), attention gradually becomes more refined and fixed.

IDEAS PHASE
This might, for example, involve an assessment of the merits of plastics versus metals.

DEVELOPMENT PHASE
This might, for example, involve an assessment of the merits of vacuum forming versus injection moulding.
DETAIL PHASE

This might, for example, involve refinement of a design so that it is suited to manufacture from a specific material by a specific process (i.e., DFMA). This kind of work is central to BIB's work: "We frequently assist our clients with getting their products into production by supervising sourcing, tooling and trouble shooting 1st production samples." [BIB, 1997:17]

Constraints

Availability of materials and manufacturing processes

The materials that a client can use might be restricted or otherwise defined. The manufacturing processes available to the client might also be restricted or otherwise defined.

Budget

Some of the briefs that BIB have worked on have had very tight margins associated with them; in some cases so tight that, for instance, changing a polymer blend (in turn making a component pennies more expensive) results in unacceptable profit forecasts. With other briefs, greater flexibility is possible because costs can be absorbed through increasing the price of a product to retailers and consumers. In some of the tighter cases, it is the designer's job to argue the case that a product needs the benefits of extra expenditure.

Problems with mixed materials

One problem that Mr Pidgeon identified as being particularly prevalent was the achievement of the same finish (e.g., colour, surface textures) on a product assembled from more than one material. Often components in different materials are sent to different manufacturing facilities around the world. Although colour reference systems like Pantone are used to match colours, in reality such matching is a "nightmare". Different polymer and paint combinations, initially classed as the same colour, exhibit properties that differ between lighting conditions and, over time, change. Such properties will change between batches too. The result can be to the detriment of product quality, with poorly matched colours. To avoid these problems it is usual to opt for designs using fewer or only one material, or to opt for contrasts in colour between components of different materials.
Product precedents
The 'product area' one is working in dictates, to an extent, the materials that will be used: "if it's 'phones then you know you will be working in plastics."

Volume of production
The projected volume of production of a product dictates which manufacturing processes are viable. With one-offs or just tens of units, hand-fabricated and time-consuming processes can be used to avoid expensive tooling. Mass production of 10,000s of units requires very different processes: for example, die-cast rather than machined metal parts are more economically viable.

The range of materials and processes that are able to be specified
Due to the diversity of the work undertaken by BIB we have first hand experience of a huge variety of manufacturing techniques. This experience puts us in an ideal position to identify and advise our clients about the suitability of a proposed manufacturing route or the possibilities of an emerging technology.
[BIB, op. cit.:15]

Mr Pidgeon pointed out that the Durabeam torch project was an example of a brief where materials and processes were wide open at the start; the possibilities for design were vast.

The Durabeam brief was the shortest and most concise we have ever received. Emanating from the US parent company, it stated simply 'We want to sell more batteries'.
[BIB, op. cit.:10]

'Green issues' in practice
Some 'green issues' are tackled as a matter of course in 'good design'. For example, designing for less (or minimal) use of material is expected of a good design approach. Mr Pidgeon stated that 'being green' in the future might be more about avoidance of environmentally harmful chemicals in product materials and assemblies, rather than promoting use of recycled materials. To illustrate this, he pointed out that BMW's claims that their cars are recyclable are not backed-up with statements on how, where and by whom this 'green potential' is actually put to use.

The nature of creativity with respect to materials and processes
Concern for technical matters, in that they are a concern at all, will constrain and (by implication) restrict the range of ideas a designer can develop. Mr Pidgeon prefers to work on briefs which have constraints stated explicitly within them. In his opinion,
creativity is in evidence when a designer is able to produce a product proposal which, through novelty, ingenuity and innovation, works with those constraints. The 'blue-sky', 'anything goes' approach is, in his opinion, the most difficult to work to.

Opportunities offered to industrial designers

Advancement of design

Sometimes design briefs will allow new materials to be used in products where previously manufacturers were using other materials. Mr Pidgeon showed examples of how new materials have been incorporated into products to add functionality and style. One example was the Artemis Desking System, where the use of steelwork was a significant change for the client.

Our brief was to create a distinctive range of systems furniture using a high standard of materials and construction, which would be suitable for various users from the secretary to the chief executive. Using fine steelwork, natural timber and sophisticated coloured laminates, the Artemis range combines the elegance of classical shapes and lines to create a style of workplace that will respond to individual requirements from a striking single desk to a more complex work station with ancillary matching furniture.

[BIB, op. cit.:4]

Fashions

Fashions for materials and finishes tend to come about because of advances in materials and processes technology. Companies are aware that their products might become 'old hat' and so consequently fashions to do with materials and finishes are important in NPD.

Miniaturisation

With advances in electronics and electro-mechanics (primarily through miniaturisation), product designers have great opportunities to package technologies in new and interesting ways (i.e., through creative use of manufactured forms). Too often, in Mr Pidgeon's opinion, designers and clients opt for conservative designs. Mr Pidgeon felt that the paying public or target users will be more receptive to new product forms than they are generally given credit. A hint was given that industrial designers should take this on board as a matter of course in their work, rather than having one foot in the past where product form is carried over simply for the sake of 'conforming' and not because of some pressing need, once present in previous generations of product, but now absent.
New technology
New materials and processes allow product designers to revisit and radically re-think established designs, something that is especially useful since much of product design is essentially repackaging exercises.

Obsolescence / longevity
The life span of a proposed product will suggest adoption of particular materials and assemblies over others.

The use of information
Mr Pidgeon stressed the importance of talking and meeting with clients and manufacturers. It was important too to keep up with new advances in design and technology, though this was conceded to be not an easy task.

Designed artefacts and the wider world
It was stated that existing products and the wider world in general definitely have a part to play in influencing choices of materials and finishes. Mr Pidgeon will often be inquisitive and study a designed object to see how it has been produced and assembled; there was no substitute for handling products to learn about design. Ideas for product form are also stimulated in this way. Forms in nature have an influence too.

Liaison with end manufacturers, material suppliers and material manufacturers
Having a working relationship with materials suppliers and manufacturing companies overcomes the problem of out-of-date literature and brings to the design work benefits of close co-operation.

Printed sources
The studios of BIB contain brochures and technical leaflets on materials and processes (but these quickly become out of date).

The use of computers
Computers are not used at BIB to help with materials and processes selection.

Knowledge and values
Knowledge on a need-to-know basis
Instead of knowing, for instance, what the tensile properties of polypropylene are, designers should know where to find out that information should they need it. Mr
Pidgeon felt that this 'knowing where to find out' and 'when to find out' was an important way of knowing for industrial designers.

**On-the-job experience**

Years of professional experience will lead a designer to become versed in broader and more detailed aspects of NPD. Knowledge of the wider issues in NPD, and of the core issues in greater depth, is something that is achieved on the job rather than expected to be part of a graduate's competence. Junior designers extend their knowledge of materials and processes by shadowing, and being involved in, senior designers' work.

**Cognitive modelling**

Mr Pidgeon offered a description of how designing 'in the mind's eye' works: along the lines of a 'process of deduction'. Importantly, the deduction works by taking into account the various constraints of a project. The deduction is led by knowledge of what materials can be shaped into what forms.

**Tasks (other than modelling) for reaching decisions on materials and processes**

In the concept phase of NPD, BIB use photographs and other visual information to build-up a broad picture of the marketplace of a product and the aspirations of its potential users. Mr Pidgeon gave an example of visual descriptions and associations with BMW cars against those of Skoda cars. Within this product analysis are included images of potential materials and finishes and photographs of products made with such materials and finishes.
INTERVIEW THREE

Grey Matter

Grey Matter is a London-based multidisciplinary design consultancy, specialising in brand development. The interview took place with Chris Forecast, Senior Product Designer, on the consultancy's premises.

The role and significance of materials and processes in industrial designers' decision-making

What we do is design things for people to buy. Processes are something for the designer to understand and the materials are used to communicate to the consumer. It's part of the presentation, whatever the product may be. (...) In terms of the whole product, you've got to be clued in about how it's going to be manufactured, definitely. I think that's what makes a good designer and a lot less of a bad designer. (...) If you can [assess manufacturability of your product ideas] then you're a good designer.

The design work at Grey Matter is led by a strong conviction to deliver to customers very desirable products. Choices of materials and processes are central to achieving a desirable product, so it is important to understand them. Although consumers "...are not so much interested in the production processes", they do come into direct contact with materials when they inspect and handle a product.

Mr. Forecast commented that for good product design there is a middle ground to be found between the tasks of generating good ideas and evaluating their practicality.

...you're not producing a concept, you know, 'well I'm going to use virtual hinges' that are, you know, magnetically levitated and all this sort of bollocks. It's going to have a fixed hinge of some kind. (...) You [might not] know exactly how it's going to do it, but you know it's going to do it.

Comparisons between engineers and industrial designers were made in the interview.

I think industrial designers make (...) good development individuals because they hopefully will have a slightly more wide spectrum [of ideas] than traditional engineers [will have]. You've got another string to your bow: form, visual language. The emotion of the product is always going to be there.
rather than just the manufacturability, the cost-effectiveness, the production ability. So you're constantly weighing up [expressive and utilitarian properties of materials and processes].

The timing and sequence of attention
Attention to materials and processes is given throughout design work: "You're always thinking 'you could make it out of this, make it out of that' [whilst] ...constantly doing other things." Issues of production come to the fore in later phases of NPD.

The level of detail reached
All designers have got different skills and some are better at concept work and others better at development. (...) Everyone gets involved in all of it, but some people do end up doing more development work than concept work by virtue of having different skills. It's important for people to get involved in what they like to do as well.

Mr. Forecast was able to tie particular lines of thinking on materials and processes to different phases of NPD.

Ideas phase
"...understanding of... the visual language, the emotion..."

Development phase
"Typically (...) you'll look at manufacturing; have an understanding of manufacturing processes, therefore you'll know at the end of the day whether or not [your ideas can be realised]. You're always looking at materials. You're always saying, 'well OK, we'll use an elastomeric here, and therefore we'll use injection blow moulded, over a metal part' and that sort of thing. Yes, I think probably conceptually there are probably wider possibilities at [this phase]. But then the truth of the matter is the manufacturer's going to make two separate bits and glue them together. But, you know, (...) you should still ask questions."

Detail phase
Production issues come to the fore.

Design work will be taken "as far as the client company wants." Often this will be "...all the way through to production details." In the case of one project for LEC fridge/freezers, the consultancy was involved with the production of engineering drawings for first tooling.
Constraints

Availability of materials and manufacturing processes
The level of manufacturing capability that a client company has places constraints on the
types of materials and processes that can be proposed for a product. In some
circumstances, a client company will have a bulk stock of a single polymer that they had
foreseen using for future products. That material has to be used in new products simply
because it would be too expensive for the client to discard it and purchase new material.

Corporate identity
The colour scheme a company uses in its products is likely to be a major part of its
corporate identity. Only certain materials may be able to conform to that identity.

Design brief and the client
At all times the design work needs to satisfy the requirements of the project brief;
text to materials and processes is no exception. Mr. Forecast gave an example of a
very constrained brief.

[The brief stated] 'it's blow moulded, it's HDPE [high density polyethylene, a
commodity thermoplastic], our line handling capabilities are this, therefore it
has to be this particular shape. We're very sensitive to volume, because we
have to sell as much liquid in as small a pack as possible to maximise our cost
ratio to palletising ratio, therefore it has to be this size'. So you'll end up with,
you know, with very thin wall thickness HDPE. It doesn't get much more
constrained than that.

The range of materials and processes that are able to be specified

...because you're in a consultancy (...) the kind of work you get involved in is
so diverse, you know. At the moment I'm doing some (...) bottles, so working
with glass and particular glass manufacturers and things like that which is
pretty different to a project I was doing a month ago which was blow
moulding, which was different to the project I was doing before that which
was injection moulding.

'Green issues' in practice
Current green design practice is limited to:

- the marking of products with material codes, e.g., SPI plastics recycling codes;
- the use of recycled materials (including in-house re-grinding of waste
  polymer).
Mr. Forecast felt that pressure to produce 'greener' products is consumer-led. Client companies will not implement green design practices unless the demand is for products that are designed and produced like this. If a company decides to take a lead on green design it will inevitably incur a financial burden that undermines the competitiveness of the company's products.

Manufacturers always think about the cost bonus, so they're always sort of shouting 'use cheap materials' anyway, so they're going to have to pass that cost on if they want to [use recycled materials, which are expensive]. That's the problem: at the moment it's cheaper to buy purer material. But if you feel there's a strong enough reason for it then I think you can push it. If you can justify that it will communicate to your consumer, if you can justify that there will be a benefit for that client company to use it, then [you should].

In current marketplaces, green design is "not high priority" and clients are sceptical, saying 'what isn't harmful to the environment?'. "The environmental effects of actually recycling could be worse than doing anything else with [material]."

There are exceptions of course. With some projects there are opportunities to make a feature of 'green' aspects of a product (e.g., in packaging design). Information on suitable recycled materials tends to come from the client.

The nature of creativity with respect to materials and processes
It is the individual designer's responsibility to know what matters in NPD.

...there are always constraints. You have to do the best you can within the constraints. I think designers tend to work in teams as well [because] you have people who are maybe stronger visually, you have people who are closer to work for production...

Team members can benefit from each others' experience to achieve a high level of creativity within a brief.

Opportunities offered to industrial designers
Fashions
...you've got to keep your finger on the pulse of design, definitely. What type of forms [are used], historically the understanding of that is essential. And materials are part of that.

Flexibility of the company
A client company may be looking to invest in new machinery, in which case the constraints that tie-down design choices are more open and there is opportunity of making use of new production technology. This was the case when Grey Matter were
working with LEC on a new range of fridge-freezers. "We were able to (...) put in, for instance, new production-line technologies for door manufacture which enabled them to make a big revolutionary door shape."

**Market differentiation**

Materials and processes can be used strategically to place a product into a particular marketplace. An understanding of the client company, form, colour and materials is needed to do this.

**Personal aims and aspirations**

Mr. Forecast discussed how one of his colleagues chose to become involved with particular types of projects and kinds of materials "in order to widen his spectrum of design, to extend himself [professionally]." Having this wider experience "...brings a fresh look to product design and [brings] a different influence to it."

**Functions that industrial designers desire materials and processes to satisfy**

It is important to have an appreciation of how processed materials feel to the touch, because industrial design is very much concerned with the human senses.

...the texture, the touch, the feel, is very much (...) one of the major emotions about a product experience. The type of material you use and the finish is part of that experience. (...) If you're trying to create the emotion of your product and saying 'well it's [this product], female market', hopefully you'll want to communicate to your client different types of (...) female beauty. [For instance] maybe aspirations of (...) European women, so you communicate different styles of beauty using imagery and use materials to [convey that imagery in a product]. It's using all the senses, well virtually all, you know. (...) These are all emotions that you would have when you use the product, [therefore] all the emotions which you communicate [about your product proposal] to the client.

**The use of information**

It was stated as important (though not easy) to keep abreast of new materials and processes technology. One way was to visit the yearly Manufacturing Week exhibition at the National Exhibition Centre, Birmingham.

**Designed artefacts and the wider world**

I think that's the most important thing... learn about things, always keep looking at stuff, the visual language of a product... [Ask yourself] 'I wonder how that works?' You just keep your eye open and that's the only way you're going to learn. And the more you see, the more you know for next time around.
Liaison with end manufacturers
Much can be learnt from liaising with experts. A client might say 'we're thinking of die-casting- what are the design opportunities and limitations of that process for our products?' With contacts in manufacturing companies, the designer can discuss design details of different processes with experts, in advance of relaying advice back to the client company.

Physical samples
Grey Matter has a technical library that contains material samples.

Printed sources
The technical library also contains trade information from materials and manufacturing companies. This information is consulted depending on the individual needs of a project. The library acts as an immediate source of telephone numbers for materials and manufacturing companies.

The use of computers
Computers are used to generate renderings to show to clients what a product would look like in different materials and finishes.

Knowledge and values
DFMA knowledge
You should know with injection moulding that there's all the basic things, you know, like wall thickness or boss sizes and stuff like that, and they're general rules. But even when you apply those, it doesn't necessarily mean you'll end up with the right result. [You need to] know more about the tool set-up, tuning of the tool, the balancing of the tool, flow, all this sort of side of things. But you know that at the end of the day, (...) it's possible [to manufacture your proposed product].

Mr. Forecast stated that in practice it is often a matter of knowing that products can be produced using particular processes, and being able to convey more detailed manufacturing knowledge to clients and manufacturers should any difficulties or queries arise.

Knowledge on a need-to-know basis
Designers will swot-up on aspects of product design that are new to them as and when a project demands. This approach to knowledge acquisition is suited to consultancy work because of the diversity of the products that are designed. As a consequence,
"...everybody [at Grey Matter] has different sort of experience levels [in different materials and processes]."

**On-the-job experience**

If a designer's work is biased heavily towards (a) creative ideas, or (b) ease of manufacture, this will result in less-than-satisfactory design proposals. The balance which is sought between these requirements of product design is something that "you can't teach... unfortunately." Mr. Forecast sees it as a skill that comes with experience. Similarly, the rules of DFMA are "...one of those things you learn on the job basically. You don't learn about it at college."

**Cognitive modelling**

I think you have to [have ideas on how you will manufacture the product forms you entertain in your mind], it's all part of the design process.

Sometimes as one is thinking-through an idea, one will find oneself inventing material and process routes that would fit the idea but just aren't possible. Soon after though, a feasible approach will be determined.

**Tasks (other than modelling) for reaching decisions on materials and processes**

Before sustained effort is put into idea generation, designers and strategists at Grey Matter undertake to understand the marketplace of their potential product. This involves an examination of existing products and an analysis of what they offer the consumer and how they might be changed. A written document will be produced from this exercise, which will later be translated into visuals as the first stages of designing.

You can't design with your head in a bag. I've seen too many situations where people are designing for themselves. We're not doing that. The job is not to design for yourself, the job is to design for your client and your client is there to produce products for an individual consumer because they want to buy. So, you're designing for that consumer. (...) We use our own internal techniques of brand mapping (...) so we can understand the client's company. If you went to a strategist company [to do this] what you would get is like a big document of words. What you're looking at here [at Grey Matter] is a visual representation of the company's brand: how you see the company's products, what you perceive of them, what they should stand for, and then further than that, what ways they should go. So, at all stages the designer and the strategist are working together. It's quite an unusual environment to work in from the designer's point of view.

Materials will be proposed and illustrated in client presentations early-on in NPD.
That's why if you do a conceptual board [a visual representation of potential products and marketplaces], you've got to have materials—samples on the side—'this is how it's going to feel, this is how it's going to touch'. (...) That's very much part of the emotional feedback of the product. If it's a product like that [Mr. Forecast points to my Sony portable cassette recorder], what are you doing? If you're presenting like the first one [of its kind] then you need [to convey] an understanding of where the batteries [and printed circuit boards and internal components] are going to go. Or are you saying you're going to do a face-lift? [In which case you will present different versions in different colours. The client knows what is inside]; what they want to see is different shapes.
INTERVIEW FOUR

Johnson Haigh Rogers

The interview took place with Andy Rogers, a Loughborough graduate and a partner of this Loughborough-based design consultancy. He was quite clear in his views of the differences between design work carried out by students in an academic environment and professional client-based designing; these views are contained in the results presented here amongst the responses to set questions. The interview took place on the consultancy’s premises.

The role and significance of materials and processes in industrial designers' decision-making

...they’re fundamental to actually, you know, achieving the job. I mean, you know, it’s like saying ‘is a pencil important to drawing?’ It’s kind of like without it, you have nothing. So yeah, it’s very important. (...) There’s no point in designing things when you don’t know what materials are available. There’s no point in designing something that can’t be made.

It is the designer’s responsibility to know about different materials and processes, because a client won’t have that knowledge.

...clients see end results and things that work well, or ways in which they want things to work. But I mean if a client comes to us and asks for a brochure, they won’t say ‘well, I want you to use a 155 screen and I want it to be printed, you know, on that machine over in the corner and I don’t want it printed on that [other] machine’. They’ll say ‘I want a brochure, I want it to feel nice and I want it to look like this’. [Mr Rogers commented that this scenario transfers directly to product design]

Part of an industrial designer’s expertise is therefore to be familiar with a variety of materials and processes so that the demands of different projects can always be addressed.

People come to us for advice. So they say ‘oh, we want a lens for this LCD [liquid crystal display]; we’ll injection mould it shall we?’, and I’ll say ‘well no, laser cut it or router it out of a piece of [sheet]... because you’ve got no set-up
cost'. So we can advise them. They've perhaps got a pre-conceived notion about a particular process and suggest it, when I'll say 'yep that's fine, that's appropriate, we'll do that' or 'no it's not', or 'have you thought about trying this, that or the other?'

The timing and sequence of attention

Materials and processes are often considered at the very beginning of a project because they can be pivotal in setting design direction.

Often it's knowing about materials and the way you can achieve a certain result that influences the design, because you want to get things that are cost-effective but look great and will work well, and the materials usually (or frequently) are the key to that.

Mr Rogers's advice to students was, rather than spending months wondering about how to do something, get ideas together promptly and test them out practically. That would be closer to professional practice. There isn't time in a consultancy to ponder over whether something might work.

Speculative product design

Materials and processes have certainly featured in the consultancy's speculative product design work. One 'futuristic telephone' project was taken from design ideas to a working plastic prototype in approximately ten days.

The level of detail reached

Mr Rogers described how attention to materials and processes evolves through a project. His descriptions have been tied to general phases of NPD.

Ideas phase

At the outset of a project, a designer will have a rough idea of the material that will be used. Ideas will then come on how the product will be manufactured.

Development / detail phase

A specific processing route is chosen.

...there's not much that happens in between; there can't be, not really, because there's so many other things you've got to sort out. I mean, whilst [your toolmaker] is busy making an injection mould tool, you can't be thinking about material any more than you were thinking about it at the beginning. The time to experiment [with materials] is when you're busy making it [see overleaf].
**Refinement phase**

For injection moulding, the final decision on exact material choice might be made only after evaluating a series of mouldings in different materials.

Within NPD there are circumstances when one can be relatively loose about the processing route for a product, as described below.

...you're designing something and you know that in principle it will work but at the moment it doesn't, or there's something that's going to be available, but you're not quite sure about it. [In these circumstances] there's no point getting hung up on the detail.

It is wise, however, to have in one's mind a contingency manufacturing plan in the event of the original idea not being possible to realise. Towards the late stages of a project, tool design comes to the fore: "you have to know a lot about tool design, how it works."

The consultancy does not carry out FEA (finite element analysis) stress calculations.

**Constraints**

**Budget**

Designing is frequently carried out with a final unit price for the potential product in mind. The price might well be such that more costly processing routes are ruled out of contention because they would not be able to deliver a sufficiently cheap product.

**Design brief and the client**

A design brief will always state that a product must perform in particular ways. The materials used must be able to deliver those requirements: "...answer the brief (...), that's the only thing that you're ever having to do."

**Detail preferences of the toolmaker / manufacturer**

Different toolmakers have their own preferences for how designs should be detailed. A component that is a "piece of cake" to one toolmaker will be a "complete disaster" in the eye's of another. To overcome potential difficulties, links are made with a series of preferred toolmakers / manufacturers to make available to the consultancy a range of expertise.

...you have to know your suppliers' weaknesses and strengths so you can really accommodate them (...) and eliminate any problems that you might encounter because they're not very good at certain things.
The range of materials and processes that are able to be specified
The range of materials and processes that the consultancy specifies for its products is
diverse, reflecting the diversity of the commissioned work.

What we do is we work on a [product] one week; we do a six thousand square
foot exhibition; we do a corporate brochure; we do something else, you know.
We're working in injection moulding; for [exhibitions] we're working in large,
flat materials; for [brochures] we're working with print. So we're hopping and
bobbing about from all sorts of things and we're mixing and matching, you
know, all our different skills and what not.

This diversity in the kinds of product that the consultancy works on is seen as something
of a double-edged sword. It can bring benefits to new design projects for the reason that
"...we try all sorts of stuff that other people wouldn't try. We (...) take that aspect of work
from over there, and stuff it in over here." On the reverse side, it can bring increased
pressure on the design work because invariably product proposals involve something new
and untested.

'Green issues' in practice
A number of points were raised in relation to green design.

- The consultancy always needs to be aware of 'design for disassembly' and
opportunities for specifying recycled materials, "...but it ought to be more
important than it actually is."

- Project budgets and time scales are regrettably so lean that it is impractical to
give green design issues the time that they warrant.

- Pressure from clients to address green design issues is notably absent,
"...except when it comes to print, when obviously we try and use recycled
paper, things like that."

- SPI plastics recycling symbols are not adopted on products.

I wouldn't like to sound like we're being irresponsible or anything but it's not
really been an issue with the sorts of products we have worked on, in fairness.
(…) I mean, if we were designing products where there was soft of like, you
know, a one hundred thousand plus production run, over a product which had
a limited life span then, yeah, obviously there is a clear implication (…)
definitely something that needs to be looked into.
The nature of creativity with respect to materials and processes
Mr Rogers stated that materials present opportunities as well as constraints but that attention to materials and processes can indeed cramp creativity, "...you think 'oh, I'd like to do this' and, well, you just can't."

Opportunities offered to industrial designers
Advancement of design
Within a design consultancy, Mr Rogers thought that the opportunity for open and wide-ranging thinking with respect to materials and processes is greater than within a manufacturing company.

...some of our clients are busy doing telephones all year, every year. They know exactly what they want to do, and they'll do buttons in a certain way and they know that they will work, and they're tweaking things to, you know, 0.2 of a millimetre. To them that might be quite a fundamental change, and yet to us we're sort of saying 'oh, well, what about if you have buttons in this sort of way' or '...you don't have buttons at all but you do that'. So we're sort of thinking, 'well it might work, we'll give it a try'. (...) That's frequently what we find we're in a position of doing. So, you know, it's not a question of 'well, yeah, we tried that particular material last year, we'll just tweak it very slightly for this year', to tweak it and refine it and what not. We're hopping about so much.

Fashions
Fashions have a bearing on swaying the use of material and finish combinations: "People like things that are trendy and chic or appropriate, so if you can come up with new materials that are really nice then yeah, you use them."

Flexibility of the company
A brief never explicitly states 'you will be using this specific material' or 'these are the processes you can look at'. Those decisions are not made by the client company; they are expected of the designer. Mr Rogers provided a medical analogy.

...if you go to the doctor, you don't say 'I want you to diagnose that, and I want you to give me those pills', you go to him and say, you know, 'what's wrong with me? (...) here's the problem, fix it'. [Clients] say 'we want a finished thing', they see a finished result, yeah? I don't think they give a toss how they get there, nine times out of ten.

Functions that industrial designers desire materials and processes to satisfy
When quizzed if, as an industrial designer, Mr Rogers might be looking for particular things from materials and processes, he laughed and commented, "I look in materials to do what I want them to do, that's it, end of story."
The use of information

Colleagues
Product proposals benefit from the open criticism of colleagues and they suffer stunted growth if one chooses to design in isolation.

[If] you have a particular problem, you go to somebody else who knows about it a bit better and (...) see what they think, see what suggestions they've got. [One cannot design] in isolation, not talking to anybody, not getting any feedback from (...) peers, which is the most important thing. You know, how are you supposed to design if you're sitting in a little cocoon? Desperately important.

Designed artefacts and the wider world
Existing products are a strong source of inspiration for design work. Mr Rogers stated that a good product designer should not be able to help themselves from gleaning information from contact with products and environments. Hands-on experience of processed materials is important because it instils an appreciation of what one can achieve (and what the limitations are) with different materials and processes.

It's no good just reading about what you can get, you've got to have samples there that you can bash, and feel and prat about with, you know. Get a piece of injection moulded material and see what a 3mm wall thickness actually looks and feels like. Do you need 3mm? Do you need 2mm? What sort of rib detail are you going to put on the bottom side of it?

Liaison with end manufacturers
It is important to liaise with manufacturers early on, to avoid abortive work; to avoid the situation where a product has been designed but it cannot be easily made. Proposals need to be workable for the end manufacturer. Manufacturers will give advice on how a product should be detailed to make production easier.

Liaison with material suppliers / manufacturers
Material suppliers are a point of contact for enquiries about new or popular materials. The suppliers are rather like brokers of materials knowledge, "...because everybody's learning from everyone else."

Physical samples
[Representatives of material manufacturers] are always sticking their head around the door, trying to throw us bits and pieces. (...) We have a room full of samples of carpet tiles and light fittings and plastics and buttons and fasteners and rivets.
The representatives will often introduce to the consultancy new or improved materials. Mr Rogers was enthusiastic about the worth of samples: "It's imperative that you have these things."

**Printed sources**
The consultancy has a "library full" of text books, reference books and other literature. Amongst these are catalogues showing examples of stocks, components, processes, materials, assembly methods, fixings, fasteners, graphics and colours that can be used in a product.

I've got a catalogue from one company which is I don't know, about one hundred different materials, all of them brilliant in certain respects and all of them opportunities to achieve something new and exciting.

**The use of computers**
Computers do not help with choices of materials and processes.

**Knowledge and values**

**Common sense**
A hint was given that the narrowing-down of choices of materials and processes is achieved simply by the application of basic product knowledge. An example was given for a forward-looking telephone that the consultancy had designed.

It's just common sense, you know. It's a telephone: a top and a bottom of injection moulded plastic, a silicon rubber [key pad] and that's it, job done, end of story, piece of cake. It's just common sense. It didn't require anything elaborate.

**Desirable core knowledge for an industrial designer**
Given the huge number of different materials and processes that can be used in NPD, Mr Rogers was sure that the designer who has a comprehensive manufacturing knowledge is at a distinct advantage. Mr Rogers did not think that there was a boundary to the materials and processes knowledge appropriate for an industrial designer. The designer should demonstrate "an appreciation of what materials are available and (...) how they come and (...) what you can and what you can't do with them. It's just so basic."

...they should know what [a tool design] is like from the point of view of three totally different injection mould makers. All the basics of injection moulding, all the variety of materials you can use, all the other moulding processes that are available: blow moulding, rotational moulding, anything else like that. Any way of making something in plastic.
Knowing that

Sometimes a design idea might be put forward that makes use of a manufacturing process with which the consultancy has had little or no experience. Contacts with specialists are important in these cases, so that a client can be told 'we reckon it can be solved in principle, we know that somebody already uses this process'.

Knowledge from practical experimentation

With regard to injection moulding, only so much can be predicted about how a mould will perform in a given material. For instance, having injected a tool with molten plastic, one might find a problem "...because [the moulding] is too soft, too hard whatever, so then you have to change it. It's often a 'suck it and see' situation."

Designers at consultancies are asked to work on a large number of products that are unfamiliar to them and this of course has implications for the work carried out. The potential sticking-points or pitfalls cannot always be foreseen. This is in contrast to much in-house work, as Mr Rogers described.

...there's an awful lot of folk who produce designs for things which are the same that they've been doing for the last ten to fifteen years. If you work for someone like Ford, where they've been making cars for the last hundred odd years, you know, the car they manufacture this year is in real terms not a huge amount different to the car they produced last year or the year before, and they are going through a very gradual, evolutionary process.

Knowledge on a need-to-know basis

When one's experience is found wanting, "you've got to find out about stuff...".

On-the-job experience

I'm very aware of what I do frequently when we talk to other folk, like younger members of the team here, who make a complete fist of something or plough down the wrong route and I think 'this is so obvious, what are you doing?'. So an awful lot of it is, you know, stuff that you just know or, you know, because of experience you've had previously of things that have worked well and things that have not worked well.

Cognitive modelling

An interesting response was given to a question asking about how one narrows-down choices of materials and processes: "That's like one of those more academic questions that you can't put your, your finger on...". Mr Rogers noted that "an awful lot" of the narrowing-down of materials and processes choices is achieved not particularly consciously.
I mean it's hard to put your finger on something that you just do automatically. (...) You can't really nail it down and say 'I'm thinking about this' and 'I'm wondering if it's, you know'. (...) I think more than anything else it's having a broad variety of resources that you can draw on. It's just having a decent palette of things to produce from.
INTERVIEW FIVE

Pentagram

Pentagram is one of the U.K.'s most well-known and prestigious design consultancies. I was unable to secure a one-to-one interview with Peter Tennent, a consultancy partner, but instead he offered to answer some questions via email.

The role and significance of materials and processes in industrial designers' decision-making

Materials and processes are "critically important" because the consultancy does not present to clients concept proposals that stand no chance of being manufactured. Proposals need to be "...technically feasible as well as a valid design concept." Some of the NPD team members at Pentagram are qualified engineers, but Mr Tennent noted that the level of responsibility is no different from one team member to another. "All members of the team are required to have a sympathy for materials and an understanding of all processes."

The timing and sequence of attention

Attention to materials and processes is given through all phases of product design, from the generation of concepts to production detailing.

Speculative product design

...all jobs require the same degree of consideration to be given to materials and processes.

From this statement, it might be assumed that materials and processes are equally as important in speculative work as for production-bound work.

The level of detail reached

Design work at Pentagram includes DFMA considerations, but under the following circumstances.
It is not the best use of our capabilities to undertake the production stages fully (...). Often [we] use freelance engineers to assist us, but there are occasions when one of the designers will have direct responsibility for detailing the parts drawings.

**Constraints**

Mr Tennent commented that the selection of materials and processes is often "obvious" and is driven by "...cost, volumes, required properties, preferred qualities etc."

**The use of information**

*Printed sources*

The design press.

*Specialist services*

The Institute of Materials' Materials Information Service.

**Knowledge and values**

*Desirable core knowledge for an industrial designer*

Mr Tennent thought that the industrial designer should have "as much [knowledge] as possible..." on materials and processes. "I cannot think of any which a designer will not need. Limiting this knowledge also limits their ability to spot opportunities." Essential subject areas were identified as: injection moulding; sheet metal processing; casting (of all types); vacuum and pressure forming; and extrusions.

**Cognitive modelling**

...this is the million dollar question. If you can summarise succinctly the 'chain of thinking' then you will be in great demand; it is exactly this mysterious assessment and balance of style, engineering, human requirements, cost, client requirements and vision which make each designer unique.
INTERVIEW SIX

Flymo

Part of the Swedish Electrolux group, Flymo are famous for their range of bright orange electro-mechanical garden equipment. The interview took place with Rick Keyfon, Research and Development Product Designer, at Flymo's design and manufacture base at Newton Aycliffe.

The role and significance of materials and processes in industrial designers' decision-making

One of the major challenges for the industrial designer is to "...have a good feeling, a good idea for pretty well everything [that affects the design of a product]", but at the same time not be a master of everything. It is a waste of effort to work on proposals that cannot be manufactured, so materials and processes are certainly important. Industrial designers need to be familiar with "engineering issues" of cost and manufacturability.

...as my boss says, you need to really live it and breath it, with the engineers, and then you can see all the problems, and you think, 'well we can help the design by designing the problems out'.

Mr Keyton was appointed at Flymo on the strength of his manufacturing experience.

In the companies I'd worked for before, I'd actually taken products (...) through from initial sketches to my model-making, to 2D drawings, to discussions with tool makers and moulders. [Because] I knew the way the things were made, I actually started to home in on my skills at designing for manufacture ...which I think is a really key point of design.

In Mr Keyton's experience, industrial designers in consultancies are driven very much by shapes, textures and image, but less so manufacturability. If proposals are produced without manufacturing having been thought-through there is a danger that those proposals will be "...completely watered-down" or "bastardised without your control" at the development phase of work.
The timing and sequence of attention

Attention is given to materials and processes from the outset of a project: "...you're trying to make it easy to make from the outset." In practice, this translates to applying some rules of production, as described below.

So, if you have a particular feature [on the surface of a component] you would try and make it in-line with the draw of a tool to save on a side-core which may cause problems later on in the tooling life of the tool, for example. So, once you know the rules vaguely, you start from day one and you just incorporate them into your designs.

The attention is on-going throughout NPD and not limited to any given phase of work. However, final choices of material need to be made prior to tool design, so that details such as shrinkage rates can be properly accommodated. The exact grade of the chosen material can be decided upon after a tool has been made.

Speculative product design

It was pointed out that early concept work, especially idea-generation, was very close to speculative work. At that phase in designing, "ninety percent of it is kicked out", forming a by-product of the early phases of industrial design.

The level of detail reached

Mr Keyton's involvement in the design of a product will normally cease once the external surface and layout have been determined to his satisfaction. At this point, mechanical and electrical engineers will detail a product proposal (and subsequent tooling). "I know where all the bits are going to go, but I don't get involved with the nitty-gritty of putting the ribs in and bosses in."

Even though the majority of DFMA and detailed lies with these engineers, elements of DFMA feature in Mr Keyton's everyday work as he thinks-through ideas and consults colleagues for advice (as below).

...thick sections have a lot of material and they have higher cycle times on the machine, so higher cycle times means the piece [component] price goes up and sometimes it's preventative to do it. (...) If you put a texture on a surface, the surface will have to have a certain amount of draft on it to release the texture.

Some DFMA considerations have major implications for the external surfaces of a product and these are of concern to Mr Keyton. One of these is the injection point for an injection-moulded component (around which there is inevitably left a small scar of protruding material). A component will normally be designed so that the injection point
is away from visually important surfaces. Another important consideration is the parting-
line for an injection mould tool, which must be such that the component can be readily
ejected from the mould. Mr Keyton will design for the simplest way around the
constraints of a manufacturing process.

With regard to materials, Mr Keyton thought that industrial designers were probably
not the best people to specify the exact grade of material that will be used in a
component.

I don't think we're technically adept enough, or will be, or would want to be...
[to stipulate engineering characteristics such as temperature ranges, flexibility
and hardness].

Constraints
Availability of materials and manufacturing processes
Flymo have found that ABS works very well for its products, having excellent mechanical
properties and offering good gloss levels and freedom to implement surface textures.
Because ABS is used so much by the company, it keeps large stocks and can purchase the
material in bulk at a very competitive price. New products will almost always make use
of ABS, so material choice is often an easy decision. Mr Keyton noted that if there was a
cheaper alternative that could perform as well as the grade of ABS that Flymo uses, the
company would already be making use of it.

The availability of manufacturing facilities is generally not a pressing constraint, since
Flymo, as part of the Electrolux Group, has an extensive on-site tool shop, "...probably
one of the biggest in Europe." It houses plastics processing equipment that can "mould
virtually anything." The facilities are sometimes used to manufacture other companies'
products. Flymo does not have facilities for manufacturing metal components and so this
work is put out to tender.

Budget
A target selling price for a new product is always set, and so from the outset of a project,
designing for minimum cost is always borne in mind.

I hate to say this because like it goes against the grain of being an Industrial
designer [but cost] is the most important thing that drives a design. Full stop.
Yeah, sounds a bit boring I know, but it's a challenge.

Mr Keyton noted that the more exotic materials are considerably more expensive than
ABS and so their use in Flymo's products is more limited. But for general parts, if the
mechanical properties of ABS are not required, the cheaper alternatives of polypropylene
and polystyrene are preferred choices. A significant point was made in relation to this: "What you shoot the tool in [inject the tool with] doesn't really [have a major bearing on the design], only from a cost point of view." By tweaking the detail design of a mould tool, the shrinkage levels of different plastics can be accommodated.

Corporate identity
The material choice for a new product needs to be such that Flymo's corporate colour scheme, high gloss orange and matte grey, can be upheld.

Design briefs
In contrast to work at other manufacturing companies, the work at Flymo generally does not warrant the use of 'exotic' materials that provide high performance in very testing conditions.

I was talking to a guy at Karrimor the other day. He was designing rucksacks (...) where [the material in the hip belt] had to go below (...) minus thirty degrees centigrade. And it had to be still flexible in those conditions.

Limitations for form creation
The company markets its products as 'light and easy' and 'friendly'. To achieve products that fit this description, Mr Keyton tries to make Flymo products "look very friendly to both the male and female consumer, so they are not the kind of hard and butch, straight, angular, nasty sort of aggressive lines that maybe other companies might employ." He will design new products to have curvaceous and soft lines which, on the production line, lend themselves to plastic injection moulding, "...not steel or cast or anything like that."

Marketing department
The marketing department at Flymo have an influence on the graphics and logos that will be incorporated into, or onto, the surfaces of new products.

Product precedents
Although not relating directly to his work at Flymo, Mr Keyton explained how knowledge of product precedents is often a decisive factor in choices of materials and processes.

...if you're designing something, say like a bottle, you know it will probably be shot with polyethylene because that's really the technology- that's what you do. (...) It is used because that's what everyone does it in.
The range of materials and processes that are able to be specified

Material choices for housings and casings are normally made from a small list of plastics that the company has tested and proven to work. These are:

- ABS (which accounts for an estimate of eighty percent of moulded parts);
- glass-reinforced polymers;
- polypropylene;
- small quantities of acetal;
- small quantities of polystyrene.

Where applicable, opportunities do exist for specifying materials in addition to those listed.

'Green issues' in practice

The Electrolux Group has a strong green design ethic that finds influence on the design of Flymo products. Products are routinely:

- designed for disassembly;
- marked with SPI plastics recycling codes;
- moulded with a proportion of in-house re-ground waste material.

The nature of creativity with respect to materials and processes

It was stressed that when designing a product, one needs to be creative within the constraints of a project.

I mean to be quite honest, anyone can design something that looks good. If you go on some training and you've got a bit of a [talent] for it, you know, you can design something that looks great. But to design something for a cost and it still looks really good, that's what it's all about.

Opportunities offered to industrial designers

Advancement of design

Materials and processes can be used to push the design of a product forward. Mr Keyton commented that he saw one of the industrial designer's key roles as pushing "the frontiers of design" and that he was trying to achieve that within Flymo. For example, on one project he suggested that the use of a ceramic blade (rather than steel) might bring benefits to a lawnmower. He thought it was important to explore the possible benefits of bringing new materials to a product and recommended that it should be an integral part
of early design work. This is despite the strong bearing that practical constraints can ultimately have.

...it's good to push the frontiers of design, that's what industrial designers are there for, really, to do that, and I'm still trying to do that within the company. But within the company, you do become more realistic as to... you know damn well that you could introduce this exotic material because it felt great [to the touch], but it wouldn't go anywhere, even no matter how well you wanted it, because it's just not viable from a cost point of view.

Cosmetic details

There's lots of areas where I now try to introduce some textures, give some contrasts, that's where it helps in low lights and stuff, and it makes [products] more interesting.

New technology

New materials and processes will sometimes have obvious application in Flymo's products. On one occasion, Mr Keyton proposed a new handle system that made use of a twin-shot injection moulding. This allowed a soft material (in contact with the hands) to be bonded directly to a structural base of a different material.

However, new technology is often seen as an additional cost. For new technology to become implemented in a new product, Mr Keyton has to put effort into convincing other design team members of the benefits, which often means he has to 'fight his corner'.

Functions that industrial designers desire materials and processes to satisfy

A recent development at Flymo has been the use of soft-touch material on the hand-grips of products, providing greater tactile feedback to the user when compared to a plain moulded ABS surface.

The use of information

Colleagues

Specialist advice from fellow NPD team members and shop-floor workers is sought when help is needed. Within the company there is a wealth of expertise. Information flows in the opposite direction too. When the time comes to commence tool design, it is important to police through the refined external product surfaces, keeping a keen eye that in the engineering process critical features are not lost or watered-down.

37 Although this approach dispenses with the need to use an adhesive to join materials, unless the materials are chemically similar a twin-shot moulding is not easily recyclable or designed for disassembly.
Designed artefacts and the wider world

Mr Keyton gave an example of how the use of materials and processes in existing products can be transferred into new Flymo products: "...we're starting to get into rubber. You see them on toothbrushes, you know those very soft, neoprene type things [as twin-shot mouldings]." Contact with existing products is important because it will provoke ideas for new products or new ways of detailing established ideas. It is important to have hands-on experience of manufactured forms, to appreciate what different processed materials are actually like, "...you pick up things, you touch things, you know, you look at the surface textures, you feel it, you play with it."

Printed sources

Printed sources are not used widely to help Mr Keyton with choices of materials or processes.

The use of computers

Computers are used for three aspects of materials and processes work.

- Rendering a product proposal in different materials and surface textures (as a visual aid). CAD does not provide any information on whether to opt for one manufacturing route or another.
- As a searchable database of material properties to identify candidate materials for a specific task.
- Mould flow analysis. Mr Keyton is not so involved with this side of component design.

Once we design the shapes and stuff it will go on the mould flow analysis (...) but that's more to help the tooling designer if you like: gate his tool and design where he's going to put the feeders and stuff.

Knowledge and values

Desirable core knowledge for an industrial designer

Mr Keyton held the view that as an industrial designer, one couldn't have enough materials and processes knowledge. He identified four key areas of knowledge, values and skills:

- to be able to draw things technically;
- to appreciate the cost of manufacture using different manufacturing routes;
• for plastics, to understand how process machines work (principally injection moulding) and design for the technical constraints associated with each process;
• for sheet metal forming, to know the smallest radii that can be achieved with any given thickness of steel or aluminium.

DFMA knowledge

I know basically how a tool (...) makes things. (...) When it comes down to plastics technology, then the rules are more or less written and within those rules you kind of obey. (...) They're sort of fairly limited; you can understand very quickly what you need to know.

On-the-job experience

Although Mr Keyfon never aspires or claims to be an engineer, working in an environment where contact with engineers is so close he admits to have become more of an engineer. It was clear that on-the-job experience, especially through first-hand contact with colleagues, helps in strengthening the level of attention that can be given to materials and processes.

I (...) sit with [the engineers] on a day-to-day, daily basis. I'm rubbing shoulders with them all the time. All the issues that they come up with (that I have problems with) like costs, constraints, tooling constraints, I get to know about them first-hand because I'm sitting with them and I deal with it all the time. So all the problems they see, I see too, and I try and design around as I'm designing a product. (...) Sometimes I will walk down to the tooling guys who make the moulding on a daily basis, and I might just ask them about, you know, 'here's my design, I'm thinking of doing this, do you think it's possible?', for example.

Experience can lead to design decisions becoming second-nature, as Mr Keyton explained.

A base-plate in a lawn mower which holds a drive chain will have to be made of glass-filled nylon because of the strength. But you know that straight away anyway. (...) You know instinctively, whatever you design, what material it's going to be in. Maybe that's what I'm saying- maybe the more experience you get with designing things, the more experience you can get to know what material it's going to be in.

Cognitive modelling

Designers need to appreciate how a component will be manufactured.
Once you've done that, then you can start introducing 'well here's a shape, here's the way it's made... now what materials can I see it being in?'. I think very much you have an idea of what you want to do in terms of (...) your product, and you just design the product. Now, whatever that product needs, and each product is different, it will encompass different materials.

3D modelling

With regard to the development of a new product, Mr Keyton is a strong advocate of foam modelling. With foam modelling, often ideas for shapes are provoked in his mind that would not have been generated using paper-based designing alone.

I love working in 3D and very often I won't spend laborious time doing drawings. I'll get sketches, quite rough, with elevations, and I'll go straight into the model shop and I'll start banging it into 3D straight away. It's the best way, and you can really deal with the 3D issues [of manufacturability] that come.

Tasks (other than modelling) for reaching decisions on materials and processes

...the thing I like to do with any product is to look at the market place; see what's in it. And for me, how can I make it completely different?
INTERVIEW SEVEN

Kenwood

Kenwood are a household name for domestic kitchen appliances, made famous in part by the 'Kenwood Chef' mixer. The interview was conducted at the industrial design wing of the company, the Kenwood Design Office (KDO) at Bramley, Hampshire. The questions were put to Johan Santer, Director of Industrial Design.

The role and significance of materials and processes in industrial designers' decision-making

...my view is the people who use the materials [designers] should be the experts so, you know, an outsider [e.g., a representative from a materials supplier] shouldn't have to come in and actually tell somebody that they probably should become familiar with something. If [designers'] business is actually using materials, they should know what's available in my opinion.

Industrial designers hold an "overview" of product design. They balance many varied criteria in order to design a desirable product, more so than any other member of a NPD team. The subjects of materials and processes are no exception to this and are at the heart of industrial design. Compared with industrial designers, other NPD team members have focused (rather than general) concerns for materials and processes. For instance, "...if you talk to a purchaser of materials (...) he wouldn't necessarily say 'well, OK it may be the cheapest material, but is it actually overall the best material for the product that we're trying to achieve?'." Holding an overview of product design deters the industrial designer from developing a product which is biased towards the interests of any one perspective (e.g., marketing, engineering, manufacturing, purchasing).

Speculative product design

Within any given design project there are inevitably product ideas generated that will never be put into production. At the commencement of a project, it is normal for three different schemes for a product to be presented, "so you know straight away that two of them are actually not going to go anywhere and you've often got no guarantee that the third one is either." So early on, design ideas are (by definition) speculative and some of
the ideas will never be developed for production. Forward-looking, speculative work is part of what an industrial designer does in the course of normal practice and is not a separate issue.

It's always struck me as a bit odd that you should be expected to do [wholly speculative work] and I think it comes back to the sort of perception of industrial design as being stylisation if you like (...) which I think is very much an over-simplification of the depth of what gets done.

The level of detail reached
A number of points were raised on the level of detail that materials and processes are attended to.

- Although the design office will recommend the use of particular materials, this will not include indications for precise sources or suppliers. Kenwood has manufacturing bases in China, in addition to Havant, U.K., and the availability of exact materials is different between the two bases.
- CAD models of the external surfaces of new products are developed and refined to a stage where they can be used directly by a toolmaker.
- The industrial designers at Kenwood are "very conversant" with manufacturing processes but are "not the experts". The kind of tooling that is required for a plastic moulding is considered. For instance, whether a straightforward two part open/shut tool will suffice, or whether collapsing cores, sliding cores and inserts are needed to achieve the desired component shape. Component and tool detailing is treated only cursorily.

...inevitably it's a controlling influence in what you can do. So we have an overview about the principle by which this product can be manufactured and assembled and we only define that, or explore that, sufficiently to move on to the broader picture...

Engineers and CAD operators undertake component and tool detailing.

I'm a great believer in using experts. I don't particularly want to (...) clutter my mind with that detail of knowledge in all aspects of NPD.
Once you've defined the principle of what you want to achieve, then it's just a process of mechanics of then actually defining that to its final degree. (...) Sometimes we have to take [detailing] quite a long way in actual fact, but we'd always be looking for cut-off. We don't get a lot of pleasure out of detail definition. Detail definition from the point of actually, you know, creation, but not for implementation. But you find that you have to do hinge details for things; you have to do a lot of definition on those just to actually present them as a proposition.

**Constraints**

**Availability of materials and manufacturing processes**

The manufacturing wing of Kenwood tends to direct the use of particular materials, partly because they have processing experience of these and know what the problems are. If a product is designed with an unusual material in mind, processing advice will need to be sought from material suppliers. In some instances, preferred materials may not provide good enough performance in a product, in which case special attention is paid to product detailing, as below.

[If a product casing] softens during temperature application (...) then suddenly you've got something that doesn't feel as sturdy, as rigid, when it comes to handling, if it is a handleable product. So you can't in those instances necessarily say 'well, you can go to a different material'. [Instead, special attention may be given to bolstering assembly details to compensate for shortcomings in the material.]

Sometimes the design office is advised by the manufacturing wing that a product component will have to be manufactured from a simple open-and-shut mould tool, having no side-action cores. If this constraint is likely to apply to a project, the design office needs to be made aware of it early-on because "...there's no point designing pure form if there is a serious constraint like that. [If the constraint is not brought to the industrial designers' attention] you usually have to modify the design to a point where it's unrecognisable."

**Budget**

A price point is set for each new product. "I think unfortunately price point can be too often too much of a driving factor because (...) instinctively there's a tendency to drive [a product proposal] towards the lower cost materials." Material choices based solely on costs is simplistic and can be detrimental to the design of a product.

**Health and safety**

A high level of hygiene needs to be achieved in Kenwood's products in order to be suitable for use in the kitchen. Products destined for food use have to be manufactured
from 'food grade' materials. This has implications for the application of materials and processes, notably in achieving different visual and tactile experiences from product surfaces.

...we tend to shy off, in a way, inserting too many materials as separate pieces because that creates joint lines. If you suddenly need to break up a product into sort of different elements [having split-lines between them]: the control area, the main body, the outside of a hand mixer etc., which you then get a lot of dirt and dust splashed onto, (...) then what you'd end up with is actually something which is less easy to keep clean, wipe down etc. So if you can introduce those materials but without the physical joint line, by insertion [moulding around a component inserted in the tool] or whatever, then that's the idea. The thing about that is it just makes it more complicated and harder to integrate because you're not only actually bringing in the new material but you're bringing in new manufacturing processes (e.g., twin-shot moulding). And that has to be a long-term investment because it's about capital.

New technology
It is tempting to make use of the newest materials and finishing technology in a product, but in practice it is generally too costly to be at the forefront of application, especially in mass manufacture, because the materials and processes are prohibitively expensive.

...there's a little sort of conundrum there. But you've certainly got to be aware of what's available because, you know, it filters through. It's got a value. It will filter through sooner or later anyway, so you either (a) sort of take advantage and pull that through yourself or (b) the market place will do that and then you're prepared for it.

The use of new (often expensive) materials can lead to conflicts.

...the purchasing department are looking for the cheapest material (...) so they can either pass on the cost-saving to the buyer, the purchaser, consumer, or indeed increase profit margins.

Product precedents
There are usually constraints on the kinds of manufacturing processes that are acceptable for Kenwood's products.

What you tend to get is a mix [of suitable manufacturing processes]. You get some flexibility in terms of the mix. I mean if you've got a generic product which typically uses injection-mouldings of different sizes, aluminium castings, stainless steel pressings, whatever, then as long as you're within the norm of those, typically, then you have some flexibility to how your product is broken up in that way.
The range of materials and processes that are able to be specified
Opportunities exist for suggesting out-of-the-normal materials and processes, so long as these are backed-up with convincing justification that established choices of materials and processes are insufficient. Mr. Santer thought that part of the industrial designer's job is to not be too dogmatic when making propositions for a product's manufacture, "...even though some people (...) may point out the fundamental error of your ways." In contrast to in-house work, Mr. Santer thought that materials and processes experience at design consultancies is more diverse.

When I was at Pentagram, you were designing say control units for Japanese manufacturers, child safety seats for cars etc. and you get [fabrics] as well as plastics. And if you're doing a bit of a portable computer you can get cases etc., so those bring in different materials, and different manufacturing processes too. It is amazing how sort of fresh that can keep you.

'Green issues' in practice
It was noted that green design is a complex issue. Mr. Santer thought that rather than concentrating on reclaiming materials from discarded products, it would be more prudent to respond to the proliferation of products. With regard to practice at Kenwood, three points were raised.

- Waste plastic from the production line is reground and re-processed so that plastic components contain a proportion of material that might otherwise be sold for very little return. The ratio of new to reground material has to be carefully monitored to prevent degradation of mouldings.
- Plastic components are marked with SPI codes and batch/date stamps to aid reclamation.
- Mr. Santer thought that commercially-available recycled materials would fall short of the standards set for food-grade plastics and for this reason doubted that the purchasing department would buy-in recycled material.

The nature of creativity with respect to materials and processes
Practical constraints have the potential to constrain a designer's creativity: "It depends whether those constraints are taken in an overview [acceptable] or they're coming in for very dogmatic reasons [less acceptable]."
Opportunities offered to industrial designers

Advancement of design

The industrial designers at Kenwood are always on the lookout for using either new materials or old materials in interesting ways, to push the boundaries of design.

What I will do there is be pushing the boundaries if you like from a very simple interpretation of the brief in the constraints that we've been given, through to something which is actually pushing the boundaries. (...) Then you've got to contend with manufacturing because usually it's pushing the boundaries for them as well. When you get near [the boundaries of what processes can achieve], you're actually demanding something of those people as well, but I think you have to. If you're not then you're going to be down in the mundane mainstream of products and there won't be much uniqueness there.

Fashions, obsolescence and longevity

Do fashions sway Kenwood's industrial designers to make use of particular materials and finishes?

...they do drag things through. I mean there's sort of a great thing going on at the moment [with the use of translucent materials], (...) you're getting kettles now which are sort of all translucent bodies etc. because that's actually sort of adding colour. And that's coming through from the housewares typically... and from the housewares it has dragged through from something else. Usually you can find fashion is an influence somewhere down the line. You know, fashion in terms of personal fashion, clothing and (...) cosmetics. But what you get, it's a kind of leapfrogging in a way because some fashions are not strong enough that they drag anything through with it, so you miss out, you know.

It was commented that fashions have a greater bearing on personal items and things that are carried around on the person, e.g., mobile telephones or personal organisers. This is in contrast to products such as those manufactured by Kenwood, which "you live with, but [they don't] live with you." A product's life span can dictate whether it is wise to incorporate fashionable materials, processes, colours and finishes.

If you think of a Kenwood mixer or whatever, I mean typically their life [before re-design] is five years and they can last longer. So you wouldn't necessarily relate those too close to fashion, because you would be tired of them because of that. If you've got, you know, 'blue is the colour of this year' sort of thing, in four years time you're going to be really cheesed-off with a blue mixer because that's not the latest thing.

For kitchen appliances, there is no great incentive to respond to regular swings in fashion because the environment in which the appliances are used changes very slowly anyhow.
Of course, there may still be a market for ‘fashionable appliances’ aimed specifically at fashion-conscious people who redecorate their kitchen regularly.

**New technology**

Two-shot moulding, where a mould tool is first injected with one material, the cavity then modified and injected with a second material, has presented opportunities for Kenwood’s designers. "You can get a very sort of soft, tactile area maybe within a handle but not by creating split-lines which have a down-side [of poor hygiene]."

A new material will come out and suddenly you’ll find an old product [rejuvenated]. You used to go to exhibitions when that first came out, and suddenly you’d see a whole range which was in this new material, and it was just using material for materials sake. But the more subtle material qualities if you like, I think they come along with new products, new product design.

**Functions that industrial designers desire materials and processes to satisfy**

An important goal to achieve, through the application of materials and processes, is to provide the user of a product with feedback, by carefully designing a product’s interface, controls and handles. For this, a sensitivity towards cleanliness of form, colour and inherent textures of materials is needed.

[A product will have components that] look as though it's something you should hold and then feels very comfortable when you do hold it. It's going to have a little bit of give, a little bit of softness to it, whatever.

The utility of materials is important too, "...if your product is getting hot for instance then that is a determining factor in lots of the materials."

**The use of information**

Colleagues

Work will often involve liaison with colleagues based at Kenwood’s manufacturing facility at Havant. "There are (...) departments within Kenwood that have the facility to [identify materials for you, based on mechanical and chemical properties e.g., strength, temperature]."

**Designed artefacts and the wider world**

...in terms of new materials, (...) you're constantly on the look-out. It's about your own knowledge, awareness and familiarity with what's going on around you... It's just general sort of product awareness or market awareness, but it tends to be very peripheral in a way.
The use of processed materials in existing products or products showcased in design magazines can be a source of cross-fertilisation for one's own design work. The handling and dismantling of artefacts is important because an appreciation of materials and assembly can come this way (and subsequently applied in design projects). Mr. Santer commented that, although valuable, knowledge of materials and processes gained this way is rather like "window shopping"; it offers a superficial level of understanding.

**Liaison with material suppliers / manufacturers**

Polymer manufacturers, such as ICI and Bayer, have consultation services which can help in the design of a product.

**Physical samples**

Mr. Santer commented that one can get ideas for products just from seeing materials in the flesh. The design office has collections of "virtually anything", including rubber, polyurethane, glass and ceramic.

Within the industry, actually trying to sort of collate samples of materials from either manufacturers or materials suppliers is extremely difficult. Indeed even things like colour swatches [are difficult to obtain]. Some of the [plastics] manufacturers (...) are getting on the ball, they're offering you ranges, not only in terms of colour but tactile qualities and visual qualities of the material. Matte finishes etc., which are intrinsic to the material, not applied as a texture or whatever. On the sales side though, which is always the initial contact, I mean they'll always try and push you into what they know, sort of standard stock etc., because that's where they know they can be more competitive.

**Printed sources**

Magazines are a medium through which designers can keep up to date with materials and process technology. A cursory scan is made of materials and tool-makers magazines. Design magazines are a richer source of information, typically highlighting innovative designs and new uses of materials. The information in the latter publications is relevant to industrial designers because it is product-oriented.

**The use of computers**

Photo-realistic renderings of product proposals are generated from CAD models and, by changing the surface attributes of the models, a variety of different materials and finishes can be mimicked. Computers do not help in assisting with choices of materials and processes.
Knowledge and values

**Desirable core knowledge for an industrial designer**

An industrial designer needs to know of the materials and processes that are generally available and the fundamental constraints relating to each, so for any given project the question 'could we use this?' can be posed.

**DFMA knowledge**

Moulding processes are very similar whether a component is to be manufactured from polycarbonate, polypropylene, polyurethane or many other plastics. General principles of product design apply for these materials and are applied in development work. Subtle differences in product detailing are required for each material though.

**Effects of materials and processes on the creation of form**

Once a product's basic form has been established, the key material requirements for the individual components of that product are scrutinised.

If it's a handle area, you are talking about form which is comfortable to hold. If you're then talking about materials then you'll actually say 'can we introduce a more tactile material in that area?' or whatever. With others, it's a visual element: sight windows for coffee makers or whatever. So it's actually what you're trying to achieve, the function of it.

**Knowing that**

Often, in proposing manufacturing routes, reasoning will be along the lines of "in principle, we know that it can be done."

**Value judgements**

I suppose, within the conceptualisation, what you're looking at...the first thing we do look at is actually form, but then you're trying to break up the different elements and what are important in those elements to the user. [see next paragraph]. [You take] a view if you like, a stance, and make some judgements about the manufacturing process. (...) If I'm honest then we would always drive [a product's design] from the form angle if we can, and then try and shoe-horn [manufacturing] in, or find the appropriate process for actually making it.

**Cognitive modelling**

This is an awkward one because it varies in actual fact. At times you're actually looking at form and you think 'well, how can I create that? how can I achieve that?'. Other times (...) the constraints of manufacture make [the choice of manufacturing route] so tight that [those constraints are] at the forefront of your mind.
3D modelling

A hint was given that CAD has ousted perhaps too much of the hands-on design work that industrial designers have traditionally been involved with. The first physical representation of a new Kenwood design is made via stereolithography or CNC machining. This is completed around two to four weeks after a product's components have been defined (the definition period typically lasts four to six weeks). "There's quite a big gap there [between initial briefing and handling a physical representation] and (...) you can get some surprises [regarding how the form works as a physical artefact]." Mr. Santer had been contemplating how some of the traditional practices might be re-integrated to overcome this problem, and thought that foam modelling could be used as a quick and acceptably accurate method of representing product form.

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38 Stereolithography is a popular prototyping technique whereby highly complex internal and external details of a product can be reproduced, direct from a CAD model.
INTERVIEW EIGHT

Nokia

The Finnish firm Nokia are one of the largest companies in the world-wide personal communications market, manufacturing a large range of innovative mobile telephones. The interview took place with James Eldon, Design Manager and Team Leader, at the company's Research and Development (R&D) wing at Camberley, where the mainstay of work is for the Japanese market. Mr. Eldon's expertise is materials and processes R&D work for Nokia mobile telephones, an unusually specialist role. His job title is "Colours, Materials and Graphics (CMG) Design Manager" and he is positioned within the Mechanical Technology Action Group (TAG), providing materials and processes expertise to industrial designers.

The role and significance of materials and processes in industrial designers' decision-making

Materials and processes are subjects at the heart of industrial design.

I was trained with this sort of puritanical modernist type of thing that an industrial designer should only design and make models in grey... [to concentrate the mind on the development of a product's shape and form]. But when you really get out into the real market, it's so much finishes and colours and materials and feels that sell. It really is. (…) It's that that can sell a product, more so than the rads [radiuses, curves]; more so than the lifestyle concept of the product...

The link between design, materials and manufacturing is strong at Nokia. A number of the industrial designers have mechanical engineering experience and, prior to employment at Nokia, were involved in the production details and ramp-up of new plastics products. As a consequence, industrial designers at Nokia are sympathetic to "the very real issues of mass-production and mouldability."

The timing and sequence of attention

Mr. Eldon's inputs need to be fed into the industrial design activity early on, during the concept phases of NPD. His work involves proposing new finishes for next-generation
products, and then assessing and forecasting the resources and investment needed to implement the new finishes into a production artefact.

The level of detail reached
The manufacturing detail with which Nokia's industrial designers are involved has changed in recent years. The nature of the work has swung away from mechanical design, CAD and detailed engineering of components, towards more conceptual work. Designs are passed on to the company's engineers for further refinement. Nevertheless, issues of manufacturability such as material performance, mould weld-lines and mould release are important to the industrial designers' work, chiefly because they are closely linked to product quality.

The quality requirements for the Japanese market are absolutely crazy. A tiny spec and it's out. A sink mark, a blemish, a stress mark, a weld line, a flow line, any colour change and we'd reject the batch. It's the Japanese customers. It's [a demand of] the people we sell to in Japan. The Japanese are renowned for it across the world.

Constraints
Availability of materials and manufacturing processes
Across the world, if we manufacture twenty million phones a year, if we suddenly decide to do something like paint then we have to find the vendors that can paint twenty million pieces of plastic over a year. Now everybody's reaction to that is 'well, the car industry paints a lot', but painting cars and painting very small bits of plastic is very, very different. And actually finding vendors with (...) the expertise and knowledge (or building those up to have that) and to get them in the right areas and get them properly licensed, is a real struggle.

Budget
Different combinations of materials, processes and finishes each have a cost associated with them, which may or may not be able to be absorbed by a project budget.

Marketing department
Generally the constraints on materials and processes choices come from mechanical and production issues. On occasions, directions from Nokia's marketing department influence materials and processes choices.

Mechanical and chemical properties of materials
A number of Nokia mobile phones make use of painted finishes. These have to be non-toxic, use solvents that don't embrittle the plastic to too great a degree and they have to be moderately wear-resistant.
The range of materials and processes that are able to be specified

Most of Nokia's products are manufactured from GE Plastics Cycoloy (a polycarbonate-ABS blend). Smaller quantities of ABS, PMMA (acrylic) and polycarbonate are used, the latter two for product windows.

There isn't much materials variation that we do. But there's becoming more of a need, especially in going to thin wall moulding, which everyone's doing in the industry, I mean you have to go for the super high flow materials.

Currently the emphasis in design work is to simulate materials with different paints and pigments within plastic mouldings, rather than making use of different base materials. Opportunities are arising for specifying out-of-the-ordinary materials though. One innovation recently has been a chrome-plated product that looks as if it is manufactured from metal and feels characteristically cool to the touch.

Experiments have been done where they've actually taken out the plastic core and having the plated product as just an empty shell. I don't know, it wasn't Nokia doing that, it was someone else. But you could do that, structurally it's very good. It's not quite metal but it's half-way there.

Graphics are closely related to materials and processes issues, and the industrial design team have design input into these. "You'll see from the IMD [in-mould decoration, see 'Opportunities'] that there's lots of graphics, and that's the way it's maybe going to go."

'Green issues' in practice

Green design issues are having an increasing bearing on Nokia product design. It was pointed out that green design is a complicated area and that, internally, a Nokia group is undertaking investigation of green design issues and the forthcoming legislation. Mr. Eldon noted that alternative 'greener' materials and finishes often involve unproven or only semi-successful technology.

The nature of creativity with respect to materials and processes

Mr. Eldon made an observation on how industrial designers go about generating ideas and product concepts.

When industrial designers conceptualise their work (...) ideally they don't hold anything back- they ask for what they want. Whether they can get that or not is another issue.
Opportunities offered to industrial designers

Cosmetic details

...when you talk to people and you say 'do you use the memories in your phone', they say 'has it got memories?' or 'don't use it all' (...). Fifty percent of people probably don't know half the software that's on these phones. It's not software, necessarily, that sells a product, or it's becoming less so. It's becoming more the look of the thing, the style of the thing, the fashion, the status.

Fashions / In-house R&D

Nokia regard themselves to be at the forefront of the application of new materials and finishing technology. Rather than follow fashions, Nokia take a lead on new product design through their extensive in-house research and development: "we like to think we're a little bit ahead." Mr. Eldon described some recent innovations, first a phone that had a mica base coat paint with a clear lacquered top coat, creating surface colour changes according to the ambient light.

These things created a fantastic stir in the market, this colour changing effect. It really has got a lot of press, and it's quite desirable. It came from (...) my team and working closely with the vendors.

Another innovation has been a phone with multicoloured changeable front panels.

Those are all painted finishes. They're metallic automotive type finishes that we considered to be a bit lower-end, and right for the more playful/fashion market.

Research and development at Nokia is directed in two key areas.

- Ways of improving the general aesthetics and cosmetics of Nokia's products.
  "That involves anything from just very open, general research, all the way through to proving things for mass volume production."
- Forecasting colour trends for products and predicting future product finishes and materials for different market sectors. "We recommend and propose different things for different products across the globe."

Nokia has close working relationships with GE Plastics and other materials manufacturers. Part of the work of Nokia's industrial designers is to generate creative ideas for Mr. Eldon to push the materials manufacturers to achieve. Advances in the technical characteristics of materials are also sought from vendors. "Because we are a
reasonably large consumer of plastic, there's incentive for the suppliers to develop the
technology and develop the materials."

Flexibility of the company

The design group within Nokia does have a very high status and we have a vice-president of design at board level, who has (...) a terrific lot of influence in what we do; a lot of decision-making power. So any hindrance doesn't really occur because of people, or disciplines [within Nokia].

Market differentiation

Materials and finishes are used to differentiate high-end and low-end products.

...we're really building up a palette if you like of materials that are available to us (...) because we're looking at such a large global market. We sell probably twenty million phones a year; we're selling to the low-end market, we're selling to leisure/lifestyle, we're selling to high-end, we're selling exclusives, limited runs. So when you ask the question 'what do we look for?', it really depends on the market. We look for everything at the moment. We have to be ready to (...) cut into whichever segment of the market. So tacky-looking bright, glitzy colours in plastics, special effect plastics, whatever, special effect paints, patterns, all sorts of things are all... they're all as relevant as the subtle effects are because they can generate revenue [within particular markets]. [Within the Japanese market, for instance], you'll see much more variety in types of buttons used: gloss buttons, chrome buttons.

Miniaturisation

The use of miniaturised electronics has implications for casing design, allowing phones to be designed smaller and more lightweight. Compared with larger casings, smaller casings are:

- less likely to break (so that the mechanical strength of the material used does not need to be so high);
- more easily moulded (because the distance that the melt has to flow in the mould is less); if the component to be moulded is also relatively simple then there exists greater opportunity to use more elaborate materials.

New technology

Mr. Eldon sees new materials, processes, finishes and printing technology as a key to future industrial design that will bring exciting new opportunities. As a member of the Mechanical Technology Action Group, he investigates new and unproven technologies that could bring benefits to Nokia products.
It's the combinations of technologies which really is the future, but applying those technologies. The technologies are out there; it's a matter of applying them and combining them [for use in mass-manufacture]. We've just launched a product in America which uses an IMD process - an In-Mould Decoration process. It's a [decorated] film that's lowered into the injection moulding tool (...) and we're using a clear material [for the mould]. That's the first application of IMD, we all believe, to mobile phones. It's not really been used before, on a complete curved front of a phone. It's been used on flat panels- Motorola have been doing it and we've done it ourselves, but it's quite revolutionary in that you can stretch a transfer around a complete moulding - in the moulding process. You're taking out that extra part [LCD window], so you're reducing costs and you're giving us that ability to differentiate in the marketplace.

The use of information

Colleagues

Suggestions for the application of materials and processes can come from the industrial designers to Mr. Eldon or, more often, ideas are fed to the industrial designers for incorporation in creative work.

Designed artefacts and the wider world

Existing products are a strong source of inspiration for product ideas.

I think mobile phones... it's not really a mature product (...). It's exploded from nothing to something absolutely massive in a very short space of time. So a lot of the technologies that are out there [in other products], of finishes and materials, have not been exploited, or simply transferred. Look at [Sony] Walkmans in the shops: all different types of finishes and materials. Look at cameras; look at the [Canon] IXUS steel-front camera. I mean (...) none of that's been done in mobile phones yet and it's terrific potential.

Liaison with material suppliers / manufacturers

GE Plastics and other materials vendors provide technical support.

Printed sources

The industrial designers have access to material specification sheets that describe mechanical and chemical properties of materials (e.g., hardness, scratch-resistance). These were produced in-house as part of Mr. Eldon's work.

We have our own internal quality control standards, we have our own engineering standards, our own drawing standards, our own way of applying functional characteristics to markets. Some of them are taken from ISO and (...) other standards.
The use of computers

Computer-based materials databases are used to search for plastics with specific engineering characteristics and physical performance.

Knowledge and values

Mr. Eldon indicated that the materials and processes knowledge of industrial designers is not always strong. "I think with a lot of industrial designers, they think they want something but half the time they don't seem to be aware of the multitude of other things that can be done."

2D & 3D modelling

In Nokia's industrial design process, physical models are made as simulations of end products.

The industrial designers work [on] concept sketching, straight into visuals and visual models, finished models (three or four variants) and then they're selected. And then it's straight into CAD engineering and [stereolithography].
INTERVIEW NINE

Samsung

Samsung is a giant multinational corporation with headquarters in Seoul, Korea. The corporation has many subsidiaries including Samsung semiconductors, construction, finance and automobiles. Its product design wing, Samsung Design, has international bases in Tokyo, Palo Alto, London and Singapore. In Seoul, the company employs over two hundred industrial designers working on products from white goods, through cameras, videos and televisions, to microwave ovens and coffee makers. The interview took place with Mark Delaney, Product Designer, at the company's European Design wing in London. At the time of the interview, the international design offices were being scaled-down because of the Far East economic crisis.

The role and significance of materials and processes in industrial designers' decision-making

The challenge facing the industrial designer is to present exciting product ideas that have been assessed for manufacturability.

There's no point in being an arty-farty designer; you're not going to get an ounce of respect going in [to a meeting] with [product ideas] that can't be moulded, or something that's going to cost millions to even mould.

Mr. Delaney commented that his involvement with materials and processes was less detailed than that of Samsung's engineers, but that the involvement was nevertheless integral to his work.

...personally I don't want to spend all my time on tools and working out how things fit together, but I feel there's no point in me handing over things that can't be made. So, still treading that middle-line.

Without involvement with materials and processes, Mr. Delaney commented that designing would be dull: "...materials and processes are where you can add some spirit to your design."
The timing and sequence of attention

It was noted that there was no particular stage when materials and processes are brought into design work. When a brief is received, thoughts on possible materials and processes tend to come very quickly to mind. A note of caution was expressed though.

...at the very initial stages, it's very bad to censor yourself. You can't start thinking... when I do an initial sketch I don't start thinking 'how can it be moulded?'. I'll do a sketch and then try and synthesise that into something that can be made.

It is important not to dwell too much on idea generation without due regard for issues of manufacturability.

You just have to come up with the idea very quickly and get it out very quickly, because you'd rather spend time policing that design through, and doing as much work as you can at the front end to make sure that the design that you hand over is as producible as possible; so that it doesn't get messed-up (rather than spending a lot of time at the sketching phase, going through millions of different ideas). (...) You just don't have time in a working environment (...) to sort of go right through all these big long spiralling loops that you go through as a student.

After potential materials have been identified for a product, the design work moves on to developing ideas for the most suited production processes. Early sketch work will look at how a product will be assembled and the number, type and layout of mouldings that will be required. With regard to company logos and graphics, these need to be incorporated from the very start so that they do not become poorly thought-through add-ons after a product's basic form has been determined.

Mr. Delaney pointed out that, where possible, he liked to receive a brief a month before committing time to a project, in order to "chew it over" and note down general design ideas that spring to mind. Time is often at a premium when working on a product, so this pre-project time is valuable.

Speculative product design

Design work occasionally focuses on highly conceptual work, exploring future marketplaces for Samsung products. Materials and processes are still a feature of such projects, in that design proposals are developed so that they could be moulded if taken to a detailing stage. Overall though, the depth of attention to materials and processes is less than for everyday design work.
The level of detail reached

...I feel my strength is coming up with the creative, realistic ideas and handing them over in a form [design engineers] can understand and work with.

When designing an injection-moulded component, details such as part lines, assembly points, bosses and injection point scars are routinely considered. Part detailing and tool design are carried out by engineers, who have expertise in detailed DFMA. Through this use of teamwork, Mr. Delaney is left with more time to work to his own strengths.

I just don't know enough about [tool design], it's such a huge field. And often when I get into situations where engineers say to me 'well, have you thought of how this will be made?', I have to say 'well I've thought a little bit and I think it can be made but that's what you're here for. If I could do that, then I wouldn't need you, I could just take this straight to a toolmaker'.

One aspect of NPD that features regularly in Mr. Delaney's work is the policing of designs through to first production runs. Before Samsung had a European Design Centre, work used to be tendered out to consultancies. Often these consultancies would produce stunning presentation models but the final off-tool production artefact would be disfigured in comparison. In such cases, Samsung would say "the model was beautiful, but our engineers couldn't do it." Hence, in the process of developing a product for manufacture, fundamental features of a product's form can become distorted. Working in-house, Mr. Delaney has developed good relationships with Samsung's manufacturing bases and is able to oversee designs as they go into production. This aspect of the work was explained in detail.

Seymour-Powell [a famous U.K. design consultancy] have a really good slide show that they give to clients. [They] take a picture of Claudia Schieffer, put her up on the screen, and say 'oh she's beautiful isn't she?', and they'd say 'oh yeah, yeah, she's beautiful'. They put another picture up and they've just changed her slightly in Photoshop. They've just moved her eyes slightly more apart, and they say 'oh, it's alright, she's still beautiful'- then they do another one and they've changed her a little bit more, and then they do another one and by the end she's looking really weird. And they say 'all we've done is move her eyes by a mill [millimetre], and made her nose five percent bigger', and they say 'it completely changes her doesn't it?' and the clients are going 'yeah, yeah'. [The response is then] 'well this is what you're doing to our products!'.

Constraints

Availability of materials and manufacturing processes

Samsung's manufacturing bases keep stockpiles of favoured materials. Consequently, directions are given to make use of these materials in new products. The engineering
departments evaluate which materials will be required in any given product and their advice is fed back to the industrial designers.

**Budget**

Mr. Delaney commented that despite an endearing aim of many industrial designers to produce products of beauty and artistic merit, in reality costs are too tight to implement out-of-the-normal materials and processes. "Often engineers will want to change things because they can mould it cheaper, and you have to say 'yes', you know, unless it's really going to ruin it."

**Design brief**

At the commencement of a project, a brief will be developed which will include descriptions of the target selling price of the new product and the kinds of constraints that are likely to impinge on the design work.

**Detail preferences of the toolmaker / manufacturer**

Often the longest fights we have are to do with shape. (...) I want very soft, ergonomic forms with very complex curving surfaces, and that's very difficult for the engineers to do. They'd much rather that I'd put a single [radius] or something. [But] it's no good being a prima donna and throwing your toys out of the pram and demanding you get this... I mean there are some things, certain types of tooling where it will save thousands of dollars, and if you can do that then you (...) make thousands of dollars more profit. So you've got to be realistic.

**Product precedents**

It is important to know what one can and cannot include for particular types of product. For instance, a mobile telephone is likely to be able to absorb the extra costs of striking finishes because the market demands those kinds of details. In contrast, a microwave oven is a product that customers will not pay a premium for and so the cheapest materials and methods of manufacture will prevail in any new design, as below.

> There's no point in me suggesting 'we'll put some real chrome in here' and 'we'll put some gold trim around here' and things like that, because [the engineering department] will just throw it straight out.

**The range of materials and processes that are able to be specified**

As an industrial designer working on mass-produced consumer goods, the vast majority of products that Mr. Delaney designs are manufactured from plastics. Major variations between plastics products are achieved through the use of different material finishes
Occasionally, on high-end products, details in wood or chrome can be added.

But the moment you do something like that, the costs just go shooting through the roof because (...) most manufacturing places are just set up with lines of injection moulding machines, chucking out injection mouldings, trundling along in turn televisions and VCRs [video cassette recorders].

Observations were made that the diversity of materials and processes that are involved in a designer's work are generally a reflection of the nature and variety of products that the employing company manufacturers. In a company producing one-offs or small batches of products, opportunity for varying material choices is greater. As a student designer on placement at a design consultancy, Mr. Delaney worked on furniture design, where knowledge of aluminium castings and wood finishing technology, rather than injection moulding, was required.

At Samsung, Mr. Delaney supervises the design of product graphics in addition to the bulk form of products.

You can't get a decent graphic designer to work full time on product graphics because it's bloody boring [for them]. They all want to do books and things like that, which is perfectly... You know, it's like asking a product designer just to design knobs.

'Green issues' in practice
It was noted that manufacturers are currently in a transition stage, where awareness and appreciation of green design issues is high, but the cost of widespread implementation of green design practices is prohibitively high.

[The drive to implement green design principles] is going to have to come from the top [legislation] or no-one's going to adhere. What you'll get is if one company starts doing it, their costs will go up and everyone else's costs will stay down... so people will say 'well why should I buy them?'.
We had this quite interesting thing with B.T. [British Telecom] phones. The way that B.T. work is they get product designers to design their phones, then they tender out to companies to make the phones for them. So we had two identical-looking phones made by two different companies. One was a European company, and one was made in Malaysia. From the outside you couldn't tell the difference, the materials were the same. It was only when you started looking at where the screw bosses were, and the fixing points were very different. What [Electrolux] said to us was we had to take these two products apart. So we took the European one apart in minutes. It was literally five minutes and the thing was all in bits, a nice pile. The Malaysian one took about fifteen minutes, and they had things like two different pieces of plastic glued together, they'd sonic-welded two things together, they had a big lump of lead glued into the handset to give it weight (...) so that was appalling. That really brought it home to us how we couldn't do that any more. As a result of that, we went through all our products, all our vacuum cleaners, found all the problems with them and tried to fix them.

This drive towards 'design for disassembly' resulted in subsequent Electrolux products having plastics labelling, batch labelling, an absence of dissimilar materials glued together and use of a minimal number of screws. A recycled polymer called Jazz was introduced as a replacement material for non-Visually important parts (e.g., motor and bearing houses).

Use of recycled materials in new products
The opportunity to specify recycled materials for use in new products is generally non-existent simply because it is cheaper to use virgin material.

Many companies will make attempts at it and make half-hearted efforts and make a big stink about how they are making these efforts, but in general no company I've seen is really making any big in-roads [on the use of recycled polymers in products].

The nature of creativity with respect to materials and processes
Mr. Delaney thinks that it is important to approach a new project with a fresh mind, open to opportunities, and to try and challenge existing products. Importantly, this should not be a challenge just to be different. Students who have worked with Samsung in the past have sometimes fallen into this trap. Rather than being creative within plastic materials, they have been "lazy" and opted to design mass-manufactured products in bizarre materials. For example, one student designed a vacuum cleaner in wood.

Any form can be created with sculpting out of marble and adding bits of leather and wood and things. (...) I mean, any fool can come up with a beautiful design. Any product designer who's done a year or two's training can come up with a beautiful looking product, but it probably costs thousands of pounds to buy and it's just not realistic [for mass manufacture].
It was stated that the hardest part of working as an industrial designer was being creative within the constraints of production processes and budgets. Often the creativity will manifest in very small design details rather than major changes in materials or processes, simply because, after initial investigation and challenges to design precedents, it will be found that major changes cannot be absorbed by a project's budget.

[Attention to materials and processes] can constrain you, if you let it, but (...) the skill [of designing] comes in being creative within the boundaries of the production processes and the costs that you've got to meet.

Opportunities offered to industrial designers

Advancement of design

Often the work at Samsung involves the tweaking of existing products by, for instance, changing controls, altering fascia moulds, updating colours and adopting different materials. Simply through changes in materials and finishes (and using the same mould tools), the entire character of a product can change. Mr. Delaney gave the example of the recent Dyson vacuum cleaner, now available in transparent plastics, revealing otherwise hidden internal components. The product is quite different to the original, produced in solid grey and yellow.

In the past we've fought very hard to hide all fixings and hide all ribs, sink marks and things, and somehow on [Dyson's transparent product] you can see all that. It just makes it (...) more beautiful, and I think fits in with Dyson's technical image; shows off his technology.

If a proposal is made to produce a new product using unusual materials and processes, much effort needs to be expended in (a) convincing colleagues that it is worth it, and (b) assuming acceptance, policing the design of that product through to manufacture. It is vital that the principles for adopting (and methods of applying) new or alternative materials and processes are thoroughly thought-through for a design. Often, when giving a briefing to colleagues in Seoul, Mr. Delaney will accompany his presentation with a written report because some of what he says does not come across accurately in the language transcription. The report acts as a basis for any future queries.

If you go in [to a project meeting] with something that's very standard and very usual and uses all the same materials as they're used to using, all the same manufacturing techniques, all the same graphics and colouring, it's easy.

New finishing technology (e.g., IMD) can be used to bring exciting new design details to products. Established technology can also be used in interesting ways to further the
Chapter Seven: Interviews with professional designers (Samsung)

design of a product. An example was given of using two injection-moulded components where one passes up, through and then re-enters the other, with the potential of creating different colours and textures on a single surface of a product.

Fashions

It is important to keep abreast of design trends but difficult to predict what the next influential fashions will be, short of attempting to take a lead on new product styling and material finishes. There is obvious risk in attempting to be too bold and creating a product that the paying public does not warm to. Mr. Delaney explained that Philips industrial design has strong influence over designers around the world and that, as a prestigious design outfit, Philips could afford to explore possible future trends. One such exploration was Philips' Vision of the Future project.

[Philips briefed their designers] on new technologies that were coming, new social trends that were coming up, and said 'go away and design sets of products'. They spent about a year making all these products. [As an outcome] they [published] a beautiful book and they made little videos of how these things would work.

The trends exhibited in the Vision of the Future book are now coming to the fore in contemporary industrial design.

...every designer who's seen them has ripped them off. (...) Philips did a very clever thing. Rather than sitting and waiting, trying to predict what the future was, they literally went out and made the future.

As a consequence, other manufacturers have had to catch up with the precedents that Philips have set, not least in choices of materials and finishes. The Vision of the Future book featured products manufactured from translucent materials, plastic metallic finishes and combinations of metals and plastics, all of which are now employed by manufacturers of consumer products. The use of translucent materials, in particular, has been carefully watched by Samsung.
Market differentiation

Often a lot of rot is talked about (...) you know, for every design there is a perfect solution, and that's complete nonsense. You can get things like the Philips-Alessi kettle which is a very expensive kettle, but when you're buying that you're not just buying something that boils water, you're buying an icon: a product that says something about you, so you're willing to pay the extra seventy pounds for it. And that all comes down to materials again, and the design. They've used design and materials to package a very standard piece of household equipment. [When you look underneath it, all the technology is the same]... and you can definitely get more hi-tech kettles cheaper. So it's all (...) understanding brand image and product placement and perceived value, and how people use design and materials to achieve those goals. That's where the tricky part comes.

One of the tasks that Samsung's industrial designers have to achieve is the differentiation between entry-level and high-end versions of the same product. In the past this was achieved by adding technical features and more buttons, but the trend now is away from making products 'hi-tech' and towards simpler, better made products. Materials are used to help differentiate product ranges: "...by adding-in soft-touch materials, translucents and metals or rubber-type things (...) you can raise the perceived value of a product, probably without adding too much cost." It is important to bear in mind that differences in perceived value exist between different world markets.

They think that in Asia, very hi-tech products with lots of buttons and flashing lights, that's like really hi-tech, 'wow that's really great'. Whereas in Europe it's sort of simpler, more austere almost, design is considered more hi-tech. (...) You want [products] in a form you can use (...) easily. And things like remote controls, by using materials and textures and different colours, you can make a remote control simple and intuitive to use, rather than like a bloody flight deck.

New Technology

Part of Mr. Delaney's job is to identify new materials and new processes that could be used in Samsung products. Research is carried out and 'design trend' reports are created as part of this process. Although certain combinations of materials and processes are favoured by Samsung's engineers, part of Mr. Delaney's job is to suggest alternatives.

It's always good to try and push things on, because often engineers are very good at engineering but not so good at innovation. I find often with engineers, if you can put a product [proposal] in front of them and say 'this is how we want to do it', they can take that to bits and they can improve upon it. But if you try and explain an abstract thought to them, you can just forget it.
Functions that industrial designers desire materials and processes to satisfy

One of the industrial designer's tasks is to focus on the experience that a user will have when operating a product. Designing for tactile feedback, using surface forms, handles and soft-touch materials, are all ways of improving the user's experience of a product: "...it's a tiny thing, but often [makes a large difference]." Designing for tactile feedback is about provoking a response from the users of a product.

The use of information

Colleagues

Sometimes if it's a particularly complex project, I've had to go out to Seoul for a briefing and meet the engineers and spend an hour or two hours crashing through all the points of what I can do and what I can't do. [For example] there's no point in designing something if you find you can't fit the PCB and batteries inside, so I like to get as close to the internal dimensions as I can.

Designed artefacts and the wider world

It's the way designers work: they sort of look around, see what's around, take little bits of this, little bits of that. And always when I'm out shopping and things like that at weekends, if I see something that makes me think (...) 'wow, that's good', then I'll make a note of that. (...) I know when I'm out shopping, my girlfriend gets furious with me (...) because I see something and I'm going 'what the hell have they done there?' And I'm looking going 'look at this part-line', and she's going 'put it down, put it down, you're embarrassing me, you idiot!' I think as a designer you're constantly (...) cataloguing ideas that you want to use. Generally the way you do it is you find products that you like, and that's how you find out [more about product design].

Handling broken products or disassembling functioning products is an important part of the on-going learning process for a designer.

Electrolux released a vacuum cleaner recently that's got nice soft-touch rubber handles on it, so you think 'wow, what's this material?' and try and find out what it is, and maybe take it apart and have a look at the labelling inside and try and track it down. (...) If there is a particular product within the existing market that we think is doing something very good, we will buy it, take it to bits, send it out to Korea and find out how [the manufacturer is achieving the end result]. That's a very standard [way of acquiring knowledge] within design.

Liaison with end manufacturers

Having worked for Samsung for several years, Mr. Delaney has built-up important relationships with its manufacturing bases. Through close consultation with manufacturing, he can check that small design details are carried through to final production and not left to slip somewhere along the way.
Physical samples
At the design centre in Seoul are a string of display cabinets containing dismantled products, showing off different materials and finishes. Each product is labelled with an explanation of how the product has been manufactured and finished, and from what. The industrial designers can use these product examples when making a presentation and say 'this is what I am thinking of', making it easier to communicate design ideas. When Mr. Delaney is considering proposing a new process or a new material, he will try to get hold of physical examples to strengthen his case and ease communication to colleagues. A collection of buttons and keypads manufactured from different materials is held within the office.

Printed sources
To keep up to date with the latest technology, the design press (e.g., Design Week, Design magazine, ID, Blueprint) is regularly scanned. Samsung Design in Korea is involved in an extensive research and development programme focused on new technologies, including new materials and processes, that have the potential to be used in future Samsung products. The motivation for the research is to gain competitive advantage (and in some cases catch up) with the largest companies in the electronic consumer goods market, such as Sony and Philips. The research programme has two outcomes that affect Mr. Delaney's work.

- Workshops, held in Seoul, where briefings and discussions are given on ongoing design issues, new materials and new finishing technologies.
- Data sheets relating to the above, to help in design decision-making. One example sheet detailed visual and mechanical properties of a new finish and indicated benefits, drawbacks and costs of the new technology against established alternatives. Most of the data were presented on a quickly-referenced graph. Plans are afoot to publish this information on an intranet site so that Samsung designers around the world can quickly access the information they need. Mr. Delaney commented that it is very rare for a company to undertake such in-house research and provide its designers with custom information.

It's brilliant to get things like that. (...) This is only the first stage and I would hope it would go on, but with all the trouble in Korea with its currency, ...stuff like this costs a lot of money and it's the first thing that gets cut when there's troubles.
The use of computers

Computers are used to render product ideas in different materials and finishes. Samsung's engineers use mould flow programs to analyse and rectify weak points in component detail design.

Knowledge and values

Desirable core knowledge for an industrial designer

[Employers are] looking for that spark of creativity, but they're also looking for a realistic creativity that they can immediately put to work on products. There's no point having someone whom you have to completely train from scratch in the ways of draft angles and part-lines.

Knowledge on a need-to-know basis

Mr. Delaney gave a vivid description of how his product design knowledge is often added to on a need-to-know basis, dispelling any notion of a boundary that might be placed around industrial designers' materials and processes knowledge.

When I did my first phone, I'd never designed a phone, so I immediately had to (...) gain knowledge of what was happening in 'phones at the moment: what was the best selling 'phone; what was the best designed 'phone; you know, that sort of thing. So you have to do a bit of research, and in doing all that research you come across interesting things, like 'oh, they've done it that way, they've back-sprayed, they've put texture', and you get a feel for how companies are raising their brand image, or raising their products' perceived value. And it might be by putting some chrome on it, or changing the shape of the buttons or something like that. (...) So there are no limits [on materials and processes knowledge]. There was one product where we were thinking about putting a neoprene case on it, so I'd have to learn about neoprene and how that was going to be produced. So (...) as a designer you're never going to be finished learning. You're always going to have to understand new things (...) and I think that's good.

On-the-job experience

Through on-the-job experience of designing products that have to be made, Mr. Delaney noted that it is now very difficult for him to generate serious design ideas that cannot be made. He talked of being "au fait" with draft angles and the ways in which one must design for manufacture. Experience has led him to "get a feeling" for whether a product can absorb the cost of certain material and process combinations.

Value judgements

Recently we did a washing machine. For the buttons I wanted a silicone rubber sort of feel, because I felt that rubber and a washing machine and water all went well together because, you know, you want something safe when you're pressing the buttons.
Cognitive modelling

Mr. Delaney pointed towards possessing a library of design details and product knowledge in his mind (that might be recalled as images in the 'mind’s eye').

...you file [a product that's caught your eye] away in the back of your brain and you think 'ah, yeah, that's how they did that, that's how they made that interesting sort of finish'. And [you can draw upon this knowledge in subsequent projects].

2D modelling

Thoughts on manufacturing interject with sketch work. Drawn ideas for a product's shape provoke questions on how to achieve that shape through available manufacturing processes.

Evidence that rigid design procedures are followed

Mr. Delaney described differences of overall approach to designing between designers in Korea and designers based in Europe.

They find [the work practices here in London] strange because in Seoul the designers work very differently, they're very methodical. They do sketches (...), someone chooses a sketch they think is good, [then] they do models. Someone chooses the models they like, [then] they do better soft models. And it sort of progresses that way and there are very definite stages, but as designers in the U.K. and Europe, we tend to work in a fairly haphazard way. I'll have a CAD drawing on the go, sketch book and a box full of foam models, all on the same project, all at the same time. When I first worked here, [the Koreans] found it very difficult. When they said 'can you show us the first stage sketch presentation', and you'd say 'err.. there you go' and they'd say 'no, no, no... just sketches' and you'd say 'we're not doing just sketches, you know, here's a model of this sketch'. So I think in Korea (...) it's a lot more structured, but as designers here, we're taught to be a lot more fluid in our design process.
CHAPTER EIGHT

The polymer acoustic guitar project

Introduction
This chapter presents findings from the author's diary of designing, produced in parallel with the design and prototyping of a polymer acoustic guitar. On account of the chapter's bulk, which is felt acceptable in order to keep all the results in a discrete study, the chapter is split into three Parts. The first Part presents the background to the design project and discusses the reasons for its selection. The second Part introduces essential support material contained in the appendices. The third Part holds macroscopic and microscopic analyses of the designing. In Chapter Eleven, the results of this chapter are contrasted with the results from other data sources.
PART A

Background to the guitar project

Almost any industrial design project could provide opportunity for analysing the nature of decision-making in relation to materials and processes. However, it was felt that a project should be selected which would require a high degree of technology to be considered, rather than simply an exercise in repackaging proven technology. A suitable project had been identified by this author’s Supervisor in 1993: the design and prototyping of an acoustic guitar constructed primarily from polymers rather than woods [Norman, 1993]. At that time, a literature search had revealed work at the University of Wales concerning the physics of guitar design [e.g., Richardson, 1992] but little else that could help in the design of such an instrument. Also at that time, two studies of acoustic guitar design (conducted independent of one another) were made by students at Loughborough University, as below.

- A small-scale study of the vibration properties of polymers, made with the specific intention to produce results useable in guitar design [Gay, 1993]. This is described in more detail shortly.
- An investigation of the aesthetic possibilities of a polymer acoustic guitar [Hanson, 1994a] and a supporting dissertation on the evolution of classical and acoustic guitars [Hanson, 1994b]. Design ideas were prototyped but none were playable (Figures 20 and 21).

Polymers have been used in acoustic guitars in the past and continue to be used today. They have been used for the backs of ‘bowl-back’ guitars like the Ovation [Ovation, 1999] and Pilgrim designs; for a glass fibre Maccaferri guitar produced by Selmer after relocating to the U.S.A.; for the ‘all-graphite’ Hawaiian Rainsong guitars [Rainsong, 1999]; for the carbon fibre / spruce laminate used in the Ovation Admas; and for injection-moulded toys for children. Put together, these predecessor instruments represent only a very small fraction of guitar sales. The limited range of models illustrates starkly the opportunity for further designs and developments of the concept. The two Loughborough studies and the product precedents set some groundwork for
designing a new polymer acoustic guitar. A number of additional points made the design of such an instrument a favourable project.

- It was likely that a final working prototype could be produced. The accompanying diary of designing could therefore relate to a number of phases of NPD.
- A successful instrument could have potentially high commercial value, opening new markets or complementing existing ones. Its pursuit would be a challenge and the final design had a high probability of being innovative.
- Both student and Supervisor were actively involved in their own music-making and so the personal enthusiasm, commitment and interest in the product development would be high. This was especially significant since the designing would inevitably span the equivalent of months of consecutive work.
- The development of instruments manufactured from materials other than wood is timely, because of the environmental issues and pressures associated with prime tonewoods.

Three limitations of the project can be identified.

- The designing was not carried out within a commercial environment.
- The author is a graduate industrial designer and has not worked professionally.
- The designing was essentially a solo (rather than a team) effort.

The design of the classical guitar (a close relation to the steel-strung acoustic) has developed empirically, largely from pioneering work in the nineteenth century by luthier (guitar maker) Antonio De Torres (1817-1892). One might have thought that, in the pursuit of further excellence in guitar design, the results of scientific study would form prized design advice for guitar manufacturers. However, consider the following description of the major effort in this field made by the famous Gibson guitar company [Bacon, 1991:10].

In 1977 Gibson launched the Mark Series acoustic guitars. In the promotional literature for the four new models, the 35, 53, 72 and 81, the company explained how, in the past, improvements to instrument design had come about by trial and error, and luck. 'That's why Gibson chose a new method in its search for a better acoustic guitar- the scientific method'. Gibson's two-year research plan involved three scientists: a professor of acoustical physics,
who recorded and analysed 'voice graphs' of popular guitar designs: a chemical physicist (also a director of an institute of molecular biophysics) to oversee structural design: and a professor of acoustics who devised new scientific measuring techniques and an environmental test chamber. But despite all this, the guitars did not prove popular and were soon dropped from the Gibson catalogue. The company returned to their old, proven method of trial and error (and luck), and most players would argue that they returned to making good guitars as a result. Gibson's high-profile failure deterred many makers from the scientific route.

Figure 20: Paul Hanson's glass fibre mould for a polymer acoustic guitar

Figure 21: Paul Hanson's vacuum-formed soundbox for a polymer acoustic guitar
If the design of traditional guitars is not easily advanced through scientific methods, what advice could science provide for the design of a polymer guitar? The small-scale study by Gay [op. cit.] had the objective of understanding relationships between the 'acoustic response' of materials and underlying measurable properties of those materials. By way of both experimentation and the analysis of suitable literature sources, the study aimed to understand how a polymer may either propagate or attenuate a vibration. The account of the study that follows was prepared mostly by Dr. Dick Heath, Gay's supervisor, for a prospective journal submission [Norman, Heath & Pedgley, 1999].

The main target of Gay's study was to find suitable equipment (and develop associated methods) to quantify sound translation, and then compare some different timbers' and polymers' acoustic properties. For the purpose of the study, a timber was considered to have a composite oriented structure. Reinforced polymers were also included in the study for comparison. The basic method employed was to impart energy at some point on a thin rectangular sample, (i.e., to strike the material to create a vibration), and then to measure the resultant amplitude for a frequency range at points away from the striking position. Several problems were observed with this method of which the following were the more significant.

- Sound generation in an acoustic guitar depends upon the vibration of free surfaces and either supporting or clamping the sample meant deviating from this ideal.
- The geometry of the test pieces had a significant influence on the results obtained.
- It was extremely difficult to apply a consistent input energy or vibration to the samples.
- The measuring devices used (transducers and accelerometers) influenced the results significantly.

This led to considerable difficulty in interpreting the results. For example, a comparison of spruce and polyester composite samples showed that for the same sample geometry, harmonics were at higher frequencies for the spruce. However, even with simple shapes, it was difficult to identify the combination of specific properties that could be used to model this behaviour. Elastic and shear modulus, density, internal friction and Poisson's ratio were thought to be amongst the more important factors. As the behaviour could not be successfully modelled in simple rectangular samples, there was little hope of modelling a real instrument with its complexity of shape, bracing and material thickness. Empirical studies with timber have shown that different wood types, drying and other ageing, cuts, lamination, etc. have marked effects on aural properties. In turn, polymers and polymer composites have a similarly large number of variables. It was clear that science would not be able to provide answers to some of the fundamental matters that would benefit the design of a polymer acoustic guitar.

- Would materials with isotropic properties perform better than those with anisotropy? Wooden components of a guitar, with oriented composite structure, have been shown empirically to perform acoustically better depending on grain directions. Polymer, and polymer composites, may be found with differing isotropy, for example, due to molecular or mechanical orientation, reinforcements, crystallinity.
• How would component geometry, including thickness, influence the acoustic properties of an instrument?
• How would component interactions influence sound transmission? It was felt that, given time, it might be possible to obtain quite a broad range of quantitative data from simple test piece shapes. However, it was evident that no software (or other means of prediction) was available to show how a vibration might be transferred in simple assemblies from one component to another, perhaps via a glue line. Hence how could the performance of a complete assembly of guitar components be predicted?

Despite the problems identified in Gay's study of generating quantifiable data on the acoustic properties of materials, the ever increasing availability of new and varied materials suggested that the opportunity for realising a new polymer acoustic guitar were better than ever. Guitars sell on the basis of their sound, appearance and playability. Polymers offer new opportunities to vary these criteria.

• Could an excellent-sounding and excellent-looking instrument be constructed from plastics?
• What marketplaces might such an instrument be suited to?

Having consulted an engineer specialising in the analysis of stringed instrument soundboard vibrations [Woodhouse, 1996], it was concluded that two basic approaches could be taken to designing a polymer acoustic guitar:

• acoustic engineering;
• 'getting stuck in' to designing and making and then evaluating the resultant instrument.

For the first approach, the study by Gay [op. cit.] had already indicated that a major scientific investigation of polymer vibration characteristics would need to be conducted to generate data for use in designing. This was not seen as a viable option on two accounts: (a) the effort to do this justice warranted a large research project in itself and, more pressingly, (b) such a study required the expertise of a materials scientist, not an industrial designer. It was clear that the second approach, reliant on sources of design advice other than science, needed to be consulted if a playable guitar was to be produced within the time constraints of a practice-based Ph.D. This was indeed the approach that was taken: to 'get stuck in' and produce prototype guitars. To help steer the design work, three collaborators were involved.
• Rob Armstrong. Mr. Armstrong is a world-renowned luthier who has built hundreds of innovative acoustic guitars. Although it might not be possible to accurately define what he knows (nor possible for him to say what he knows), there was no doubt about the value of such expertise to somebody new to the field. Mr. Armstrong provided general design advice.  

• Dr. Dick Heath. Dr. Heath provided expert advice on polymer selection and processing. 

• David Hodson. Mr. Hodson is an experienced luthier who helped in the construction of the final prototype. 

The resultant prototype instruments were not targeted to a specific marketplace. That was regarded as something better left until the feasibility of the product had been demonstrated. The most developed PDS for the project is contained in Appendix XIII. In addition, a report [Pedgley, 1999] has been produced containing more details of the guitar, intended to direct further development of the instrument and possible commercial manufacture.
PART B

Project appendices

Support information for the guitar project is contained in three separate appendices.

Appendix XIV: Glossary of terms

Appendix XIV lists and describes the personnel, trade names and miscellaneous abbreviations mentioned in the diary entries. Some of these terms are also used in the main text of this chapter.

Appendix XV: The summary diary entry catalogue

Appendix XV contains a catalogue listing the days on which a diary entry was made and includes each day's diary entry summarising the work carried out on the guitar project. The catalogue is split into two parts to separate data from the concurrent and end-of-the-day formats of diary.

Column 1: Diary date
This is the date that an entry was made.

Column 2: Day
This is the diary day number (corresponding to the nth day that an entry was made). The first entry was made on 16 May 1996 and the last on 9 March 1999. Work on the guitar finished approximately one month later (the intervening period was used to complete and evaluate the final prototype).

Column 3: "No detailed entry" day?
This column is relevant only to the end-of-the-day format of diary. A 'YES' in this column indicates that the day's entry was recorded on the 'no detailed entry' stationary. That is to say, the day's work on the guitar project did not hit upon the subjects of materials and manufacturing processes.
Column 4: Figure
Photographs showing the construction of prototype guitars (contained in Appendix XVI) are indexed in this column. The figures are provided as a visual record of prototype development.

Column 5: "What happened today?" (verbatim) / "Day's main activity" (verbatim)
This column contains a verbatim transcript of those diary entries summarising the day's work on the project. Days on which no summary was provided have been marked "<not filled in>".

Column 6: Day's main activity (translated)
This column contains a translation of the data in column 5, in order to (a) clarify ambiguous entries, and (b) impose a consistency of English across all of the entries. The translation 'NOT DESIGNING' is used for days when the main activity was stated as something other than related to the guitar project. The terms 'design work' and 'concept work' were used interchangeably at the time of writing the concurrent diary. The intention with both of these terms was to refer to a period of idea generation. Entries marked "<not filled in>" in column 5 have been translated to "<n/a>" (not applicable).

Column 7: Classification
This column provides a limited number of categories into which the data from column 6 have been classified. This enables an 'at a glance' description of how the design work on the guitar progressed. For the most part, data have been classified according to the descriptions of NPD phases presented in Chapter One (and duplicated below).

- Phase 1: Concept development
- Phase 2: System-level design
- Phase 3: Detail design
- Phase 4: Testing and refinement
- Phase 5: Production ramp-up

In order to assess whether the work fitted better as 'concept development' or 'system-level design', it was necessary to review sketch sheets between days 18 (where 'development' was first mentioned as a design activity) and 152 (prior to the major effort to produce prototype 3). Some of the summary diary entries were better categorised as specific activities rather than phases of NPD. Six categories were sufficient to describe these activities, all deriving directly from the statements in column 6.
The category "<unclassified>" was used for days when statements in column 6 read "NOT DESIGNING", "<n/a>", "Miscellaneous" and "Photo shoot session".

Appendix XVII: The detailed diary entry catalogue
Appendix XVII contains chronologically correct listings of the main (detailed) entries. The catalogue is split into two parts separating the concurrent and end-of-the-day formats of diary. Out of a total of 408 detailed entries, 96 (24%) have been omitted from the catalogue for one of two reasons. First, from February 1998, detailed entries tended towards reports on the progress of prototyping rather than changes in design. Entries describing workshop procedures have therefore been omitted from the catalogue, except in cases where implications for the guitar design are also described. Second, across the length of the project, some off-topic entries were made.

Column 1: Diary date
This is the date that a detailed entry was made. The letters 'EOD' refer to entries made at the day's end when the concurrent format was in use.

Column 2: Entry no.
This is the consecutive detailed entry number. Each diary entry has an individual entry number. Figures in square brackets throughout this chapter [e.g., 156] refer to entry numbers.

Column 3: Artwork
If an entry made reference to artwork, the artwork source is noted in this column. 'DS' refers to sketch sheets; 'DIARY' refers to artwork contained within the day's diary entry; 'LB' refers to the project log book. All of the listed artwork was photocopied and digitally scanned for possible inclusion in this chapter.
Column 4: Content (verbatim)
This column contains a verbatim transcript of each detailed entry. On occasions, paraphrases have been added in square brackets to clarify the content of a statement.

Columns 5-13: Codes
These columns are used to code the entries. The codes are the same as those presented in Chapter Six.

Wn abbreviation for WHEN
Lv abbreviation for LEVEL
Cn abbreviation for CONSTRAINTS
Fn abbreviation for FUNCTIONS
In abbreviation for INFO
Kn abbreviation for KNOW/VALUE
Cg abbreviation for COG
2d abbreviation for 2D
Ts abbreviation for TASK

The remaining Chapter Six codes were not assigned to the data for the following reasons.

ROLE
The role and significance of materials and processes in industrial designers' decision-making is predominantly a philosophical matter that is revisited in Section Four of this thesis.

SPECULATIVE
Attention to materials and processes in speculative product design is a subject related specifically to professional design practice.

RANGE
The range of materials and processes considered in the design project was small and could easily be identified from the diary entries without the need for formal coding.

\[\text{The code is used here to refer specifically to an intentional effort by experimentation to derive new product-centred knowledge and values. Use of existent product-centred (and procedural) knowledge and values would be evident in diary entries assigned other codes.}\]
GREEN
'Green issues' were rarely mentioned in the diary and so did not merit formal coding.

CREATIVITY
The nature of creativity with respect to materials and processes is predominantly a philosophical matter that is revisited in Section Four of this thesis.

OPPORTUNITY
The opportunities that materials and processes offer to industrial designers is predominantly a philosophical matter that is revisited in Section Four of this thesis.

COMPUTER
At no time in the project were computers used to direct decisions on materials and processes.

3D
Materials and processes in the context of 3D modelling were rarely mentioned in the diary and so did not merit formal coding.

FORMAL
Written design procedures were not adhered to during the guitar project.
PART C

A brief retrospective review

Having reviewed the two diary entry catalogues and recollected important events in the design work, it was clear that the origins of three critical events involving materials and processes were not evident in the catalogues (i.e., not entered into the diary). These were: (i) the ‘tapping’ of potential materials to assess their acoustic properties, (ii) the idea that potential materials should be aerated, and (iii) the effect of paint on aerated polymer sheet. It was therefore necessary to attempt to locate evidence of these events in the project archives.

Tapping of materials to ascertain their acoustic properties

No evidence of the origin of this could be found in the project archives. To the best of the author's memory, it originated from a demonstration by Rob Armstrong at the first design meeting on 18 July 1996. Materials with potentially good acoustic properties should have a 'ring' rather than a 'thud' when suspended lightly between the fingers and tapped at the opposite end. One should be able to feel the vibrations in one's fingers and hear a note produced.

Potential materials should be aerated

This was first mentioned by Rob Armstrong at a design meeting on 25 November 1996 and was documented in LB1:18.

Spray painting lessened the metallic 'ring' of a material sheet when tapped

To the best of the author's memory, this observation was made on the day of entry 209 but was not written into the diary. It was stated (ambiguously) in entries 223 and 225.

The timing and sequence of attention

Figure 22 provides an 'at a glance' view of how work on the guitar project progressed. The Figure is derived from the summary diary entry catalogue and shows design activities plotted against diary entry days. At the base of the Figure, the different phases of design
activity have been highlighted; these show the five-phase skeletal structure of the guitar project, as follows.

- Entry days 1 to 93: concept development for prototypes 1 and 2.
- Entry days 17 to 102: testing and refinement for prototypes 1 and 2.
- Entry days 78 to 143: system-level design for prototype 3.
- Entry day 114: detail design of the bridge for prototype 3.
- Entry days 112 to 227: testing and refinement for prototype 3.

Consecutive phases of work overlapped significantly. Overall, the work was directed towards the production of one-off prototypes to test the feasibility of different designs. One-off components were manufactured by the author using a combination of machine and hand tools. Prototypes 1 and 2 essentially acted as test-runs of ideas and design details prior to the production of the third (and final) prototype. System-level design culminated in both a final prototype and a final design report recommending design details, material choices and manufacturing routes for a prospective mass-manufactured version of the instrument [Pedgley, op. cit.]. On only one day (day 114) could the work be described as detail design; on this day it was necessary to define the guitar bridge for CNC manufacture. The 'production ramp-up' phase of NPD was absent because the project terminated with the production of a pre-competitive prototype. The lack of detail design is discussed in the section 'the level of detail reached'. A number of observations can be made from Figure 22.

- 'No detailed entry' days (end-of-the-day diary days on which materials and processes did not feature) were concentrated in periods of 'testing and refinement', in which work was directed at making prototypes rather than proposing changes in design.
- Attention to materials and processes spanned the full length of the project and was not tied to any particular phase of work, although attention was significantly reduced in the last third period of the project, after system-level design of the final prototype. It was in this last third period that work was directed towards the testing and refinement of the final prototype.
- CAD was used only during system-level design and the testing and refinement of the final prototype. At no time in the project were computers used to direct decisions on materials and processes.
Figure 22: Summary chart of design activity for the polymer acoustic guitar project
(with design activity phases indicated)
Information gathering, meetings, planning and report writing were distributed across all phases of the project. Work on registered design rights was carried out during the testing and refinement of the final prototype. Information use will be examined in detail later in this chapter.

An examination of the detailed diary entry catalogue revealed the sequence and level of attention paid to materials and manufacturing processes during the guitar project. In the first third of concept development, especially very early on, there was a planned avoidance of technical issues, including materials and processes [1; 3; 45]; on one occasion the work was described as a "styling exercise" [49]. This avoidance was made in order to focus on how the overall product might look. Even so, at times it was not possible to avoid thoughts on manufacturing, as illustrated below.

Ideas being formed here are purely from a visual/visual-stimulus perspective. Although I have shown some technical details (bridge, tuning holes), these have been added superficially and act merely [sic] to 'complete the picture'. Closer inspection of the guitar tuning positions on 'X' [Figure 23, below] will show that these are not in a practicable position at all. On drawing 'X', I have changed track slightly, probably because I was enthusiastic about this shape and have, in my mind, given a quick once-over evaluation of its suitability for moulding as a bowl-back...

Figure 23: Brief consideration of materials and manufacturing processes interwoven with ideas for product form [22]
During the first third of concept development, planned attention to manufacturability was limited to reviews of existing guitar designs (in order to become aware of features for potential inclusion in the polymer guitar). These reviews had a specific purpose which, at the time, did not include synthesis of findings with ideas for product form [15; 27; 21].

The purpose so far is to question why the guitar is as it is at the moment: it promotes an understanding which I know will help me in changing the design and coming up with new ideas.

During the latter two thirds of concept development, attention was directed towards the manufacturability of product ideas. For example, the merits of reinforced plastic lay-up and injection moulding for the neck and head of the guitar were contrasted [53]. Towards the end of concept development, plans were made for the number of prototypes that would be produced and how system-level design would progress.

Agreed with Eddie that the initial prototypes will be: (a) a 'have a go' quick prototype in foamex-type material (to see what ballpark the sound quality is in); (b) material/soundboard design based on calculations/acoustics literature.

The plan was to "...create polymer versions of key guitar parts." [96] This was achieved initially through experiment and design-and-make activities (for prototypes 1 and 2), followed, later, with greater design (on paper)-then-make activity for the third prototype [122], with particular attention paid to how a mass-manufactured version of the instrument might be made [189]. Attention to much of the assembly design was purposefully postponed until the first two prototype instruments had been evaluated [118].

The level of detail reached
The initial investigation by Eddie Norman, prior to the polymer acoustic guitar being proposed as a design project, had established that sources of design advice, other than science, needed to be consulted if a playable instrument were to be produced. It was therefore decided to direct much of the designing according to the advice of Rob Armstrong. Work concentrated on the achievement of working prototypes rather than wide-ranging materials testing and acoustic engineering prior to the creation of a working instrument. The prototype approach was justified on a number of occasions in the diary, principally in the light of meetings with Dr. Heath [82; 92; 188; 269]. The approach of first producing prototypes using commodity plastics, in order to avoid the
"variables" [82] associated with acoustically more promising foamed plastics, was rejected. Material choices were "...more to do with using what sounds as though it would be right and testing it out." [82] To this end, it was stated that "...I need to have something in front of me which I can touch, hear and get a feel for." [92] The different approaches, prototype-based and materials testing-based, were discussed with Rob Armstrong at a meeting to determine prototype construction.

I stated Dick Heath's position- that design parameters should be altered steadily- and that we should use a basic PS sheet as the starting point material, but this was agreed between us as not really the way forward at this stage. The hands-on, going for a prototype that will have the most potential (using current knowledge) was agreed to be the way. Optimisation of the material and construction could then follow.

The adopted prototype-based approach was effectively an "educated experiment" [101] to find out about the acoustic and mechanical performance of materials when implemented into an instrument. Overall, work was directed towards "...experimentation and practical testing, rather than definitely opting for one [material or process] or the other..." [111] and as such was strongly "R+D" in nature [111; 132]. This had implications for the level of detail of attention that was appropriate.

Last night I had a bit of a think: if I was to say to somebody now- 'go and make my final design', they wouldn't be able to, because I've not yet produced any drawings which are intended for anybody else to produce it. Some of the fine details of construction and material shape (such as thickness of bracing and precise location of struts, and how to produce the speckly [sic] finish on the guitar back) exist in detail (or 3/4-thought through) only in my mind. Why? Out of a lack of necessity to produce a formal description of the design or methods of manufacture at this stage... and also because the whole thing is in a state of flux- not least because details of the neck and head, for instance, have been left to the control of Rob Armstrong.

It was not until system-level design that firm decisions on suitable mass-manufacturing routes for the instrument were made explicit.

Some of the reasoning written down in the [draft final report] I am sure has not been written down before- this is because I am now in anticipation of final presentations where my design reasoning needs to be communicated explicitly.
At a meeting with Eddie it was agreed that it wouldn't be necessary to provide exact dimensions for the components involved, but rather to communicate the proposed materials, production and assembly details (...) After all, final dimensions had not been decided upon... they would be meaningless at this stage.

It strikes me now, on reflection, that many of the guitar's components are at the 'roughly correct shape' stage but far from dimensionally committed. This is on purpose- I have decided not to detail parts which are (a) not going to be made by me in the prototype and (b) are in need of further development work to see what configurations will work well in practice. For the most part, this boils down to the neck and head parts. I feel I will have done my part in the project when: (a) the correct shape has been specified by me for all prototype components (and 'roughly correct shape' for all mass-manufactured counterparts); (b) details of manufacture, material, finishing and assembly have been provided, and a costing; (c) a report on the merits of (a) and (b) have been completed.

Attention to materials and processes therefore culminated in the production of a report [Pedgley, op. cit.] recommending possible mass-manufacturing routes. The guitar bridge was detailed since this component needed to be manufactured almost wholly using CNC methods [245]. No other components of the guitar were formally detailed for manufacture: it was not appropriate to detail components that were not, in their current state of development, intended for manufacture by industrial processes. In addition, the author was not experienced in tool design and detailed DFMA work. An evaluation of product cost (and therefore possible market placing) could be made only after the manufacturing technology required for the instrument had been established. A formal costing was therefore left until after the completion of system-level design (and is included in the final report). It was agreed with Dr. Heath that a period of further development would be necessary to ready the guitar for manufacture by industrial processes.

Dick was firmly of the mind that an indication of potential sound quality can come from the [final] prototype- and if it's a good quality tone then that bodes well for a mass-manufactured version, but you won't really know what you're dealing with until you make a guitar via these industrial processes. Dick sees future development work as (a) needing a lot of money being put up front and (b) testing of materials and manufacturing process combinations- a scientific approach to design in order to understand just what's going on and propose different, cheaper or more optimal combinations.
Constraints

Availability of materials and manufacturing processes

A number of constraints based on the availability of materials and manufacturing processes were encountered during the project.

- In order to produce prototypes using the Department's facilities, it was necessary to acquire sheet (rather than granulated) polymer [89; 93].
- The minimum sheet thickness of the chosen Forex-EPC material was 3mm [132].
- Lexan sheet suitable for the guitar bridge was available locally only in 10mm thick sheet [214].
- The chosen Forex-EPC material was available only with opal, grey or black pigments [215].
- Coloured polycarbonate sheet of any thickness was not available [223] (only clear sheet was available, so this had to be used in the prototypes).
- The chosen adhesive could practicably be applied to the guitar only at the adhesive manufacturer's premises [224].
- The chosen adhesive was available only as a blue/green opaque liquid [224].
- The chosen black Forex-EPC material could be obtained only direct from AlusuisseAG [225].
- Coloured acrylic sheet of 10mm thickness was not available off-the-shelf; it would have to be manufactured in bulk as a one-off order [240; 255; 260].
- Only 200gsm woven roving for GRP lay-up was available locally [299].

Budget

Costs were not considered in the context of a limited budget, except in the case of manufacturing processes for producing the prototypes (e.g., the high costs of screen printing [258] and the prohibitive cost of obtaining 10mm thick acrylic sheet [260]). Costs of mass manufacture were not a real constraint since the design work was focused towards pre-competitive prototypes rather than commercial production. Nevertheless, awareness of costly mass manufacturing processes was demonstrated in the design work. For example, in the tooling of a soundboard with an integral bridge [57]; in the tooling of a soundboard for manufacture by RIM [145]; and in the need to reduce the number of individual components in a mass-manufactured instrument [290].
Design brief
The requirement that the main sound generating parts of the instrument should be constructed of plastics was a major constraint.

Limitations for form creation
Combinations of materials and processes were compared for their suitability to create desired product forms. This involved making judgements based on the strengths and weaknesses of manufacturing processes as they were understood to be [46]. For example, the strength of compression moulding and injection moulding for creating complex curved forms was acknowledged in entry 49.

...whatever configuration of shapes I came up with would not individually have major design implications for the (projected) manufacturing processes was considering that 'the designs can be made anyway'. [49]

The last comment of that quotation was, with hindsight, based directly on Rob Armstrong's advice regarding product form (below).

Rob Armstrong is not overly concerned with the guitar shape w.r.t. the tone being produced (more concerned with the construction). This also goes for the size and shape of the soundhole. [36]

The time-saving benefits of hot-plate and vibration plastic welding techniques (as compared to rod welding) were described in entry 171. Comparisons were also made between fibre-reinforced plastic lay-up and injection moulding.

...the neck/head may need some intricate detailing, not possible with fibre-reinforced plastic lay-up, (...) Therefore wondering if it is perhaps best to make bowl back composite [acoustically more important]- neck and head I.M. [not acoustically important]- join will be difficult. [53]

Other instances were described in entries 57 and 308 (problems of achieving definition of form in GRP); 170 (problems associated with rod welding two unlike plastic components); 215 (the limitation that the outside surface if a GRP shell will normally be very smooth and shiny); and 258 (the low DPI output of screen printing, in contrast to the relatively high DPI output of printed transfers). One concern that persisted during system-level design was the purpose of the final prototype, as described overleaf.
Chapter Eight: The polymer acoustic guitar project (Part C)

What I'm faced with is a practical dilemma between making the guitar sound good (keeping material choices simple and sticking with polycarbonate clear sheet) and making it look like a production item (laminating coloured acrylic)-or, as Eddie suggested today, simply coating (probably paint because it's quick and easy) the clear polycarbonate on a very temporary basis so that photographs can be taken of the guitar as close to what it would look like as a production product. [269]

The chosen route was to ensure that the utility of the guitar was not compromised, in order to prove the technology behind the instrument. Consequently some of the visual details of the prototype instrument were not how they would be intended for a mass-manufactured version.

Mechanical and chemical properties of materials

The mechanical and chemical properties of materials constrained their use in the guitar.

- Epoxy adhesive, traditionally used in guitar building, was insufficient for creating a strong bond between the polymer components of the guitar [114].
- Spray-painting and lacquering the Forex-EPC material had a detrimental effect on the resonant properties of the material [223].

The range of materials and processes that are able to be specified

The brief stipulated that the sound-generating parts of the instrument should be constructed from plastics, but for other components, any materials and processes could have been specified. In the event, the following were either considered or proposed for use in the instrument.

- Polymers
  - Vacuum formed off-the-shelf expanded polymer sheet
  - Fabricated off-the-shelf expanded polymer sheet
  - Fabricated off-the-shelf polymer sheet
  - Injection moulded polymer resin
  - Injection foam moulded polymer resin (with inserted components)
  - Compression moulded fibre-reinforced polymer resin
  - Pultruded fibre-reinforced polymer resin
  - Hand lay-up fibre-reinforced polymer resin
  - Spot colour cut vinyl transfers
  - CMYK printed cut vinyl transfers
• Wooden neck, head and fretboard (for the prototype)
• Adhesives
• Paints

Bought-in components were manufactured mostly from metals (e.g., strings, machine heads, strap eyelets, truss rod).

'Green issues' in practice

Attention to 'green issues' amounted to no more than an acknowledgement that Forex-EPC was, according to sales literature, recyclable and that components of the guitar manufactured from this material could potentially be recycled [120; 143]. Design for disassembly was not considered. To help achieve a good-sounding instrument, it was important that the construction was solid and acoustically sealed [Pedgley, op. cit.]. No recycled polymers suitable for use in the guitar were identified during the project.

Functions that industrial designers desire materials and processes to satisfy

Throughout the different phases of designing, significant attention was paid both to expressive and utilitarian functions of materials and processes. These are listed below.

Expressive functions

• A desire for interesting qualities in the soundboard material [4; 22; 225]

...I want the final product to have a dark grey, sophisticated look- but did not know exactly what the combination of colour and sheen was like [for the different versions of Forex-EPC]. [The black version] suits my requirements exactly- it has a really appealing overall visual quality. The black version really is special, and since I cannot paint the opal for fear of acoustic side-effects, I really need to get hold of some. [225]

• Opportunities for soundboard decoration, including a rosette [8; 80] and high quality printed graphics [249; 252; 265; 270].
• Implications for perceived quality based on the assembly methods used in the instrument's construction [62; 98; 219].
The riveting (or screwing) idea came into my head a few days ago. Potentially interesting aesthetics—will consult RA about technicalities.

[98]

- Use of a high gloss finish to highlight inherent properties of clear polycarbonate [202; 224].
- Investigation of colour schemes of components [215; 217; 222; 223; 254; 260; 261; 268; 306; 310].
- Neatness and interest in: (a) the soundboard edge finishing detail [221; 232]; (b) adhesive joints [224]; and (c) the GRP shell surface finishes [301; 308].
- A desire that materials have surface texture to help disguise scratches and dents [132; 236].

A couple of diary entries (below) illustrated starkly how visual and tactile functions of processed materials can be strongly interrelated.

- Possibilities for the incorporation of Rob Armstrong's logo into formed and machined components [224; 241], to feel and look "great" [247].
- Inherent surface finishes and contrasts between surface textures on a single component [78; 309].

Utilitarian functions

- Concern for how different components of the guitar would connect [6; 39; 47; 50; 51; 55; 58; 64; 91; 137; 142; 170; 296].
- A desire to reduce the number of individual components needed in the instrument (compared with a traditional wooden guitar) [40]. An integral bridge was considered [20; 41; 132], as were integral frets [37], integral bracing [131; 132; 171; 267], a one-piece soundboard [145; 148; 286] and an integral headstock and 'Armstrong' logo (below, and Figure 24).

Design A went to design B because it's cheaper (one component; no painting) and visually it looks fine.

[290]
A desire that the neck material be smooth to aid playability [61].

Concern for the weight of the GRP shell [305] and the density of polycarbonate and Forex-EPC [159].

A desire that materials exhibit musical acoustic resonance [18; 63; 80; 89; 94; 198; 207; 223; 236; 260; 270; 294].

A requirement that materials are stiff to prevent flexing and to distribute sound waves [12; 17; 55; 73; 94; 159; 192; 194; 226; 230; 284; 291; 305].

A requirement that assembled components can withstand forces due to tensioned guitar strings (particularly with respect to adhesive choice) [107; 114; 128; 139; 141; 149; 151; 175; 260; 289].

A requirement that materials used for the guitar binding and edging are flexible [196; 221; 234; 246].

A requirement that some materials dampen acoustic vibrations [19; 38; 52].

A requirement that some materials resist scratches and dents [61; 83; 132].

A requirement that the colour of materials remains stable after sustained exposure to ultra violet light [143].

For prototype fabrication and prospective mass-manufacture, comparison between the softening temperature and melting temperature of polycarbonate and Forex-EPC [159].

The mechanical and chemical properties of potential materials were established mostly by practical testing rather than use of numerical data, although there were exceptions (see later sections in this chapter). The feasibility of desired forms for prototyping and production was assessed. Examples are given overleaf.
• The difficulty of reproducing intricate design details in a hand lay-up GRP mould [46; 53; 57].
• The difficulty of creating uniform rough surface texture in a hand lay-up GRP mould, and of releasing the associated shell from the mould [236].
• The need to prepare a GRP shell prior to painting [307].
• The use of vacuum-forming to create changes in thickness of wall sections [85].
• The ease of, and opportunities for, fabricating Forex-EPC [80; 105; 152; 153; 210].

Dual consideration of functions

For convenience, the functions of materials and processes in NPD have in this section been categorised as more or less expressive or utilitarian. Sometimes whilst designing, however, utilitarian and expressive functions were given dual consideration. For example, scratches, dents and cracks could weaken the mechanical integrity of the instrument (utility) but also look and feel unappealing and, hence, lessen the perceived quality of the instrument (expression). Also, ultra violet light, as a component of daylight, could over time seriously damage the mechanical integrity of the polymer (utility) and bleach once vivid colours (expression). The following two examples were made explicit in the diary.

Received the ultrasonically-welded test joint. The material has been pulverised— if this is the kind of result to be expected then it is not a preferred route for the guitar on the grounds of very poor finish quality and structural interference.
[179]

Was thinking that the bridge could not be foam moulded [as part of a one-piece soundboard] because (a) visually it needs to be a different colour [to the soundboard], and (b) the foam won’t take the compressive force of the strings.
[287]

The use of information and the derivation of new product-centred knowledge and values by experiment

The wording of the entries in the detailed diary entry catalogue was sufficiently clear to make a study of information use a simple exercise. Figure 25 shows when different sources of information were used during the design of the guitar. The y-axis is split into three categories of information and, within each category, different information sources.
• Category one information is 'happened across' during designing, by casual
observation and acquaintance.
• Category two information is not sought but is instead offered by somebody.
• Category three information is sought in order to find something specific out.
  This category includes the carrying out of experiments to derive new product-
centred knowledge.

Of the total number of diary entry days (227), 6 days (3%) involved use of category one
information; 5 days (2%) involved use of category two information; and 94 days (41%)
involved use of category three information. Overall, information sources were cited on
97 out of 227 diary entry days (43%). For the remaining 57% of diary entry days, no
information sources were recorded as used. Within the working constraints of the diary
method, one could assume that personal experience was used on these remaining days.

Category one information
Information of this category featured very rarely and came from only three sources:
designed artefacts, physical samples and printed matter. The information was 'happened
across' whilst engaged in other activities and so the timing of its use was not planned.
During a visit to London, an existing polymer acoustic guitar was stumbled across.

One of the music shops had an original 1950s Maccoferri plastic acoustic
guitar for sale (shop was closed so I couldn't go in and hear what it sounded
like...). Shop was on Charing Cross Road. I thought it looked very 'plasticy' in
a bad sense- shiny material, cheap-looking. Also thought the construction
and body shape looked too much like an enlarged violin.

A sample of Forex-EPC was accidentally knocked, from which its susceptibility to dents
was revealed [226]. Information on structural foams and polymer types was encountered
whilst reading as part of the Ph.D. programme [65; 131]. Information on structural
adhesives was happened across when scanning the shelves of the University library to
gather non-guitar related information [125]. Whilst having a tidy-up of literature related
to the guitar design, information on ITW adhesives was found [81] (with hindsight, this
was very significant information on the final adhesive specified for the instrument).
Figure 25: Summary chart of materials and processes information use for the polymer acoustic guitar project (with design activity phases indicated)
Category two information

Information of this category featured very rarely and came only from colleagues offering spoken design advice. Most of the information came from Rob Armstrong [19; 23; 35; 37]. The advice was given during the period of idea generation at the start of the project, during which a large number of guitar features were considered for possible inclusion in a polymer acoustic guitar. All but one of the colleagues' advice [224] was given at arranged meetings.

Category three information

This category of information featured extensively across all phases of the design work. The rank order for the consultation of different category three information sources is shown below in Table 9. Some days involved the consultation of more than one information source.

<table>
<thead>
<tr>
<th>Information source</th>
<th>Number of days for which the information source was cited (as a % of the total days for which category three data were consulted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiments</td>
<td>36%</td>
</tr>
<tr>
<td>Printed sources</td>
<td>34%</td>
</tr>
<tr>
<td>Liaison with material suppliers / manufacturers</td>
<td>23%</td>
</tr>
<tr>
<td>Colleagues (Dr. Richard Heath, core personnel)</td>
<td>16%</td>
</tr>
<tr>
<td>Colleagues (ancillary personnel)</td>
<td>16%</td>
</tr>
<tr>
<td>Colleagues (Eddie Norman, core personnel)</td>
<td>15%</td>
</tr>
<tr>
<td>Physical samples</td>
<td>12%</td>
</tr>
<tr>
<td>Liaison with end manufacturers</td>
<td>10%</td>
</tr>
<tr>
<td>Designed artefacts and the wider world</td>
<td>9%</td>
</tr>
<tr>
<td>Colleagues (Rob Armstrong, core personnel)</td>
<td>5%</td>
</tr>
<tr>
<td>Internet sources</td>
<td>4%</td>
</tr>
</tbody>
</table>

Table 9: Rank order use of category three materials and processes information

The different sources were consulted across all phases of the design activity, with the following exceptions.

- Most advice from ancillary personnel was sought during system-level design.
- Internet sources were consulted only during system-level design.
- Liaison with end manufacturers took place only during system-level design and testing and refinement of prototype 3.
Most liaison with material suppliers and manufacturers took place during
system-level design and testing and refinement of prototype 3.

Overall, the consultation of category three information was most concentrated during
system-level design and the first quarter of the testing and refinement phase for
prototype 3. This was a busy phase of designing, involving both preparation for the final
prototype and the formulation of recommendations for mass manufacture. Prior to the
commencement of system-level design, 35 out of a total of 77 diary entry days (45%)
involved consultation of category three information; during system-level design and the
first quarter of prototype 3 testing and refinement, this figure rose to 49 out of a total of
66 diary entry days (74%). After system-level design, consultation of category three
information declined dramatically to 10 out of a total of 84 diary entry days (12%). The
decline in consultation towards the end of the project reflected the change in work from
finalising the guitar design to making the final prototype. Figure 26 shows clearly that
information of all categories was rarely consulted, received or happened upon on days
when 'testing and refinement' (which mostly comprised prototyping activity) was the day's
main activity. 'Making' activities were for the most part separate to materials and
processes information-gathering activities. Exceptions are described later in this chapter.

Subject-focused information hunts
The way in which information was consulted during the project was revealed starkly by
the detailed diary entry catalogue. Throughout the project, discrete blocks of
information-searching could be identified, within which most of the information sought
related to specific materials and processes issues that were unable to be resolved with
existent knowledge and values. These subject-focused information hunts are listed in
sequential order overleaf, and illustrated in Figure 27.
Figure 26: Summary chart of materials and processes information use against periods of testing and refinement.
Figure 27: Summary chart of category three materials and processes information hunts for the polymer acoustic guitar project (with design activity phases indicated)
Hunts prior to system-level design

- Hunt 1. To establish the various materials, manufacturing processes and construction methods used in guitars [9; 10; 14; 16 to 18; 20; 36; 38; 43].
- Hunt 2. To identify potential soundboard materials and to locate distributors of these materials [66 to 68; 70 to 74; 75; 77 to 80; 87; 93; 94; 104].

Hunts during system-level design and testing and refinement of prototype 3

- Hunt 3. To become knowledgeable on plastic-to-plastic joining techniques (including welding and adhesives) and to locate local manufacturers [107; 113; 114; 137; 139; 140; 149 to 151; 154; 160 to 164; 166 to 170; 172 to 174; 176; 178 to 180; 182; 184 to 186; 190; 191; 199; 201; 203; 208].
- Hunt 4. To evaluate the suitability and availability of coloured polycarbonate and PMMA sheet, for use on the final prototype [223; 231; 240; 255; 260 to 262; 269; 271; 273; 277 to 280; 302].
- Hunt 5. To evaluate the suitability of different techniques for prototyping product graphics, and to locate local manufacturers [238; 243; 249; 256 to 258].

Hunts after system-level design

- Hunt 6. To decide upon a suitable resin and construction method for the GRP back of the guitar [301; 303; 304; 305; 308].

The subject-focused hunts show that much of the design activity involved periods of learning unfamiliar subjects on a 'need to know' basis. The third, fourth and fifth hunts were each made during system-level design and resulted in a significant increase in the frequency of information consultation, as previously described.

Experiments to derive new product-centred knowledge

Experiments were conducted to establish properties of materials, manufacturing processes and guitar construction that could not otherwise (or not easily) be established from other information sources. Many of the experiments involved investigation of unproven technologies (i.e., materials and construction methods not previously used in guitars).

I see materials in this design project as critical to its success—simply because the innovation—making a stringed instrument from polymers—is on uncharted territory [sic]. It is R&D work, clearly, and made more obvious by the fact that I am testing materials in prototypes. It is far from any kind of repackaging exercise.
Experiments linked to the information hunts

During information hunts 1, 2, 3 and 6, experimentation was used to complement the findings from other information sources.

- Hunt 1 involved the investigation of the effects on acoustics of restricting the vibration of the back of a guitar [38].
- Hunt 2 involved the flexing, tapping and dropping of materials to evaluate their acoustic response [73; 80; 94]. This property could not be ascertained from other information sources.
- Hunt 3 involved the identification of suitable adhesives by making test pieces [107; 113; 114; 139; 169; 178; 184; 186 (carried out by the technician at ITW); 191; 199; 201; 203; 208; 312].
- Hunt 3 involved an evaluation of a Forex-EPC and polycarbonate weld joint [170; 179 carried out by ARC Plastics; 182; 185].
- Hunt 6 involved the determination of a suitable construction method for the GRP back of the guitar [305].

This first-stab [at a back shell] using a combination of woven roving (for neatness) and chopped strand mat (for stiffness) has been produced in order to: see how stiff 3-layer (WR/CS/WR) system is; see how thick and heavy this system is; get to grips with epoxy lay-up (the resin is a lot thicker); generally see how the product turns out... A bit unknown at the moment, what with it all being new... just a matter of seeing how it turns out. [305]

Other experiments

Other experiments, not linked to the six information hunts, were conducted during the designing.

- Identification of the resin used for the bowl back of the Ovation guitar [76; 90, carried out by colleagues in IPTME].
- Investigation of ways to create a clean circular hole in Forex-EPC [105].
- Investigation of the thermo-forming capability of Forex-EPC in order to determine whether vacuum forming and fabrication were suitable methods for creating the guitar back [152; 153; 210].
- Determination of the possibilities for spray painting Forex-EPC, Lexan and GRP [209; 274; 307].
- Fabrication of Lexan strips to determine a suitable material thickness for a binding component [246].
Made some test samples of Lexan strip to see if these would be suitable for the binding. At 2mm thick it is quite flexy. Thicker samples did not bend, so I added bandsaw indentations at regular intervals (same technique as wooden guitar making I think) to add flex. This seems to work really well.

- Evaluation of the acoustic response of the prototypes by tapping the materials used in situ [198; 207].

Strangely, now that the bridge is fixed into place, the sound chamber seems to be responding quite well to 'finger taps', clearly resonating at different frequencies according to position on the soundboard. The dampening/thudy [sic] sound that I got a few days ago by just placing the PC block onto the soundboard has been replaced by resonant vibrations. Perhaps the adhesive has somehow formed the 'missing link' between the Forex and the Lexan, in terms of vibration transfer. I cannot help but be reminded, as I write this, of Rob Armstrong's contention that the construction of the guitar is paramount, and that each component should come together to form a greater whole. Perhaps the adhesive is providing that very coherence?

- Assessment of the stability of the prototype construction when under the tension of the guitar strings [108].

Use of printed sources
A range of different printed sources were consulted during the different information hunts.

Information hunts 1 and 2
In the idea generation period of concept development, guitar books were used to establish the various features that might be incorporated into the polymer acoustic guitar [9; 10; 14; 16; 18; 20]. Guitar sales literature were consulted for the same purpose [43]. Also during concept development, various internal design reports, including dissertations and undergraduate work, were consulted as a reminder of the various materials and processes issues that needed to be considered [29; 99; 100; 121; 123; 132; 142]. In addition, materials sales literature were consulted, chiefly for information on manufacturability [66; 67; 80; 142; 143].

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40 Digital audio recordings were also taken, from which spectral analyses of the sound vibrations for each string were made. In the event, the information from these analyses was not used in the designing.
Information hunts 3, 4, 5 and 6

The printed sources consulted during system-level design differed to those of concept development. Technical books and journal papers on materials and processes were consulted, principally for recommendations on design details, assembly and materials data [87; 101; 120; 137; 138; 140; 149; 151; 159; 165; 231; 267]. Bralla [1986] was used extensively. Directories of material manufacturers and suppliers were used to gather company contact details [75; 131; 163; 164; 168; 243; 257; 277; 278]. Materials sales literature were again consulted [229].

Liaison with material suppliers, material manufacturers and end manufacturers

Material suppliers, manufacturers and end-product manufacturers were contacted mostly by telephone but also through written correspondence and visits to premises.

Liaison with colleagues (core personnel)

The core project personnel were consulted primarily through arranged meetings to discuss design direction and product details. E-mail was used extensively for correspondence with Dr. Heath. Meetings with Eddie Norman and Dr. Heath were made more frequently than those with Rob Armstrong because both of these colleagues were accessible on the University campus. Although meetings with Rob Armstrong were infrequent, many points of discussion were raised in one session, rather than just a few questions.

In retrospect, the most critical advice that Rob imparted was during the early stages of concept development, in relation to the composition of materials for use in the guitar's sound-generating parts. Rob described the essential properties that he anticipated would lead to good musical qualities. As a craftsman, Rob did not talk of moduli of elasticity, yield strength or creep, but he did refer to the essence of these properties in plain descriptive language: of stiffness, of collapse and of instability, phenomena which are easily felt and observed when materials are handled. In order for a non-wooden soundboard to be successful, Rob was sure that the soundboard material would need to be aerated (Figure 28).
The same principle also applied, he felt, to the bowl back of the guitar.

[Rob's advice] ...try to use, after the gel coat, as much heavy loose fibre with as little resin- to encourage some thickness and air rather than a dull, thuddy resonous [sic] bulk.

[111]

Rob's descriptions were used to limit the search for candidate materials to foams, cellular polymers, composite sandwiches and aerated FRP [LB1:16]. Although Rob's advice on material composition was at face value quite simple, it resolved what was potentially a major barrier to progress and proved pivotal to the success of the final instrument. Luthiers (guitar makers) learn about the nuances and details of instrument-making by forming a practical, intimate (and possibly tacit) knowledge of the materials of their trade. From this point of view, it was fortunate that Rob was able to state explicitly what he thought the composition of potential materials should be. When handed the first prototype and a sample of the most promising polymer, Rob handled it and played it and knew, instinctively, that the material "...was right" [109]. This was an excellent display of Rob's connoisseurship.

Liaison with colleagues (ancillary personnel)

Colleagues who were ancillary to the project were consulted when specialist information and 'second opinions' were sought. For example: for advice on how to create vinyl transfers [126]; for opinions on the visual qualities of materials [261]; and for names and addresses of material suppliers [262]. The consultation took the form of arranged meetings (mostly with University employees outside of the Department of Design and Technology) and casual meetings (mostly with people based within the Department).
Use of designed artefacts
Features of guitars were established through a process of hands-on examination of
existing instruments [17; 60 to 62; 115; 218]. On one occasion, the type of graphics
used on an unrelated product (an Apple Macintosh Powerbook computer) was cited as
desirable for use on the guitar [238].

Use of physical samples
Physical samples of processed materials were gathered in order that their potential use in
the guitar could be evaluated first-hand by handling and experiment [78; 129; 260]. The
samples were also used as an aid for discussion with colleagues [68; 79; 80].

Use of internet sources
The GE Plastics web site was consulted to gather technical information on Lexan,
including the joining and welding possibilities of the material [158; 160]. A web search
was undertaken for U.K. stockists and manufacturers of coloured, 10mm thick PC and
PMMA sheet [277; 278].

Cognitive modelling and attention to materials and manufacturing
processes
In Chapter One of the thesis, cognitive modelling was defined as the generation of
product ideas (or analogues thereof), held either solely in one's 'mind's eye' or expressed
through media such as drawings and worked objects. Whilst many of the diary entries
fitted this description well, some entries made reference to externalised and non-
externalised thinking that closely resembled cognitive modelling but, with the definition
given, could not be strictly described as such. Discrepancies centred around both the
presence (or otherwise) of 'mind's eye' images and the scope of the term 'product ideas'.
These were critical matters that demanded a closer look prior to any sustained analysis of
cognitive modelling.

On the evidence held in the detailed entry catalogue, it was sometimes uncertain that
non-externalised designing drew (or was likely to have drawn) upon images held in the
'mind's eye'. For example, the gathering of information [16]; the preparation of the PDS
[30]; the decision to purchase a guitar and to affix to it different soundboards [59]; the
decision on the sequence of prototypes that would be produced [69]; the recollection of a
possible manufacturing route [112] and the determination of suitable adhesives from a

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41 Included within this were perceptions of sound, touch, smell and taste, as well as vision.
compatibility table [137] may or may not have involved 'mind's eye' images. Where there was ambiguity over the presence of 'mind's eye' images, entries listed in the detailed catalogue have not been coded as relevant to cognitive modelling.

An examination of the detailed diary entries revealed there to be two kinds of product pictured in the 'mind's eye': (i) those yet-to-be-produced and existing as ideas and (ii) those already-produced as physical artefacts. On first inspection, the latter kind of product does not seem to fit with the definition of cognitive modelling given; it makes no reference to emerging design ideas (as below).

I hold in my head an image of what good quality printing on products can come out like- I especially like the quite thick printing used on some beer bottles these days. If I remember correctly, Carlsberg Ice is one in particular that I like the finish on.

To have images in the 'mind's eye' of existing products raises important limitations of the definition of cognitive modelling so far provided. A critical theoretical point is that images of already-produced products held in the 'mind's eye' will not necessarily be well-formed and could in fact be no more than superficial. What one visualises may be not so much a specific existing product but rather a semblance of that kind of product- a partial recollection- constructed from one's limited experience. Without comprehensive and specific product knowledge, it seems a fair supposition that the only way to manipulate an already-produced product in the 'mind's eye' (i.e., to rotate it, disassemble it or modify it, as the needs of designing require) is by way of heuristics. It follows then that elements of 'mind's eye' images of already-produced products will be works of fiction and that, therefore, cognitive modelling is present. This use of 'mind's eye' images has therefore been coded as cognitive modelling in the detailed entry catalogue.

Cognitive modelling sometimes involved varied use of different 2D and 3D media. All modelling in 3D media constituted 'model-making' (the making of physical analogues of a design, from foam models through to working prototypes). In relation to materials and processes, this mostly involved putting a pre-defined design into practice but, as will be described later in this chapter, occasionally model-making and made models initiated 'mind's eye' images of revised design ideas.

The final area in need of clarification concerned the nature of 2D modelling during the project. It was clear from the detailed diary entries that 2D media were used not just to aid the evolution of design ideas (as described in the definition of cognitive modelling in Chapter One) but also, for various reasons, to illustrate existing products and established design ideas. Although such uses of 2D media did not explicitly involve there-and-then generation or development of product ideas, it is difficult to imagine that the preparation
of the artwork did not involve the invoking of images in the 'mind's eye' prior to committing pen to paper. This is of course a theoretical point, but one that usefully expands the definition of cognitive modelling to include additional 2D-based design activities that were clearly in evidence in the diary entries. These activities will be examined in detail shortly.

Cognitive modelling and different media
Figure 29 shows when cognitive modelling in relation to materials and processes featured during the designing. Overall, cognitive modelling was identified on 51 out of the total 227 diary entry days (23%). Of those days, 12% involved modelling with 3D media; 23% involved non-externalised modelling; and 69% involved modelling with 2D media. The extensive use of 2D media is a reflection both of the author's design training and the inherent convenience that 2D media offers. As with information use, cognitive modelling was concentrated around concept development and system-level design and was less evident during the testing and refinement of prototypes 1, 2 and 3.

Functions of cognitive modelling with 2D media
Cognitive modelling with respect to materials and processes had specific functions, falling under the following headings. Each function will be examined in turn.

- Illustrations for colleagues.
- Illustrations and textual reminders of existing products for oneself.
- Project co-ordination.
- A record of ideas and decisions from meetings.
- The generation and development of design ideas.

Illustrations for colleagues
Some drawings had the specific purpose of aiding discussion of materials and processes ideas with colleagues [119; 126; 220; 228; 229; 293]. All but one of these drawings was prepared in advance of the discussions. The exception was a simple sketch produced in the course of a meeting with Dean Bates [220, Figure 30].

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Excluding days spent prototyping on which no revised materials and processes ideas were initiated.
Figure 29: Summary chart of cognitive modelling in relation to materials and processes during the polymer acoustic guitar project (with design activity phases indicated)
Figure 30: A simple sketch used to explain to a colleague how the guitar soundboard assembled to the back.

The artwork associated with entries 119, 228, 229 and 293 (Figures 31 and 32) was much more informative and complete, in order to make current design ideas clear to colleagues and to avoid misunderstandings. A common feature of the artwork was the liberal use of annotations and, generally, a diagrammatic approach to the line work.

Figure 31: Artwork intended to communicate to colleagues (a) rosette manufacture (top) [119] and (b) instrument surface textures (bottom) [228]
Figure 32: Artwork intended to communicate to colleagues (a) the stages in GRP lay-up needed to prototype the guitar (top) [229] and (b) overall assembly of the instrument (bottom) [293]
Illustrations and textual reminders of existing products for oneself

During the early idea generation period of concept development, 2D media served as a personal space for recording illustrations and textual reminders of the features of existing products [2; 7 (Figure 33); 11; 24; 84]. Such use of 2D media was cited both as a means of learning product-centred information and as a memory aid. This use of 2D media was described in an entry in the project notebook.

"The concept design stage has involved placing [technical/functional] details into [my] solution space- not using them in the design of a new product yet, but presenting the material to myself in a way that will greatly aid design work in the immediate future.

[Project notebook, 1 August 1996]

Figure 33: Artwork associated with [7], illustrating the intricate construction of the side wall and purfling on a wooden guitar.

Project co-ordination

It was often the case that 2D media were used to help project co-ordination, by the restating of established design ideas, the recording of out-of-hours designing, the clarification of design criteria and the stating of findings from information searches (including experiments) [64; 98; 108; 134; 141 to 144; 146; 159; 160; 195; 216]. Especially clear examples are given overleaf.
Getting back up to speed on the design. Have been away on vacation for 2 weeks (...) reminding myself of some of the materials properties of the soundboard, from my own knowledge initially.

[64, Figure 34]

With this illustration I was showing, to myself, the joints of the bridge and making explicit, again to myself, the basic construction requirements.

[134, Figure 34]

This is me presenting to myself what the joint is, and annotating some of the properties of the Forex around the drawing (these were taken from the information data sheet, supplied by SBA plastics). My purpose for considering the joint is because I want to move towards final designs, recommending the use of industrial processes. I am laying out the parameters to which I am working.

[141, Figure 35]

Made use of the GE Plastics WWW site (http://www.ge.com/plastics) which I had visited previously. Noted down some of the key points relating to designing and working with Lexan polycarbonate sheet. These are noted on LB1:39.

[160]

This was clearing up, in my mind, how the build-up of components for the final design was going. I was thinking whilst drawing these that I would need to produce CAD models of each.

[195, Figure 35]
- Air to provide volume?
- Fibrous structure - uni-directional?
- Rigid interface between soundboard + sides.

- Mouldable (e.g. fully integrated bridge, possible then)

advanced

compressed

Thix foams

foam composite

sandwiches.

Composites

Composite boards

(laminar) - CF/GF

Mouldable wood

Fibre (e.g. Kevlar, aramid)

"Maderon"

Figure 34: Artwork acting as personal reminders of materials and processes design ideas and criteria [64; 134]
Figure 35: Artwork acting as personal reminders of materials and processes design ideas and criteria [141; 195]
A record of ideas and decisions from meetings

Ideas and decisions from meetings were recorded into the log book or onto sketch sheets [23; 25; 35 to 37; 39 to 41; 147; 183; 187; 212; 229; 294]. The records were made after meetings had finished and, as such, contained after-the-event illustrations of ideas rather than evidence of ideas worked up at the time of conception. The only exception was a discussion held with a colleague, Jon Allen, who illustrated his thoughts in the course of a meeting [211]. Four example entries are given below.

[Notes from the video session with Eddie 29.5.96 written down in Log Book].
This was to make sure as much information is stored in a readily-used format...
[25, Figure 36]

Overall design was considered: 3 moulds: (i) soundboard; (ii) bowlback/neck/head; (iii) fingerboard. OP/EWLN/RA mutual agreement.
[40, Figure 36]

Final comments on each of the joining methods are listed in the logbook on LB1:44, in the light of today’s meeting [with Dick Heath]. These are a formal method for me to keep a tab on what design options are open to me.
[187, Figure 37]

Design sketches of prototype 3 manufacture, for me to visualise what RA was explaining to me. I’ll find it easier to make use of this information in the near future when it’s in illustration rather than memory.
[212, Figure 37]
Chapter Eight: The polymer acoustic guitar project (Part C)

19 June 1996

Figure 36: Artwork produced in the wake of meetings, as a personal record of materials and processes design ideas and criteria [25; 40]

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This is the back of a multi-pen colored paper where O.F. Pedgley, Ph.D. (1999) notes his meetings and discussions about the acoustic guitar project. The notes are written in a concise, informal manner, likely intended for personal reference.

The writing includes:

- Consider the qualities inside a mould and those on the exposed outside.
- Polymer finishes:
  - Mechanical
  - Superficial but aesthetic finishes, coatings, laminations
- Consider durability against knock.
- "Oneness" - block off cavity for neck - from; acoustically dead.
- Interaction of soundboard and back; do we want acoustic transmission to be minimised or preserved?
- Indicator:
  - Soundboard
  - Backer
  - Neck/Head
  - Fingerboard

The diagram shows a detailed drawing of a guitar body with various parts labeled, such as a soundboard, neck, and fingerboard, highlighting the complexity and design considerations involved in the project.
The generation and development of design ideas through cognitive modelling

The primary use of cognitive modelling was for the generation and development of design ideas. This was an intensely personal and hidden activity where design ideas were conceived and worked-up, often with the support of 2D media and occasionally with 3D media. From an examination of the detailed diary entries, three subject areas were identified to describe the generation and development of design ideas through cognitive modelling.

- Subject one: primarily to attend to expressive qualities of processed materials [215; 217; 222; 261; 268; 301; 306; 308; 309; 311].
- Subject two: primarily to attend to utilitarian properties of processed materials [12; 52; 97; 123; 175; 194; 196; 234; 259; 287; 291].
• Subject three: primarily to envisage and propose the manufacture and assembly of product ideas (by industrial processes or prototyping) [5; 6; 8; 20; 22; 46 to 48; 50; 53 to 55; 57; 63; 83; 85; 105; 115; 120; 127; 128; 133; 135; 136; 171; 184; 193; 197; 214; 219; 221; 235; 241; 245; 246; 267; 284; 286; 289; 290; 296].

These subject areas will be visited shortly to examine how cognitive modelling was used to generate and develop design ideas.

### Primary generators of cognitive modelling

In Chapter One, design 'moves' were stated as initiated from a starting point determined by the designer (i.e., initiated in the mind of the designer). This starting point has been termed the 'primary generator' [Darke, 1979] and has been described as the origin of conjectures during designing [Hillier, Musgrove & Sullivan, 1984]. The detailed diary entry catalogue holds documentary evidence that moves achieved through cognitive modelling are initiated by contact with information sources and with work in 2D and 3D media, as well as in the mind. Put differently, information sources and work in 2D and 3D media sometimes acted as the primary generator for design moves and, it can be asserted, as the spark of a reflective conversation with the situation [Schön, 1983]. All of the instances when information sources and 2D and 3D media acted as primary generators are quoted in the next sections.

#### Cognitive modelling initiated by information sources

The majority of instances involved contact with printed sources.

Integral bridge in mould: thought of when considering bridge-soundboard interface in Guitar Handbook [book].

[20, Figure 38]

---

4 The diary entries do not constitute real-time trains of thought (as with protocol analysis) and, as such, provide insufficient evidence to identify the structure of Schön's reflective conversation (i.e., names, frames, moves, reflections) in relation to cognitive modelling. On the available evidence, one could not distinguish, for example, if reflection was made on or in a particular episode of designing. Nevertheless, it seems probable that the structure of reflective practice is independent of the kind of primary generator involved.
The stimulus for producing a large recycling logo on the plastic body was sparked off by me re-reading my PDS section to do with recycling. Paul Wormald had given me an information sheet on the standard logos and these two issues seemed to 'click' in my mind. I immediately thought of making the logo as part of a moulding or pressing- and wanted it big to really shout out 'recyclable product design!'- the most suitable surface area without spoiling the form of the product was on the back.

[120, Figure 38]

Finished the revised PDS today- and used my notes on materials and processes (mentioned yesterday, a document I had produced through my research reading) to add a few more 'checklist' material properties to the appropriate section in the PDS. I basically went through the materials list (which is not comprehensive) and noted down which properties would be important in the guitar, based on my understanding of how/where the guitar will be used and how/where it will be stored.

[123, Figure 39]

I am swayed by the brighter 7T03 sample because it seems to fit in with the image I have in my mind of the final design- erring towards primary colours but still quite dark. (...) The two darker samples are, I think, too little a contrast with the black Forex.

[261; modelling not externalised in 2D or 3D media]

Had a look at Bralla, DFMA book with reference to IM structural foam. I hadn't realised that it was used so extensively. Picked up the fact that the process creates a smooth skin (in contact with mould) with a foamed core. Made notes on LB1:58 for future use in my section on mass manufacture in my final design report. Had visions in my mind about how the inserts might work- and that holding a 'spider' (...) bracing pattern (one component, pre-injection moulded) would be a lot simpler than clamping each bracing member separately... (I was thinking how to make the manufacturing process simple).

[267, Figure 39]

When you write down a job list like this, I think you can't help get images of final products and how you'll achieve them... I certainly did when writing the project completion plan.

[276; modelling not externalised in 2D or 3D media]

As I write a draft report like DS56, I clarify where I am going with my design and I also get revised design ideas come into my head. (...) Particularly, I had some visions of how the binding might be made integral with the soundboard.

[283; modelling not externalised in 2D or 3D media]

...I have my eye on Aluminium metal powder which is listed in their [Polyfibre's] Aug '97 catalogue. I'm thinking that this could be added to any colourant [sic] to create a speckly [sic], interesting surface (rather than using it, as described, to mimic a completely metallic surface).

[301; modelling not externalised in 2D or 3D media]
Figure 38: Artwork associated with cognitive modelling initiated by printed information sources [20; 120]
2.11 Polymer requirements / adhesive requirements

2.11a UV stability to prevent discolourisation over time.
2.11b No distortion or degradation due to exposure to temperatures between x and y (based on typical extremes of product surface temperature when left outdoors).
2.11c No catastrophic plastic deformation due to high stresses from the strings.
2.11d Moisture resistance.
2.11e Humidity resistance.
2.11f Water resistance.
2.11g Surface finish resistant to scratches.
2.11h Surface finish resistant to spoilage by stains and dirt.
2.11i Suitably tough to withstand minor impact forces (knocks).
2.11j Ability for material to be coloured.
2.11k Consistency of semi-finished material.
2.11l Materials should be suitable for reclamation/recycling and should be labelled as such.

Figure 39: Artwork associated with cognitive modelling initiated by printed information sources [123; 267]
Cognitive modelling initiated by work in 2D media

Cognitive modelling was initiated by work in 2D media in two ways: (i) through the act of drawing; and (ii) through contact with artwork already produced.

Cognitive modelling initiated through the act of drawing

Diagonal stripes: property of [material]: sparked off by colour/pen swipes/wash of pen.
[4, Figure 40]

This 3D representation was used by me to visualise possible machining points (especially the groove where the strings fit).
[133, Figure 40]

When I was drawing this, I was envisaging a flexy polymer bead which would be mounted using adhesive.
[196, Figure 41]

All the while whilst on DS45 I knew that I would be working with 8mm [10mm] depth polycarbonate and that the bridge would be machined using CNC methods because of the intricate/precise curves required. When working on the right-most drawing (marked 'X') I had in my mind an image of a block being machined to produce the shape I wanted- using the Department's Workshop 1 machines. I found myself 'extending profile lines' as if they were paths for the milling cutters to follow. I also imagined the milling machine producing the overall edge shape, 1mm or so [depth of cut] a time. I concluded that the whole component could be produced on the CNC machines, save a few operations which cannot be performed in 2.5-D machining.
[214, Figure 41]

Cognitive modelling initiated through contact with artwork already produced

How to connect top + bottom: sparked off by seeing my drawing 'floating around'.
[6, Figure 42]

Flexing of this section [on the rosette]: Prior experience tells me about loose protruding sections of material.
[12, Figure 42]

Was looking at the head [on the sketch sheet] and, in the light of today's earlier work [strength calculations], concluded that it would require reinforcement. I 'automatically' envisaged a sheet metal plate for this component.
[193, Figure 42]

I saw the shape [of the head reinforcement member], and that it was intricate with holes, and immediately linked it to pressed metal.
[197, Figure 42]
This material sprung to mind because I looked at my drawing and thought 'bendy thin plastic' and linked that to the integral hinge properties of PP.

[234, Figure 43]

Again, the cue for this idea [making edging integral to a one-piece soundboard] was through looking at my drawing. All the details of this component are aligned so that it would be easy to pull out of a mould.

[235, Figure 43]

I used this left-hand drawing to remind me of how the prototype will be constructed around the neck. It led me on to thinking about the same in the mass-manufactured proposal... the block was providing stability, and rigidity in particular, - how could this be achieved in the mass manufactured version, using lay-up/moulding? A web of walls I thought, rather like strengthening ribs in injection moulded components... The idea was then superceded [sic] on DS55 main.

[284, Figure 43]

Similar to DS55a, I moved my thinking on about re-inforcement. A block of foam would be easier to produce and is the same process as producing the soundboard, as explained. I think the only reason I thought of it this way was because I had already looked at a similar problem in the soundboard, on the same page. The idea just seemed to arrive, anyway. Without reinforcement in this region I could 'feel' in my mind the head twisting and creaking.

[291, Figure 43]
Figure 40; Artwork associated with cognitive modelling initiated by the act of drawing [4; 133]
Figure 41: Artwork associated with cognitive modelling initiated by the act of drawing

[196; 214]
Figure 42: Artwork associated with cognitive modelling initiated by artwork already produced. From top to bottom, [6; 12; 193/197]
Figure 43: Artwork associated with cognitive modelling initiated by artwork already produced. From top to bottom, [234/235; 284; 291]
Cognitive modelling initiated by work in 3D media

Cognitive modelling was initiated by work in 3D media in two ways: (i) through the act of model-making/prototyping; and (ii) through contact with models/prototypes already made.

Cognitive modelling initiated through the act of model-making/prototyping

...when I was redesigning the prototype form (blue foam model mk.2 for a 'final prototype' guitar) I was envisaging a similar construction method to traditional wooden guitars (i.e., strips/faces of wood bonded, simply replaced with polymer materials)...

When sanding back the 4th shell I left the 'A' logo to the end. I loved the surface texture change that I happened across when I did this- matte surround and high gloss logo [Figure 44] - I thought that it might be quite a good design detail change in a more 'upmarket' version.

![Figure 44: Contrasts in surface texture whilst preparing the back of the guitar](image)

Cognitive modelling initiated through contact with models/prototypes already made

Was looking at my prototype 2 thinking that welding each component (bridge and braces) onto the soundboard would be a very time-consuming task for a mass-manufactured version. Instead, I thought [of] making a skeleton [that] could be vibrated / hot-plate welded as one piece on the soundboard. That way, only 2 (+bridge) components would need to be assembled.
When I placed the shell against my table (reasonably dark wood) it confirmed in my mind (and what I'd drawn on DS51) that I'd like the neck and head to be manufactured from very light coloured wood. It looked too dingy and furniture-like with the darker wood.

[306]

Removed the 2nd guitar shell today. I love the finish you get with the glass fibre texture hidden just below the surface of the transparent coloured resin. When polished up, this would look great (and a fantastic contrast to the satin sheen soundboard).

[308]

Cognitive modelling for attending to utilitarian properties of processed materials

A common feature among diary entries describing cognitive modelling and utilitarian functions of processed materials was the acting-out of component scenarios. That is to say, the anticipated circumstances that a product component would be subjected to in use (e.g., stresses, spoiling, heat) were acted-out in the 'mind's eye' and, from the conclusions, candidate material and process combinations (design moves) were eliminated or proposed.

The following quotations have had emphases added to show the deductive structure of the author's cognitive modelling of product utility. The structure took the following form: from a modelled scenario in which a product component needed to perform, to the proposition or elimination of materials (based on whether or not those materials would perform satisfactorily within the modelled scenario). The modelled components are identified by bold text; the proposition/elimination components are identified by bold italic text.

Wanted a rough idea of how well the methacrylate adhesive from ITW would perform under the conditions experienced by the guitar bridge.

[175, Figure 45. From the simple shear stress calculation on Figure 45, the ITW adhesive was determined to be suitable]

The mechanical calculations (DS42A) were an advancement on yesterdays [sic]. I now have a clear idea of what the Forex can/cannot do as a structural member of the guitar, through working-through the design solution. [The mathematics have 'helped me'] 'picture' the worth of steel as a superior stiff material to plastics and, hence, in the designing of slim-line structural components.

[194, Figure 46]
This material [polypropylene] sprung to mind because I looked at my drawing and thought 'bendy thin plastic' and linked that to the integral hinge properties of PP.

[234]

Was thinking that bridge could not be foam moulded because (a) visually [the material] needs to be a different colour, and (b) the foam won't take the compressive force of the strings.

[287]

Without reinforcement [in the region of the neck and head] I could 'feel' in my mind the head twisting and creaking.

[291]

\[
\text{Two entries contained references to only the modelled component. These are quoted below.}
\]

Flexing of this section [on the rosette]: Prior experience tells me about loose protruding sections of material.

[12]

[I] noted down which properties would be important in the guitar, based on my understanding of how/where the guitar will be used and how/where it will be stored.

[123]
ones roch which are chat large m section. This leads me to think that my safety factor on the column load is excessive. I shall reduce this to 3 rather than 5 from anticipated load.

Therefore, new \( P_e = 1500 \text{N} \) (original \( P_e = \text{mean} + 1.667 \)).

From this, we see that the updated \( I \)-values are divided by 1.667:

\[
I(\text{mm}) \text{ for } P_e = 1500 \text{N} = \frac{2.5 \times 10^8 \text{mm}^4}{1.667} = 1.5 \times 10^8 \text{mm}^4
\]

\[
I(\text{mm}) \text{ for } P_e = 1500 \text{N} = \frac{1250 \text{mm}^4}{1.667} = 750 \text{mm}^4
\]

The required diameter to withstand the 1500N load with a solid semi-circular section can be calculated as follows.

\[
D(\text{mm}) \text{ for } P_e = 1500 \text{N} = \sqrt{\frac{4500 \times 1.5 \times 10^8}{\pi}} = 121 \text{mm}. \quad \text{Still far too great.}
\]

\[
D(\text{mm}) \text{ for } P_e = 1500 \text{N} = \sqrt{\frac{4500 \times 750}{\pi}} = 32 \text{mm}. \quad \text{ANNUL SIZE.}
\]

What shape for something other than a solid semi-circle?

Consider basic mass rod section - a "T" shape.

Assume load axis a plane XX.

\[
I(\text{mm}) \text{ for part A} = \frac{bd^3}{3}
\]

\[
I(\text{mm}) \text{ for part B} = \frac{b_a d_a^3}{3}
\]

Total \( I(\text{mm}) = \frac{bd^3}{3} + \frac{b_a d_a^3}{3} \)

For this T-section to fit within the case of an "average" guitar neck, we need to fit the dimensions.

Let \( b = 20 \)mm

Let \( d_a = 8 \)mm

Let \( b_a = 3 \)mm.

Do these dimensions work, and if so what does the value of \( d \) need to be?

Rearranging the formula to make \( d \) the subject:

\[
d = \sqrt[3]{\frac{\frac{3 \times 1500 - b_a d_a^3}{b} - \left(\frac{3 \times 750}{20}\right)}{20}} \quad d = 3.3 \text{mm}.
\]

Figure 46: Mathematics associated with entry 194
Cognitive modelling for attending to expressive qualities of processed materials

Through a close examination of the diary entries, it was possible to construct descriptions of how design 'moves' were achieved during cognitive modelling.

In contrast to the modelling of a product's utility, the modelling of a product's expressive qualities had a less obvious structure. Proposals for materials could be identified in the diary entries (e.g., bright 7703 acrylic, aluminium powder, opaque finish polycarbonate) but the scenarios to which these choices applied were not stated explicitly. This might have been inevitable, however, given that expressive qualities of materials are often known tacitly and, therefore, beyond precise verbal expression.

A common element in diary entries relating to attention to expressive qualities of processed materials was the exercising of aesthetic and hedonic value judgements. Design moves relating to surface finish and colour were made on the basis of personal preferences. However, even though decisions were self-centred, that is not to say that the modelled scenarios were frivolous. They may have, implicitly, involved assessment of the aesthetic fit of a design to its surroundings or taken into account current fashion trends. A weakness in the design work was that potential users were not asked their opinions on the semantics of a polymer acoustic guitar; only casual discussion with colleagues took place. It would have been beneficial to have interviewed potential users to establish a better base on which to make judgements on material, process and finishing combinations. However, the designing was focused not so much on creating a marketable product but on proving underlying technologies prior to developing a marketable product. In addition, the presence of confidentiality agreements restricted what could be disclosed of the design project to the public. The lack of involvement of potential users needs to be seen in this context.

The following quotations have had emphases added (in bold) to show clearly the exercising of aesthetic and hedonic value judgements during the modelling of the expressive qualities of materials.

...I am working-up my preferred choices [for product colours and textures] at the moment. (…) I didn't really want a shiny/smooth finish…
[215]

Further exploration of colour choices for the materials (just my own preferences for colours and limiting myself to the Magic Marker gamut of colours).
[217]
I am swayed by the brighter 7T03 sample because it seems to fit in with the image I have in my mind of the final design—erring towards primary colours but still quite dark. (...) The two darker samples are, I think, too little contrast with the black Forex.

[Aluminium powder] could be added to any colourant [sic] [in the GRP mould] to create [in my opinion] a speckly [sic], interesting surface [similar to that found on CD players].

When I placed the shell against my table (reasonably dark wood) it confirmed in my mind (and what I'd drawn on DS51) that I'd like the neck and head to be manufactured from very light coloured wood. [In my opinion] it looked too dingy and furniture-like with the darker wood.

I love the finish you get with the glass fibre texture hidden just below the surface of the transparent coloured resin. [In my opinion] when polished up, this would look great (and a fantastic contrast to the satin sheen of the soundboard).

When sanding back the 4th shell I left the 'A' logo to the end. I loved the surface texture change that I happened across when I did this—matte surround and high gloss logo— I thought that it might be quite a good design detail change in a more 'upmarket' version.

[When sanding the bridge] the surface finish was really quite interesting—clouded and transparent in the way that a lot of plastics products are at the moment. I thought that this would be a possibility to include on a final production version... But for now, I prefer the plastic as it is shined-up and so I will continue to construct the prototype like that.

Cognitive modelling for envisaging and proposing the manufacture and assembly of product ideas (by industrial processes or prototyping)

Two of the diary entries provided limited evidence that cognitive modelling of assembly involved, in the same way as consideration of the utilitarian functions of materials, the modelling of scenarios. The two entries are quoted overleaf. The modelled components are identified by bold text and the proposition/elimination components are identified by bold italic text.
...I was envisaging a similar construction method to traditional wooden guitars (i.e., strips/faces of wood bonded, simply replaced with polymer materials)...

[115]

Working out dimensions for CAD modelling today, I couldn't help think about some more assembly details. In particular, I had more thoughts on the design of the upper head casing. An image of the stiffening member came into my mind whilst walking back from home this lunchtime... It clicked in my mind that the machine heads would need to be supported by this component, and so (accordingly) the detail on the head casing need not be as intricate as I had up until now envisaged. Supporting columns would not need to be moulded-in to the upper head casing.

[296]

Stronger evidence (although sporadic) existed in the diary entries for how suitable manufacturing processes were decided upon. The common element in cognitive modelling with regard to process selection was a concern that component shapes were achievable. Similarities in diary entries that described this aspect of design activity were identified.

- All entries made reference to 'mind's eye' images of a desired component shape.
- Some entries made reference to 'mind's eye' images of the shapes that are possible from manufacturing processes.
- All entries made reference to the proposition of a manufacturing route.

The entries are listed below. Passages relating to 'mind's eye' images of a desired component shape are highlighted in italic text. Passages relating to 'mind's eye' images of the shapes that are possible from manufacturing processes are highlighted in bold text. Those passages relating to the proposition or elimination of a manufacturing route are highlighted in italic bold text.

For now assuming that [for mass manufacture] the bowl back will be moulded (blow, vacuum or appropriate...). Aim is to have a clearer idea of how the guitar will be made (was thinking about the shape of existing backs for inspiration).

[48]

...I envisaged in my mind [a desired product shape] (...) [which could be manufactured from a] fully vacuum-formed mould (in Forex).

[83]
Was thinking how to produce the thickness tapering effect using a conventional forming method. **Thermoforming** came to mind because I 'pictured' drinks cups with different wall thicknesses [sic].

I saw the shape [of the head reinforcement member], and that it was intricate with holes, and immediately linked it to pressed metal. [197]

...the cue for this idea [making edging integral to a one-piece soundboard] was through looking at my drawing. All the details of this component are aligned so that it would be easy to pull out of a mould. [235]

[How could rigidity be achieved in a GRP mould?] A web of walls I thought, rather like strengthening ribs in injection moulded components. [284]

The cognitive modelling described in all of these entries involved a process of deduction between desired component shapes (designs) and knowledge of shapes that are achievable by industrial manufacturing processes. It was not clear from the entries precisely how this process of deduction was achieved in the 'mind's eye', but in all cases the end result was an evaluation of manufacturability and a design move (the proposition of a suitable manufacturing route or detail). Speculation on how the deduction was achieved can be found in Chapter Eleven.

**Tasks (other than modelling) for reaching decisions on materials and processes**

Work towards the project PDS [26; 28; 29 to 33; 123], design reports [28; 34; 44; 281; 283] and costings [86; 298] could be identified in the detailed entry catalogue. The creation of these documents aided decision-making on materials and processes by clarifying (and making explicit) current thinking, especially in preparation for project meetings. The PDS was described as "...the hub of project development..." [32] and that without it, "...design work would tend to float and the chance of doing mis-guided or mis-placed design work is much greater." [28] The first design report had a similar function.

Report 1 (...) allows me to 'form the most complete picture of design work as it stands- giving me confidence (and an appropriate level of understanding / planning) to move onto the second phase of design work. [28]
To reach the very structured description of materials and processes requirements contained in the PDS it was necessary to sift through a complex of different requirements. Figure 47 shows the whole of DS10, the first step in the generation of the guitar PDS. Diary entry 31 describes how the sifting was achieved.

The preparation of the final design report acted as an alerted to materials and processes issues that still needed to be resolved [281; 283].
CHAPTER NINE

The skydiving helmet project

Introduction
The purpose of this parallel study was twofold: (i) to gauge the potential of the diary of designing as a data collection instrument for use in future research projects; and (ii) to provide additional data on industrial designers' attention to materials and manufacturing processes. The participants in this parallel study were two middle 2:2 class finalist undergraduate designers studying towards a B.Sc. Degree in Industrial Design and Technology with Education, at Loughborough University. For the purpose of this thesis, the students are referred to as Aaron and Zachary.

The two students were asked to complete a diary of designing describing their attention to materials and manufacturing processes whilst working on a project to design a free-fly skydiving helmet for The Cool and Groovy Fridge Company. Free-fly skydiving is an exhilarating sport where showmanship is an important part of its enjoyment. The helmet was to be designed to reflect the 'wild and wacky' image of the sport. In addition, the helmet needed to have a facility for side-mounting a Sony digital camera so that skydivers could be filmed in the air.

After the completion of the project, post-diary semi-structured interviews were held with the two students. Both students were able to provide recollections of how they attended to materials and manufacturing processes for their emerging designs. Both students were also able to describe their experiences of writing the diary. Details of the interviewing technique were described in Chapter Five.
Commentary on the diaries

Full catalogues of the students' diary entries are shown in Tables 10 and 11.

- The 'diary date' column refers to the days on which entries were made.
- The 'entry number' column refers to the nth consecutive detailed entry.
- The 'artwork' column provides an index to 2D media referred to in entries.
- The 'day's main activity (verbatim)' column provides a verbatim transcript of summary entries.
- The 'detailed diary entry (verbatim)' column provides a verbatim transcript of detailed entries.

<table>
<thead>
<tr>
<th>Diary Date</th>
<th>Entry No.</th>
<th>Artwork</th>
<th>Day's main activity (verbatim)</th>
<th>Detailed diary entry (verbatim)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.10.97</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.10.97</td>
<td></td>
<td></td>
<td>A look at a few design sheets.</td>
<td></td>
</tr>
<tr>
<td>28.10.97</td>
<td>1</td>
<td>LB1:9</td>
<td>Design sheet + ideas on camera mount.</td>
<td>Log book - review of possible materials + what I want as a designer for the material to perform like. Summary - to find out more about all the possible materials to be used. Specifics of materials to be found. See page 9.</td>
</tr>
<tr>
<td>30.10.97</td>
<td>3</td>
<td>DS5</td>
<td></td>
<td>Details of shell and liner with camera mount.</td>
</tr>
<tr>
<td>30.10.97</td>
<td>4</td>
<td>DS5</td>
<td>How the mount will work.</td>
<td>Camera mount.</td>
</tr>
<tr>
<td>30.10.97</td>
<td>5</td>
<td>DS5</td>
<td></td>
<td>Camera mount.</td>
</tr>
<tr>
<td>30.10.97</td>
<td>6</td>
<td>DS5</td>
<td></td>
<td>Foam liner to protect the helmet.</td>
</tr>
</tbody>
</table>

Table 10: Catalogue of Aaron's diary entries

Compared with the diary produced by the author, the undergraduates' diaries were wholly inadequate. The diaries were so sparse of entries that it was not possible to perform any detailed analysis. The students' explanations for their sparse diaries will be examined shortly. Both students worked on the helmet design from October 1997 to May 1998, but failed to regularly provide a summary of each day's work that they spent on the project. The detailed entries that were made read more like a list of product specifications than insights into the dynamics of decision-making. The reported design
rationale was limited to very brief statements of material requirements (e.g., protection, strength and light weight). Information use could not be determined from the data. Despite the poor data, the diary entries did constitute elements of otherwise hidden decision-making, and in this respect showed that the diary could be used (at least partially successfully) by other designers. The tracing sheet stationary was used successfully by both students.

<table>
<thead>
<tr>
<th>Diary Date</th>
<th>Entry No.</th>
<th>Artwork</th>
<th>Day's main activity (verbatim)</th>
<th>Detailed diary entry (verbatim)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.11.97</td>
<td>1</td>
<td>DS8</td>
<td>&quot;Ideas for overall look of helmet.&quot;</td>
<td></td>
</tr>
<tr>
<td>25.11.97</td>
<td>2</td>
<td>DS8</td>
<td>&quot;Strap material or hard plastic.&quot;</td>
<td></td>
</tr>
<tr>
<td>3.12.97</td>
<td>3</td>
<td>DS9</td>
<td>&quot;Inner lining [sic] development.&quot;</td>
<td>&quot;Hard foam or polyester [sic].&quot;</td>
</tr>
<tr>
<td>3.12.97</td>
<td>4</td>
<td>DS9</td>
<td>&quot;Nylon strap.&quot;</td>
<td></td>
</tr>
<tr>
<td>3.12.97</td>
<td>5</td>
<td>DS9</td>
<td>&quot;Foam pads for helmet protection.&quot;</td>
<td></td>
</tr>
<tr>
<td>8.1.98</td>
<td>6</td>
<td>DS13</td>
<td>&quot;Form of helmet development.&quot;</td>
<td>&quot;Clear plastic visor.&quot;</td>
</tr>
<tr>
<td>8.1.98</td>
<td>7</td>
<td>DS13</td>
<td>&quot;Some kind of sunglasses [sic] material. Impact resistance plastic.&quot;</td>
<td></td>
</tr>
<tr>
<td>27.1.98</td>
<td>8</td>
<td>DS20</td>
<td>&quot;Camera mounting.&quot;</td>
<td>&quot;Metal frame to protect lens of camera.&quot;</td>
</tr>
<tr>
<td>27.1.98</td>
<td>9</td>
<td>DS20</td>
<td>&quot;Side camera mount. Metal for strength and to stabilize the camera.&quot;</td>
<td></td>
</tr>
<tr>
<td>17.2.98</td>
<td></td>
<td></td>
<td>&quot;Model-project requirements.&quot;</td>
<td></td>
</tr>
<tr>
<td>24.2.98</td>
<td></td>
<td></td>
<td>&quot;Planning-testing.&quot;</td>
<td></td>
</tr>
</tbody>
</table>

Table 11: Catalogue of Zachary's diary entries

The undergraduates' comments on writing a diary

The primary cause of the poor diaries was a lack of commitment by the students. Neither student treated the diary-writing as a high priority and both were busily occupied with work that ran in parallel with the skydiving helmet project. Zachary noted that it was also difficult to commit to diary-writing because work frequently and irregularly switched between projects. As a result of a lack of commitment, some of Zachary's entries were made retrospectively after a couple of weeks rather than at the end of the day's designing. Aaron thought that diary-writing was too time consuming and tedious and commented that setting time aside for it was difficult. Even though both the students said that they managed to memorise the main questions/prompts for the diary, they also
commented that in practice knowing what to write was difficult. The students had opposing views on whether the diary asked too much of them. Zachary noted that thinking about what to write and reviewing the work covered extended the diary-writing time. Prior to writing entries, Aaron felt compelled to write down a great deal about designing, even though this was not what was requested.

You're more enthusiastic about writing comments on the design work which is of high interest to you personally. (...) The diary wants you to think about the bits you don't want to think about [rejected design ideas]. You almost feel embarrassed about putting down [these] bits.

[Aaron]

Zachary thought that three different formats of stationary was too many and that a single sheet would have been better. The students had opposing views on the ease of use of the tracing sheet. Aaron suggested binding the diary as a book rather than having loose sheets that are inclined to becoming lost. He also would have preferred use of an A2 tracing sheet to be compatible with his A2 sketch sheets. Both Aaron and Zachary commented that, had they been motivated to write a full diary, they envisaged the process of reflection would have benefited their designing by clarifying decision-making. Zachary felt also that his materials and manufacturing knowledge was weak and that it therefore did not feature strongly in the project.

Administration of the student diary studies

Both of the students stated after their briefing that they had understood the requirements of the diary and were happy to progress with it. At the post-diary interview, the students confirmed that the briefing had been sufficiently clear but that, as described, they had not been sufficiently motivated to complete a diary. In retrospect, too few checks were made on the students' progress. The informal verbal checks that were carried out failed to uncover the serious practical problems that the diarists were experiencing. This was a failing of the administration of the student studies. Chapter Ten contains a step-by-step recommendation for future diary studies, devised for researchers to avoid pitfalls.
Aaron's attention to materials and processes (findings from the post-diary interview)

The timing and sequence of attention

During the initial idea generation stages of the project, efforts were channelled into form exploration (which Aaron occasionally described as "pure styling"). Ideas were as "wacky and ...off the top of my head as possible." Materials, processes and assembly were considered only cursorily as "two minute ideas" (e.g., protection of the video camera by a metal casing and fabric helmet streamers for creating a wild effect, Figure 48) and "practicalities weren't really thought of." As the project progressed, attention to materials and processes became more purposeful.

Figure 48: Streamer design using trails of fabric

The level of detail reached

A common theme throughout the interview was Aaron's concentration on the styling of the helmet. Although firm decisions were made on choices of materials and processes, there was no evidence in Aaron's designing that his final proposal was detailed for potential manufacture and assembly (i.e., described in 'part' and 'general assembly' engineering drawings). Production of such drawings is recommended for final year projects.
Constraints

Budget

A proposal for a carbon-fibre protective camera surround was dropped for the final design on the grounds that it was too expensive.

Design brief and the client

Aaron put special effort into giving his ideas some technical weight prior to the first formal client presentation. There was a threat that support would be withdrawn from proposals that did not impress the client.

Limitations for form creation

Aaron pointed out that hand lay-up was decided upon as the manufacturing process for the helmet shell because with this method a visually interesting mix of glass fibre and Kevlar could be achieved. Injection moulding of the helmet shell was also possible because the shape had no re-entrant features. For the manufacture of the inner lining of the helmet (which needed to be a close fit with the face), a bespoke manufacturing technique was considered. The following verbatim transcription of the interview reveals the rationale behind the proposal.

Owain: "Did you have any thoughts on what was happening inside, underneath the main shell?"
Aaron: "Yeah, a little bit. It was going to be this kind of scrum cap which would fit in... be strapped into it. Originally I was thinking that it would be [a gel]. It sets to this rubbery sort of stuff... [You put the shell and strapping on] and then you injected this sort of liquid, and you'd have to sit there for half an hour while it set. But then [the inner lining] would really be to your head. [The client] said that the cameramen like [the helmet] to be as rigid as possible, so you don't get it shaking and moving when you put it on."
Owain: "So that was a distinct possibility?"
Aaron: "Yeah, it was looking at the sort of ski boot technology: put your foot in and it sets to the shape of your foot... It was going to be your helmet and it would fit to you."
Owain: "Did you include that in your final design?"
Aaron: "No, it sort of got lost [because the client, originally saying it wanted to be really snug, later said that it needed to fit different people]. So at the end of the day, it changed to a basic sort of rugby cap helmet. Foam inside a liner, and two like shoelaces with a toggle on it on either side, so you just toggle it up [to make it fit to your head]."

Product precedents

Two examples were given during the interview of how existing products set a precedent for design proposals.
The main body of the helmet was probably going to be fibreglass or injection moulded, purely because [the client] made one previously which was fibreglass, and their competition was injection-moulded. (...) It works and it's the only cost effective way of doing things, depending on scale, you know...

[Existing helmet manufacturers] use just an aluminium bracket [for mounting a camera pod]. You know, it was probably going to be along the same lines, it was going to be an aluminium or steel bracket basic mount...

**Volume of production**

During the project, "...the [projected] production runs seemed to get less and less." In the light of revised figures for the anticipated volume of production, hand lay-up (rather than injection moulding) was finally proposed as the method of manufacture for the helmet shell.

**Opportunities offered to industrial designers**

Aaron noted that the opportunity to modify the helmet shell design was greater with hand lay-up than injection moulding (based on the relatively low cost of modifying lay-up mould tools).

**The use of information**

**Client**

In the project briefing, the client provided details of helmets that the company had previously produced and described the manufacturing processes that were involved with those.

**Designed artefacts and the wider world**

Two instances were described when designed artefacts were used to help decision-making on materials and processes. First, the client made available a rival's injection moulded helmet to handle and evaluate. Second, Aaron came into contact with a fellow student's scrum cap and envisaged how its construction and material could be used in a lining for the skydiving helmet: "...I just liked that idea of it being really quite spongy and soft, and quite rigid."

**Printed sources**

Aaron spotted a Kevlar material in a magazine from a speaker company (Figure 49) and incorporated the material into his final product proposal.
Attention to expressive qualities of processed materials

Design ideas exploiting expressive qualities of processed materials were discussed throughout the interview.

- Attachment of fabric streamers to the rear of the helmet (Figure 48).
- Use of bright primary colours as "visually exciting" patterns on the helmet shell.
- Addition of painted surface patterns (e.g., a yellow and black leopard skin pattern).
- Use of different materials to provide different colours on the helmet shell.

The importance of aesthetic and hedonic value judgements was plainly revealed, as the following quotations shows.

[A loudspeaker featured in a magazine] had this Kevlar fibre for the bass [speaker]... and that texture, to me, was fantastic, absolutely (Figure 49). And the way the light captures the different weave: it does shine almost. I wanted to incorporate that into these yellow bits [on the helmet]. That was the thought [behind] the colouring. I thought 'oh, wow, that's great, I'll bung that in there'. [The Kevlar fibre] was, for me, the way to go. I loved that sort of tactile, visual. and the sort of space-age technology with the helmet. It was like, 'God, people will rush out and buy it'. Well, that was my thoughts anyway.

Aaron: "...I said to the client, 'what about, you know, carbon fibre or Kevlar?', and he was going 'oh, well, it's obviously going to be a lot more expensive'. And I don't know about the weight of Kevlar, I'm not sure, but... immediately [the client] said it was going to cost a lot more than your average helmet." Owain: "You wanted it for the visual effect?"
Aaron: "Yeah, it wasn't purely... I mean, everyone wants the newest technology, and Kevlar and carbon fibre are 'wow' materials. Everybody likes something that's made out of carbon fibre, everyone looks at it and says 'that's fantastic'. So it was trying to bring in some kind of visual and... tactile sort of
qualities to the helmet, so you could touch it and feel it and it would look nice, as well as the sort of 'wow, it's got a bit of Kevlar on it, that's fantastic'."

Carbon fibre was considered by Aaron to be a suitable material for the protective camera casing component, especially given the semantics of the material.

...the camera is the most expensive bit, it costs £1500. So if you damage it, it's going to cost you a packet. [With carbon fibre] I wanted... the space-age 'that is going to protect my helmet [means camera] because it's bullet-proof'. In people's minds, they see something that's bullet-proof on something... and it doesn't need to be bullet-proof, but people think 'God, that's absolutely really going to protect it'. It might not, you know, it might shatter because of the shape of it or whatever, but people will automatically think 'that will do the job'. So that was the idea behind it.

Attention to utilitarian properties of processed materials
Aaron described how manufacturing routes were chosen because they could satisfy utilitarian functions of emerging design ideas. Aaron anticipated the circumstances in which a product component would need to perform and, from his conclusions, decided upon a suitable material for that component.

- For the camera casing and bracket, protection was a main concern. Early ideas involved a metal roll-cage. Later ideas involved a full shroud around the camera but with a clear screen in front of the lens. To prevent the metal bracket abrading and damaging the helmet shell, a "...big rubber washer that compresses when you tighten it" was proposed. When compressed, the rubber would form around the irregular shape of the helmet.
- Protection of the skydiver's eyes was a key concern and a visor was designed for this purpose.
- The inside lining of the helmet needed to provide the dual functions of grip, protection and comfort.

Cognitive modelling
At one point in the interview, insight was gained into how Aaron pictured materials in his 'mind's eye' as already-produced material forms. He stated that the material for the visor component of his helmet would not be manufactured from "Formula One" visor material because it was, in his opinion "too thin". Instead, the visor would comprise "Oakley [sunglasses] frames... you know, the big cricketers' ones, but integrated a bit bigger across into the helmet."
3D modelling

Aaron was clear in his mind that his final prototype (Figure 50) should be constructed from the materials specified in the final design, rather than constructed as a block model. The final prototype shell was produced from laid-up glass fibre around a bought-in helmet foundation.

…it had to be wearable and it had to be an actual helmet you could see. You know, it wasn't going to be a solid thing that weighed two tonnes on your head, or you couldn't put it on because it had three inches of wood stuck through it. So you know, it had to be almost a production prototype.

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Figure 50: Aaron's presentation model skydiving helmet

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Zachary's attention to materials and processes (findings from the post-diary interview)

The timing and sequence of attention

The development of product form was the priority for Zachary: "...definitely the materials selection of it came second. Only at the end did I really think 'ahh, what can this be made out of?'." During the initial idea generation period and much of the subsequent
concept development, design ideas were developed without purposeful regard for materials or processes.

The level of detail reached
Zachary considered materials and processes to be one of the least fun elements of industrial design. He stated that he liked to concentrate on the form of the product. Zachary felt also that his materials and manufacturing knowledge was lacking, and that it therefore did not feature strongly in the project. There was no evidence in Zachary's designing that his final proposal was detailed for potential manufacture and assembly (i.e., described in 'part' and 'general assembly' engineering drawings). Production of such drawings is recommended for final year projects.

Constraints
Limitations for form creation
Whilst developing ideas for the shape of the outside shell of the helmet, Zachary was anticipating that the component would be manufactured as a single plastic moulding (Figure 51).

Figure 51: Ideas for the shape of the main shell of the helmet
To achieve the desired shape for the camera pod bracket, it was suggested that the component would be formed from stamped or machined metal. The pod itself would also be manufactured from metal.

Erm, it would be cut and you know... I'm not totally sure on the manufacturing processes, but cut from a sheet and then folded. I imagine it would be pretty basic to make...

The client stipulated that the helmet should be a comfortable fit for people with different sized heads. Zachary proposed a bespoke assembly method to be employed at the time of purchasing a helmet to overcome difficulties of achieving a universal fit. The method is described in the transcript below.

Zachary: "I thought it would be... simpler to manufacture a one-sized outer shell (...) and then at the time of purchase (or you order it) [you would have your head measured to determine what quantity of foam would be needed to 'pad out' the space between the standard-sized outer shell and standard-sized inner straps and lining. The foam would then be fitted to the helmet to suit individual needs]. You'd go into the shop... and [the foam] would be glued in permanently."

Owain: "Did you have any idea how the foam might be manufactured?"

Zachary: "I know it is mass-manufactured in big sheets..."

Owain: "Is it malleable enough to sort of bend it to the curves you want?"

Zachary: "Yeah, yeah. A lot of [the foam pieces] would be just straight punched out, they're very straight..."

Product precedents
Zachary noted that other helmets, comparable to those used by skydivers, were manufactured from glass reinforced plastic. This material was chosen for the helmet shell because it was relatively easy to process.

The use of information
Client
The client provided information on the relative impact resistance of different materials used in helmets.

Designed artefacts and the wider world
Zachary's idea for a foamed inner component to fit around the face was an idea borrowed from the design of cycling helmets. Other already-produced helmets were referred to as sources of information:
• a forerunner Kevlar helmet from the client company was examined and evaluated;
• reference was made to 3mm thick glass fibre used in climbing helmets (from which a conclusion was drawn that 3mm thick material would be suitable for the skydiving helmet);
• the primary colours of existing skydiving equipment were stated as an influence on Zachary's ideas for the helmet colour.

Printed sources
Materials lecture notes were used towards the end of the project to confirm materials choices.

Knowledge and values
Something of how Zachary knew about materials and processes was revealed in the interview, although given his other statements over paying little attention to manufacturing, this looks to be a reflexive comment.

... I suppose, it's always in the back [of your mind]. I don't really like sit down and think directly about it, but you have ideas in your head, even if you don't write them down or investigate them at all.

Attention to expressive qualities of materials and processes
Zachary wanted the outside shell of the helmet to have a highly polished, coloured surface (Figure 51), although it was not stated how this would be achieved.

Attention to utilitarian properties of materials and processes
Utilitarian material choices for the visor were driven by the semantics of utility (e.g., perceived to be strong) rather than establishing that preferred materials were indeed strong.

...I chose to have [the visor manufactured from a hard material] because when we had a meeting with the client, he was saying that the top world guy, what's really cool about him is he wears a visor which pulls down. A hard one, almost like a motorbike helmet, and that's really tricky to [use]. You look good, but no-one else can do it, wear it, because you can't really see out of them very well. But it's 'the thing to wear'.

Semantic considerations were also a factor in materials choices for the camera pod. One of the questions Zachary was asked at his presentation examination was 'why didn't he make the shell and the camera bracket / protection system out of the same material, to
create a more coherent product form?’. His response is quoted below. The final presentation model of the helmet is shown in Figure 52.

It was one thing I didn't look at because it didn't cross my mind. I thought of it as two completely separate bodies [a helmet and a camera pod]. It didn't really matter if they were of the same material or not. And I wanted metal around the camera, so it was actually stronger [than the helmet]. Even though the helmet was strong, I wanted [the camera pod] to look like it was stronger. I just wouldn't be happy sticking the camera in just a mould on the side of the helmet.

Utilitarian functions of materials and processes were important considerations for many of the individual components of the helmet. Like Aaron, Zachary anticipated the circumstances in which a product component would need to perform and, from his conclusions, decided upon a suitable material for that component.

- The outside shell needed to have high impact resistance and a hard surface (as well as be perceived as highly impact resistant). An initial idea that the helmet could be constructed in a similar manner to a cycling helmet (a compact foam structure bonded to vacuum-formed plastic) was dismissed because Zachary did not envisage such a construction to be "strong enough to be bashed around continually".
- The internal padding needed to be composed of a soft, impact absorbent material to protect the skydiver's head. Foamed plastic was decided as suitable for this purpose. For comfort, low density material could be used for areas in direct contact with the face and for protection; higher density material could be used for impact-prone areas.
- The inner lining, to tighten the helmet, was specified as nylon strapping (Figure 53). Elastic material was considered as a means of keeping the helmet tight once it was fitted.
- The camera pod mounting bracket and the pod itself were designed for manufacture from metals "...because it's stronger, to protect [the camera that will fit inside]." The component needed to withstand forces due to the wind but water resistance was not important because skydiving was generally not performed in the wet. Aluminium was favoured for the pod material on the grounds of comfort (its low weight would lessen any discomfort or imbalance to the helmet). For the section of the pod where the camera lens protruded, a steel frame was proposed since, unlike aluminium, this would not bend (Figure 54). Inside the camera pod, the same low density foam as used in the face padding would be used to prevent metal-on-metal friction damage to the
camera by maintaining a "tight fit" between the pod wall and the housed camera.

Figure 52: Zachary's presentation model skydiving helmet
Figure 53: Nylon strap configuration

Figure 54: Sketch of a protective steel frame around the protruding camera lens
Cognitive modelling

Zachary specified that the visor would be manufactured from "sunglasses material". This provided a glimpse that materials were pictured in Zachary's 'mind's eye' as already-produced material forms.
CHAPTER TEN

The diary of designing: an appraisal

Introduction
This chapter provides an evaluation of the diary of designing as an instrument for collecting data on design activity. It also contains recommendations for the structure of future diary studies of designing, along with a number of recommended avenues of enquiry that stem directly from the findings of this current research. Readers are referred back to Chapter Five for preliminary comments on the opportunities and limitations of the diary method of data collection.

The effectiveness of the end-of-the-day diary of designing
The diary of designing has been a highly effective data collection instrument for recording the author's designing over several years of work. It has been demonstrated to be a feasible, systematic and methodical data collection instrument for a longitudinal study of designing. The tracing sheet format was especially successful towards explaining the motivations and origins behind design work externalised in 2D media. Attention to materials and manufacturing processes has been successfully documented and the collected data have been useable in forming both macroscopic and microscopic descriptions of design activity. Both descriptive and philosophical comments were contained in diary entries. Constraints that operated on the designing have been revealed and the uses of different kinds of information and knowledge have been tracked. The dynamics of decision-making and the functions and structure of cognitive modelling have also been revealed by the diary.

A couple of limitations of the diary method were revealed during the analysis of the author's diary of designing. First, the diary is not a real-time recording method and, as such, cannot be used to record a designer's skill, connoisseurship, know-how, intuitive decision-making and precise trains of thought. All of these can be identified only in some
practical response or action, for instance by making a protocol analysis study of designing. In this respect, the diary should be seen as a data collection instrument that complements, and does not replace, established techniques. The second observed limitation concerned differences between entries made early and later on during the guitar project. Later entries were generally more detailed and revealing. Such improvement in the 'quality' of entries is something to be expected as one becomes more of an expert diarist.

In contrast to the author's efforts, the two undergraduate diarists were unable to commit to diary-writing. Of the small number of entries that the students made, most read more like a description of product specifications than accounts of reasoning. Nonetheless, the accounts of designing given in the post-diary interviews did correspond to those provided in the diaries. In their interviews, the undergraduate diarists gave a number of reasons for their unease with the diary.

- The writing of entries was not treated as a high priority. Other (assessed) project work took precedence and, consequently, commitment to the diary slipped.
- In practice, diary-writing was found to be time consuming and rather tedious.
- Despite memorising the diary instructions, it was still difficult to decide what to write. (Some re-design of the pre-formatted stationary might help to rectify this: perhaps by including a larger number of 'questionnaire' sections to fill in.)
- The diary works against one's natural inclinations by asking for accounts of designing to be given that are (to one's own mind) substandard, misdirected or, in Zachary's case, simply not engaging.

The effectiveness of the diary as an instrument for studying other people's designing has not been demonstrated. However, a number of methodological problems have been usefully raised by the two undergraduates' attempts at diary-writing. It can be asserted that the effectiveness of the instrument hinges on two key requirements: (a) commitment to regular writing (once participation has been agreed); and (b) skill to report on pertinent issues. The author's relative ease with diary-writing might be explained by having been (a) the developer of the diary method and (b) submerged in the subjects of materials and processes for several years. Over the length of the research programme, the author effectively became an expert user. Without this background, a diarist might always find it difficult to commit to diary-writing. Further trials are required to determine this. To develop skill at reporting on pertinent issues, it is envisaged that diarists will need to attend a well-structured briefing session prior to being asked to complete a full diary of
designing. A recommended procedure for future diary studies is described towards the end of this chapter. Further empirical studies are needed to establish the wider effectiveness of the diary as a data collection instrument.

Diary-writing in practice: a personal reflection

During the author's design project, the different formats of diary stationary were used in the following rank order.

- 47% of days involved use of only the 'standard' stationary.
- 44% of days involved use of only the 'no detailed entry' stationary.
- 9% of days involved use of the 'tracing sheet' stationary.

Although the 'tracing sheet' was relatively little used, it proved to be a very convenient way of describing the thinking behind work in 2D media. The time required to make a diary entry varied from around forty-five minutes for the few very intensive days to around ten seconds for days when the 'no detailed entry' sheet was used. Having completed and analysed a diary, a number of points regarding its use are worth noting.

- Some early teething problems were experienced with the diary: off-topic entries and detailed entries in spaces where only a summary was required.
- Commitment to the diary for over two and a half years was a strain. The diary was not born of affection and consequently it became something of a chore towards its completion.
- Diary-writing benefited from the use of a quiet area with no interruptions.
- Some of the analysis was in a way quite painful. The process was a stark reminder of just how much time was spent on the guitar project and it also alerted oneself to how things could, with hindsight, have been handled much better. It was tempting to criticise and pull apart the designing as it stood documented in the diary, but this had to be strongly resisted.

Effects on the authenticity of the spotlighted designing owing to the requirements of the diary

Overall, the effects of diary-writing (and of simultaneous academic study) appeared to be positive. The author found that the process of diary-writing (or more precisely, the process of reflection inherent in diary-writing) eased the grasping and comprehension of design issues, thereby aiding further decision-making (a phenomenon described by Schön
\& Wiggins [1992:155]). At no time did the diary-writing impinge on, or appear to hinder, the flow of the design work. On a few occasions, the prospect of design activity rich with attention to materials and processes fuelled an excitement that strong entries would be written. Both of the undergraduates who attempted diary-writing stated that, had they persevered, they envisaged the process of reflection would have brought benefits to their designing.

**Recommended foci for future research**

Notionally any element of industrial designers' activities can be studied with the diary method (with the acknowledged limitation that episodes of designing drawing upon tacit knowing cannot be reported with precision). The diary also has potential for use in other areas of the design field. By assembling the results of naturalistic, longitudinal studies on a number of elements of industrial designers' work, a broad view of work from designers' perspectives could be constructed. Although the strength of the diary is in its suitability for long-term design studies, this does not exclude its use for short design exercises. This current research has identified a number of key areas of industrial design activity where further research effort, using the diary method of data collection, could provide greater weight to the body of knowledge that describes how designers think.

- **Cognitive modelling.** Are the functions and structure of cognitive modelling as identified in this thesis shared among designers? In what ways is cognitive modelling used differently? Do different styles of pen-on-paper markings (and different kinds of 3D modelling) bring the same cognitive modelling benefits for different designers? How valid is the description that cognitive modelling of product manufacture and assembly involves the comparison of juxtaposed images of (a) desired product forms and (b) forms known to be achievable?

- **Information use and knowledge derivation.** What information sources are used in relation to other elements of designers' work? How is that information used? What formats of information are conducive to industrial designers' cognitive modelling?

- **Design synthesis.** How do designers tackle and achieve design synthesis? What is the role of intuitive (rather than analytical) decision-making in achieving synthesis?
Securing participants for future diary studies

The discipline of diary recording is considerable, and no one would do it if they didn't feel they had to.
[Brett, 1987:xi]

The quotation from Brett summarises the main operational difficulty with the diary, as compared to interviews or other short-term data collection methods. It requires commitment of time and personal dedication and, without the lure of an incentive or a track record in collaborative research, designers are not likely to agree to participate. The prospect of advancing design research is, in itself, not seen by this researcher as a sufficiently strong incentive. In the next few paragraphs, suggestions are made for how to overcome the problems of securing designers' agreements to participate.

The researcher as a diarist
Assuming that one's design skills are considered suitable for scrutiny in a research programme, an option is to make oneself a diarist. This way, attracting participants is, by definition, not an issue and the benefits of incorporating a practical element into a research programme can be realised. One will be committed to the task of diary-writing because the generation of data will form an essential element of one's final thesis submission. However, the author experienced several problems with the incorporation of a practical element into a Ph.D. programme. Using oneself as a diarist requires a balance between academic study and the practical activities that generate data. The difficulty of achieving this balance should not be underestimated. In the author's case, the design work became stretched out very thinly over two and a half years in order to accommodate, in parallel, other necessary work for the Ph.D. programme. With the design work persisting over such a long period, two negative effects were experienced. First, the project (and, hence, the diary-writing) came close to becoming a chore by the end. Second, with weeks (and sometimes months) spent away from the design project, details of the project were often not fresh in the mind. It was necessary to repeatedly remind oneself of the work covered and of the work needing to be done. The slow progress of the designing was at times very disheartening.

With hindsight, the most obvious way to overcome these problems is to avoid spreading the design work across the duration of the research programme. For future research projects it is therefore recommended that a period of time be set aside to work only on the practical element (maybe eight months of a three year research programme). Concentrations of academic work would need to precede and follow that period. Within eight months of sustained design work, it should be possible to complete a challenging
design project which is modest in scope but genuine in nature. This should also be sufficient time to produce a presentation model or a working prototype. As a methodological point, it might also be a good approach to be ignorant of the exact longitudinal design exercise that will be set, leaving it to a research supervisor to secure or decide upon a small portfolio of suitable projects (within a general area of interest). With this approach, design ideas would not be generated before data collection methods were in place.

**Undergraduates as diarists**

Undergraduates might be motivated to participate in a diary study under two circumstances. First, if diary-writing were set as an additional requirement of a compulsory project (i.e., if it formed an essential part of an assessed piece of coursework). Second, if a financial incentive were offered to work on a diary study outside of term time. For the latter, the design brief might relate to work that would be of direct benefit to the research institution. One pressing limitation of using undergraduates as research subjects is that they are still in training. They may not yet have developed (or needed to develop) design processes which lead to manufacturable products (as was indicated by Zachary in his post-diary interview). This state of affairs might increase the likelihood of reflexive diary-writing, where diarists adjust their normal work practices in order to be 'seen in a good light'.

**Practising designers as diarists**

The participation of professional design consultants is more likely to be secured if the design work is conducted on the same terms as the typical commissioned work. That is to say, with a negotiated brief, timeplan, 'deliverables' and a fee (rather than design work which stems from existing commissions, which are, in any event, likely to be confidential). This approach could prove expensive if a number of different designers were to be studied, so a modest design project (perhaps lasting no more than two weeks) should be considered. The choice of project would depend in part on the number of phases of designing that are to be studied. For instance, a new chair design might be taken from a brief to a detailed design in just two weeks, but this may not be sufficient time to complete the concept development of a new laptop computer. As recommended for future undergraduate diary studies, the chosen brief might be one for which the outcomes are directly useful to the research institution. If studies of in-house practices are to be made, these must be (by definition) in relation to a firm's new product programme. This programme is likely to be highly confidential and, as such, will make agreement to participate in a study especially difficult to secure.
A recommended procedure for future naturalistic, longitudinal diary studies

The following ten-stage 'good practice' procedure is based on the author's substantive involvement with the diary and the comments of the two undergraduates who attempted diary-writing. The basic sequence of the procedure is: (i) a period of pre-diary administration; (ii) the carrying-out of the diary study; and (iii) the conducting of post-diary interviews and data analysis.

Stage 1: The subject matter
 Limit and define the subject(s) that are to be investigated. This process will involve a thorough literature review to identify weaknesses in current knowledge and understanding. The subject(s) will need to be easily comprehended by the participants so as to ease diary-writing.

Stage 2: The participants and the diary format
 Decide upon the group of participants that will take part in the research and seek their participation: students, practising designers or oneself? Will it be solo or team designing? How many individual studies will be made? When seeking agreements to participate, provide clear information on the purposes of the diary, how it is produced and its significance to the research project. Once agreements have been secured, obtain copies of the participants' C.V.s and find out what media the participants normally use to externalise their thinking (e.g., A2 marker pad, A5 spiral ring pad or work directly onto a computer). From this information, design and produce a suitable diary format. Depending on work practices and available facilities, the diary may be wholly paper-based, wholly computer-based or a combination of both.

Stage 3: The project
 Decide upon the design project that the participants will work on. If detailed cross-case comparisons are to be made, it is recommended that all the participants work towards the same brief. Negotiate with the participants the kinds of 'deliverables' that will be expected at the end of the design work (e.g., a report, foam models, presentation models, working prototypes) and the time scale for producing these. The completed diary and copies of any material to which entries refer (e.g., sketch sheets, models) will obviously form one of the end requirements of the design project. Projects that are not subject to confidentiality agreements are preferred, since results can be published without having to disguise sensitive data. The participants could be granted anonymity if they so wished.
Stage 4: The briefing and the trial runs

It is anticipated that with a full day's briefing, including involvement with several trial run design exercises, the participants will become sufficiently accustomed to the diary method to be ready for the full design project. At the briefing it will be necessary to present example entries (based on the specialised subject under study) and to discuss the following points.

- The necessary procedure for writing an end-of-the-day diary.
- The need to make entries as intelligible, clear and precise as possible.
- The need to pay special attention to describing work in the same sequence that it was covered; to this end encourage 'bullet point' accounts of designing.
- That participants' entries will not be scrutinised for 'good' or 'bad' practice; the aim of the exercise is that participants simply give an honest account of their practice.

Accounts of designing that refer to thinking that would otherwise be left hidden should be encouraged. The main focus of the diary should be on describing what the day's designing has involved, not on what tomorrow's designing might involve. The exceptions are philosophical accounts of designing that reveal long-term intentions (e.g., 'my approach to this phase of work is now to...'). Such descriptions are useful for constructing a macroscopic view of design activity.

By the end of the briefing, it is most important that the participants fully understand what is expected of them and that they are happy with the general technique of diary-writing. The participants should be handed clear written instructions covering all the salient points of the briefing.

Stage 5: Production of the diary

Production of the diary of designing should commence on a day negotiated with the participants. It may be helpful to stagger multiple studies, in order not to become overburdened with administration. It is essential that, whilst the participants are involved in diary-writing, regular contact is maintained to rectify practical problems and provide advice. This stage of a diary study requires exemplary administration: a case in point is the two undergraduates described in this thesis who, even though they had not fully understood what was involved in the diary-writing, did not ask for clarification or advice.
Stage 6: Creation of an archive
When the diary is complete, collect all the paperwork, models and (if appropriate) software and store these as an archive. Take photographs of 2D and 3D design work as required.

Stage 7: An initial review
Make an assessment of the diary content and note down any points that need clarifying or expanding upon in the post-diary interview.

Stage 8: The post-diary interview
Use a semi-structured interview technique so that the participants can clarify and expand upon any points in the diary and explain the use of any jargon or odd uses of words. Use the same interview to record the participants’ opinions of the diary and their reflections on what it is like to be a diarist. In the case of the researcher also being the diarist, a personal review of the designing and of the diary entries acts as a suitable substitute for a post-diary interview (which in effect becomes self-administered). In the author’s experience, hindsight was valuable on a number of occasions during the data analysis.

Stage 9: Analysis
Undertake the main analyses of the data.

Stage 10: Dissemination
Make copies of the findings available to all the participants.

Uses of the diary beyond research
Although procedural knowledge is central to a designer’s work, it is rarely (if ever) recorded for passing on to a client as part of a proposal package. The process that leads to the achievement of a final proposal might be jealously protected (perhaps legally) by a design firm. This may not be the case in the future, however. A key observation made by Gibbons et al. [1994] is that knowledge is increasingly a currency of business. A future in NPD can be imagined in which, for instance, knowledge of how to design a product forms an integral part of a proposal package. The client will receive not only a product proposal but also a map of the key data, considerations, activities, decisions and rejections that were involved in the proposal’s conception and development. This transfer of knowledge from a design consultancy to its client, enabling the client to understand and therefore act upon the design of its products, might form a new measure of high
quality design consultancy. A similar treatment of procedural knowledge was discussed in Marsh's thesis [1997]. Marsh was concerned with design firms' aspirations to retain their 'corporate expertise' after the departure of expert staff.

For any transfer of knowledge to be possible, design decision-making needs to be recorded in some way. The diary of designing may be one way of achieving a suitably accurate archive of how designing progresses, from which critical procedural knowledge can be drawn. For a design firm, such an archive can be consulted as the needs of future design projects dictate. At the IDEO design consultancy, a computer database of information, activities and decisions from past design projects (referred to as IDEO-University) exists as a resource for subsequent design projects [Stoddard, 1997]. A computer programme for documenting critical design rationale in engineering is now commercially available [Brice & Johns, 1998].

Other potential uses of the diary of designing can be identified. Diary-writing was found (and anticipated to be) of benefit to design activity because the process of reflection that it involves helps to clarify design considerations. The writing of diaries might therefore benefit the everyday practices of students and practitioners of design, and entries could also form the starting point of intriguing discussions on design and designing. A diary might also be used to form an archive to counter any claims of negligence arising from harm caused by a company's product, by showing that due attention was given to health and safety issues.
SECTION FOUR

Conclusions, discussion and recommendations
CHAPTER ELEVEN

Conclusions from the macroscopic and microscopic analyses

Introduction
This final chapter contains conclusions on industrial designers' attention to materials and manufacturing processes. The findings from the interviews with professional designers are compared with those from the author's diary of designing and those from the post-diary interviews with the two finalist undergraduates. Similarities, disparities and unique features are highlighted in the text. Where the name of one of the interviewed companies appears in square brackets [e.g., Nokia], this refers to a finding that was specific to that company. Numbers in square brackets [e.g., 25] refer to detailed diary entries made during the author's guitar project. The chapter is split into three separate Parts, as below, corresponding to the chief research questions of the enquiry.

• In Part A, discussion is focused on attention at a macroscopic level, opening with conclusions on the role and significance of materials and manufacturing processes in industrial designers' decision-making. A diagrammatic guide to good practice is presented.
• In Part B, discussion is focused on attention at a microscopic level, ending with conclusions on what constitutes industrial designers' 'distinct way' of expressing and generating materials and processes knowledge and values. Statements are made on designers' uses of resources and cognitive modelling.
• In Part C, implications of the conclusions for industrial design education and providers of design information are discussed.
The role and significance of materials and manufacturing processes in industrial designers' decision-making

All of the interviewed professional designers were plainly concerned with the external form of their product proposals. However, none of the interviewees was involved in purely expressive 'visual form' exercises and none were involved solely with imaginative idea generation. To be so would to be far removed from the commercial pressures of NPD and the need to deliver to a client a manufacturable product proposal. All of the interviewees, working in-house or at consultancies, were involved with devising manufacturable product proposals (since nearly all designs were destined to be put into production). All stressed the fundamental importance of due consideration of product manufacture. It was abundantly clear that there was no place in professional practice for designing a product that could not be manufactured or that did not take into account the very real and varied constraints of manufacture. Due consideration of manufacture, it was agreed, was the key to achieving a final production item with a form exactly as intended. Without due consideration, the form of a product can be expected to undergo unfavourable modification in later phases of NPD, in order to accommodate the working constraints of an end manufacturing process.

Materials and processes can be considered the very fabric of designers' creations: products are made, literally, from processed material forms. From the industrial designer's perspective, combinations of materials and processes are used to: (a) convey (express) messages about a product to its user, for example as an opportunity to "...add some spirit to [a] design" [Mark Delaney, Samsung]; and (b) meet utilitarian requirements. Surface finishes, as the top layer of a product, are of great concern to industrial designers. Combinations of materials and processes give a certain finish and it was stated in the interviews that this is increasingly important in the marketing of a product, rather than the concept behind the product [Nokia; Samsung]. In a recent article in Design Week, Josh Morenstein of the German Frog Design consultancy is quoted as saying that the combining of materials will be a major feature in future product design,

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44 Under some circumstances, speculative ('future-looking') design work was not destined for manufacture.
especially where intriguing contrasts and tactile properties of materials can be exploited [Sweet, 1999:16].

In the finalist undergraduates' work, materials and processes were treated more as outlying concerns. The students involved themselves predominantly, though not exclusively, with visual-form exercises (i.e., styling) and did not integrate the details of manufacture into their design proposals. One of the students, Zachary, seemed to be a little preoccupied with perceptions of processed materials rather than demonstrable utility (i.e., a manufactured form looking as though it will provide protection rather than establishing that it will indeed do so). The same student stated that he did not take great account of materials and processes because he did not find it fun.

In the author's diary of designing, attention to materials and processes was shown to be a common element throughout the guitar project, with the exception of a period set aside during concept development to explore ideas for product form and features. Two major differences of the students' and the author's design work, as compared to that of the professional designers, could be identified. First, the constraints of designing to a production budget were absent. With the author's project, costs were prototype-led rather than production-led (the designing was not directed towards a production item). Awareness of high manufacturing costs was demonstrated, however. Second, the work was a solo effort rather than as part of a NPD team; the scope of the work that could be reasonably covered was much less than for a team with diverse expertise. Detailed DFMA considerations were beyond both the undergraduates' and the author's capabilities.

Industrial designers' recommendations for a manufacturing route are shaped by very real and pressing constraints. However, materials and processes also provide many opportunities for the designer. Johan Santer, the Director of Industrial Design at Kenwood, made a comment that industrial designers balance a greater number of diverse product considerations compared to any other NPD team member. Although the comparison cannot be substantiated by this current research, the diversity and complexity of industrial designers' decision-making has certainly been revealed. Figure 55 summarises the key factors in industrial designers' decisions on product materials and manufacture. The Figure is essentially descriptive rather than prescriptive. It is presented so as not to dictate procedure (as with a flow diagram) but, rather, to assemble for the first time the wide ranging considerations that industrial designers synthesise. Within the framework shown in Figure 55, attention can, in effect, be as simple or as complex as the designer has opportunity to make it. For some design projects, material choices can be very straightforward. For example, many new components at Flymo are manufactured from ABS in order to use large stocks of a material with a proven track record. For other projects, choices of a manufacturing route can be much more open. In the case of a
product undergoing a full overhaul at a consultancy, it would be prudent to pay attention to all of the considerations outlined in Figure 55.

Figure 55: Key factors in industrial designers' decisions on product materials and manufacture

The remainder of Part A of this chapter contains detailed conclusions on the following subjects.

- Creativity and synthesis with respect to materials and processes.
- Functions that industrial designers desire materials and processes to satisfy.
The timing and sequence of attention and the ultimate level of detail reached.

Speculative product design.

Constraints and the range of materials and processes that are able to be specified.

'Green issues' in practice.

Opportunities offered to industrial designers.

Creativity and synthesis with respect to materials and processes

At the heart of industrial designers' consideration of materials and processes lies an important distinction between imagination and creativity. Professional designers' creative attention to materials and processes was stated as hinging on due consideration of practical constraints, not just opportunities. Purposeful avoidance of constraints may well leave one's imagination free but, ultimately, this approach will not lead to an appropriately manufacturable product proposal. The consensus amongst professional designers was that constraints form the arena within which to be creative. To design 'free of constraints' is relevant only during initial idea generation (as in the process of, for example, 'brainstorming'), and only then if time is available (which it usually is not). To overcome problems of time, two of the interviewed designers recommended that project briefs are requested to be made available ahead of the work commencement date, so that design ideas can be contemplated during spare moments of time outside of paid work [Dartnall Design Associates; Samsung]. At Samsung, creativity will often manifest as small changes in design rather than radical changes, simply because the costs of implementing the latter are often too high.

For industrial designers, the challenge of design synthesis with respect to materials and processes appears strongly to be between, on the one hand, generation of exciting ideas (pushing the frontiers of design) and, on the other, ease of manufacture within a budget. Within this is the union of product expression and utility (for a product to appeal to the senses whilst also meeting performance criteria). Achievement of synthesis requires skill and is not easy. Chris Forecast of Grey Matter commented that this skill comes with time, but just how synthesis occurs was not made clear in the interviews. Pointers were given to underlying tacit knowing and to intuitive decision-making, which would explain the designers' difficulties of describing how synthesis occurs. Various comments were made.

The determination of an appropriate manufacturing route is achieved not particularly consciously; it is done 'automatically'. [Johnson Haigh Rogers]
Selection is often "obvious". [Pentagram]

Synthesis involves a "mysterious assessment" of multiple requirements; how one achieves synthesis is "...the million dollar question." [Pentagram]

One gets to know instinctively, whatever product one is designing, the material that will be selected for its manufacture. [Flymo]

After on-the-job experience, it is difficult to propose designs that cannot be made. [Samsung]

Quite how designers tackle and achieve design synthesis, and the embedded role of intuitive and analytical decision-making, are subjects that a future diary study of designing could seek to address.

Functions that industrial designers desire processed materials to satisfy

Expressive functions

Properties of materials and processes are used by industrial designers to entertain people's senses and, in so doing, contribute to the desirability of a product. Processed material forms are chosen not just for their utilitarian functions but to stimulate people's thoughts and provoke responses too, such as associations, perceptions, aspirations, emotions and a sense of quality (i.e., elements of product semantics). This was underlined by Tim Brown of the London IDEO consultancy in a recent Design Week article. He believes that "...materials are an integral part of a product's character and in part suggest how we might respond to it." [Sweet, op. cit.:16] Although all five human senses may be stimulated by a product or its constituent components, it was visual and tactile properties of processed materials that were prevalent amongst the concerns of the studied designers. Smell and taste were at no time mentioned. Sound was of course a concern in the author's guitar project, but this was from a utilitarian perspective (the guitar could not perform its most basic function if it did not produce a musical tone).

Sight

Design for appearances. For example: reflectivity of light; interaction of colour, pattern and graphics; aesthetics of component joints; visibly high quality manufacture.
Touch
Design for tactile experiences. For example: pronounced textured patterns; subtle textures; friction; smoothness; temperature; hardness; elasticity; plasticity; weight; solidity of assembly.

Sound
Design for audible experiences. For example: non-creaky assemblies; sounds that are agreeable if a component is tapped or knocked.

Smell
Use aromatic materials to stimulate people's reactions.

Taste
Design for a pleasant or foul experience if a product is supposed (or likely) to be placed in the mouth.

Utilitarian functions
Industrial designers' choices for materials and processes are led in part by whether or not a given manufacturing route will satisfy utilitarian functions of a product component. Such functions vary widely between products. Examples of utilitarian function include: transparency for reading the fill level of a jug kettle; elasticity for comfortable handles; an ability to be wiped clean for hygiene; and an ability to perform under testing conditions, such as low rigidity at low temperatures, high torsional strength, wear resistance and impact resistance. For the author's guitar project, two pressing utilitarian functions were for the instrument to have a good sound and to be mechanically stable (i.e., withstand the force of tensioned strings). For the undergraduates' skydiving helmet, the pressing concern was protection of both the skydiver's head and the camera mounted on the helmet.

Constraints
In proposing a manufacturing route that satisfies the desired expressive and utilitarian functions of a product, a designer will take account of a number of important practical constraints. If these constraints are not given due consideration then it is probable that, at some point later in NPD, design work already covered will need to be modified or even aborted. All of the practical constraints that arose from the empirical studies of this research are now presented in alphabetical order.
Availability of materials and manufacturing processes
What is the client's (or firm's) current manufacturing base? Are preferred materials and preferred suppliers used? Do stocks of material need to be used? Is diversity possible and acceptable?

Budget
Costs were a dominant concern for the interviewed professional designers. Choices of materials and processes need to result in a product that falls within an acceptable price bracket. Under some circumstances, a project budget will be so tight that opting for a slightly more expensive polymer blend will incur unacceptable additional costs. Under other circumstances, increased costs can be absorbed by increasing the price of the product to the consumer. Careful use of marketing will probably accompany the latter.

Corporate identity
The colour scheme a company uses for its products is a major part of its corporate identity. Are candidate materials compatible with that colour scheme?

Design brief and the client
Materials and processes choices ultimately need to satisfy the design brief and the client; different briefs afford different scope for materials and processes choices. With the author's guitar project, all sound-generating parts needed to be designed in polymers.

Detail preferences of the toolmaker/manufacturer
A toolmaker or manufacturer may prefer to have products detailed in one way rather than another because of past experiences. With injection moulded components, for example, are side-action mould cores acceptable? For consultancy work, contact with a range of toolmakers and manufacturers was recommended so that different design details could be competently handled [Johnson Haigh Rogers].

Directives from in-house marketing departments
An in-house marketing department might direct the use of graphics and logos incorporated onto, or into, the external surfaces of new product components [Flymo].

Health and safety
General health and safety issues in product design can be addressed through choices of processed materials. For example, is a desired form hygienic? Can it be easily wiped clean and is it devoid of places for debris to collect? Are candidate materials and finishes

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non-toxic? Are any large glass surfaces strengthened? At Kenwood, product components that come into contact with food are required to be manufactured from 'food grade' materials.

Limitations for form creation
Can a given manufacturing route be used to achieve a desired component form? Is the size of a desired form too big for a given process? Can a desired component form assemble to neighbouring components without restrictions? Can finishing techniques be used without damage to underlying materials? Combinations of industrial materials, manufacturing and finishing processes are the means to achieving a desired component form, comprising the following features.

- Overall external shape
- External surface details (e.g., pronounced holes, ridges, grooves and patterns; subtle surface finishes)
- Internal surface details (e.g., wall thickness, stiffening and assembly webs)

Particular attention needs to be paid to the details of manufacture\(^4\), since manufacturing processes have important limitations that affect product design. A two millimetre thick, grade A medium tempered aluminium alloy sheet, for example, is recommended to be cold formed to a right angle with a minimum bend radius of one or two times the sheet thickness [Bralla, 1986:2.45]. With injection moulding, the maximum size of a component may be restricted by the capacity of available processing equipment. Injection moulded parts need to be designed so that inherent features of the injection moulding process (e.g., injection point scars, weld lines (along mould tool core joints) and ejector pin marks) do not interfere with critical visual and tactile regions of a component's form. Draw angles need to be incorporated into a component to ensure that, in production, the component easily releases from its mould. The implications of internal webbing for causing sink marks on a component's external surface need to be addressed. The use of a specific manufacturing or finishing process may be restricted because of problems of, for example, realising design details, bi-metallic corrosion or embrittlement of plastics due to contact with adhesive solvents. In this way, choices of materials and processes have direct implications for the assembly of a product.

\(^4\) The precise level of detail that industrial designers are involved with differs between firms. This point will be discussed later.
New technology
Are the latest developments in materials and processes technology, although offering benefits, currently too expensive to adopt?

Problems with mixed materials
It is notoriously difficult to match surface colour and texture across different materials. Material ageing and ambient lighting conditions can amplify differences. Where materials differ in a product, consider contrasts in surface finishes rather than similarities [BIB].

Product precedents
A product intended for a competitive marketplace must compete. A common approach to ensuring competitiveness is to use the same kinds of materials and processes employed in competitor products. In this way, precedents within a given 'product group' (e.g., kettles, digital cameras, desk lamps) can serve as a powerful limit on choices of materials and processes. Use of materials and processes different to those in product precedents is likely to increase, rather than lower, production costs.

Volume-cost relationship
The anticipated volume of production and target cost of a new product are closely interrelated and have implications for the suitability of different manufacturing routes. Some automated processes are generally too expensive for low volume production runs (e.g., the high tooling costs associated with injection moulding) but are quick and therefore suited to mass manufacture, where costs can be recovered by selling a product in bulk. A product with a very high prospective selling price but a low volume production run can equally be suited for automated manufacture. With low production runs, manual production techniques are logistically possible but can be expensive because of high labour costs.

Opportunities open to industrial designers
Despite the pressing constraints just listed, industrial designers do have opportunities to suggest the use of materials and processes that are unusual and against current trends and product precedents (and, therefore, inclusive of some added risk). Central to this, however, is a parallel activity to provide convincing arguments of the benefits of adopting the unusual manufacturing route. For example, the additional costs of implementing chrome-plated components for a new product might be offset by a net strengthening of a
company's long-term brand identity. What follows is a list of the opportunities that materials and processes afford the industrial designer, identified by the interviewees. The sections describing 'cosmetic details', 'fashions' and 'market differentiation' are closely interrelated.

**Advancement of design**

Materials and processes can be used to distinguish an innovative and exciting product from a mainstream and mundane product. Can alternative choices of materials and processes be identified that will improve the utility and expression of a product? Can the number of component parts in a product be reduced through use of alternative manufacturing routes? What can be learnt from the history of the product?

**Cosmetic details**

Textures, patterns, colours and creative uses of manufacturing technology can provide a product with a distinctive and attractive appearance. With injection moulded components, for example, surface textures and finishes can be added and mouldings can be assembled in such a way that they overlap, undercut and reappear (rather than simply butt-up). In the case of some Nokia mobile phones, users can adapt the cosmetics of the product to their own tastes by replacing injection moulded panels.

**Fashions**

Changes in fashion in product design (from both within and outside a given product group) serve to lessen the desirability of older product models in favour of those that embody new trends in expressive uses of materials and processes. This process of obsolescence works in favour of the manufacturer, enticing a steady stream of purchasers of new products. Johan Santer of Kenwood Design noted that fashions are less relevant for products that "...you live with, but [they do not] live with you", in contrast to personal items such as personal stereos, personal organisers, watches and clothes. Can fashions be forecast?

**Market differentiation**

Market differentiation is when a company strategically positions a new product so that it appeals more to one sector of the marketplace than another. The sector of the marketplace may be newly created or it may be well established and crowded with competitor products. Although market differentiation is often achieved by limiting or boosting a product's utilitarian function, expressive uses of materials and processes can also contribute. The semantics of a product can be used to help differentiate, for
example, 'entry level', 'sports' and 'flagship' products, as well as products destined for the Far East rather than the U.K. Thoughtful use of materials and processes, independent of market sectors, can provide a product with identity and, in turn, strengthen a company's brand image. The following examples show how expressive uses of materials and processes have contributed to the identity of products.

- Desktop G3 Power Macintoshes assembled with semi-transparent blue and white injection moulded cases, compared with light beige Intel-based P.C.s assembled with fabricated steel cases.
- Silver painted fabricated steel cases for Korg's 'Z', 'Trinity' and 'Triton' ranges of professional synthesisers, compared with dark grey injection-moulded cases in home keyboards.
- Pigmented, coloured polymer in the Ford Ka3 dashboard, compared with walnut veneer inserts in the Rover 200 dashboard.

**Miniaturisation**

With modern miniaturised electronics and electro-mechanics, designers have opportunities to package technologies in new and interesting ways through creative use of manufactured forms. Less material can be used, thereby reducing costs. Or, for the same overall cost, more exotic materials and finishes can be specified.

**New technology**

New materials and processes offer designers opportunity to re-think established designs and challenge precedents. Many of the interviewed professional designers stated the importance for an industrial designer to keep well informed on new advances in design and technology [BIB; Grey Matter; Kenwood; Nokia; Samsung]. It was conceded that keeping up-to-date was not easy. The following are examples of recent developments in injection moulding technology.

- 'Twin shot' moulding, in which a single component is formed from two different materials. The different materials often have quite different properties (e.g., stiffness, colour and texture) and provide different functions for different regions of a component. The process is good for simplifying assemblies and eliminating component joint lines.
• IMD (in-mould decoration), for which a decorative film is positioned around a mould cavity prior to the cavity being injected with molten plastic. The resultant injection moulded component contains an integral decorated surface finish. IMD may be used solely for expressive purposes but can equally serve to simplify an assembly and eliminate component joint lines. For example, a window for a liquid crystal display can be created by a combination of an appropriately designed film and a transparent polymer.

In a few cases, manufacturing companies have in-house research and development programmes focused on the identification and exploitation of new materials and manufacturing technology [Nokia; Samsung]. New technology was at the core of many of the product concepts in Philips' Vision of The Future projects [Philips, 1999].

Obsolescence/longevity
The anticipated life span and disposal of a product will suggest adoption of particular materials over others. In some circumstances, life spans can be planned to terminate through material failure. In other circumstances, any material degradation may be seen as detrimental to product quality.

Personal objectives and aspirations
Chris Forecast of Grey Matter described how one of his colleagues chose to satisfy personal objectives by attracting design briefs that would give rise to work in unusual materials.

Scope for capital expenditure
If a firm or client is prepared to make capital expenditure in new processing equipment, this widens the manufacturing options open to the designer.

'Green issues' in practice
'Green issues' were surprisingly not a large influence on the work of the interviewed professional designers. The exception was at Flymo, where as part of the Electrolux group, design for disassembly is a routine concern. A number of reasons were given for why serious attention to 'green issues' is currently not widespread.
• Cost is a central issue. To test and implement 'design for disassembly', 'design for recyclability' and to use recycled material adds time to NPD and this, in turn, increases costs. Regard for these 'green issues' may move overall costs beyond a level at which a product can remain competitive. 'Greener' product finishes are often unproven technologies and, as such, require thorough investigation before committing to them [Nokia].

• Regard for 'green issues' is generally reactive rather than proactive. If competitor manufacturers are not paying serious attention to the issues, and if consumers are not demanding 'greener' products, a high priority is then not set on addressing the issues. The general feeling among the interviewed designers was that, currently, proactive consideration of 'green issues' by manufacturers amounted to little more than a corporate gesture.

• It was stated that virgin material is cheaper to purchase than equivalent post-consumer recycled material. The unknown melt processing characteristics of post-consumer polymer was cited as a major reason for manufacturers' avoidance of such material [Dartnall Design Associates]. Johan Santer of Kenwood suspected that post-consumer recycled polymer would not qualify as a food grade material. No mention was made in the interviews of the use of post-consumer semi-finished recycled material (i.e., material pre-formed into boards, tubes and other shapes).

Despite this rather negative outline, 'green issues' are routinely addressed, but on a less pronounced scale.

• Widespread use is made of the SPI (Society of the Plastics Industry, U.S.A) recycling symbols to identify the precise polymers used in plastic components.

• Manufacturers commonly use a proportion of in-house re-ground waste polymer in their melt processing (e.g., from sub-standard mouldings and mould runners). To maintain the quality of final moulds, the proportion of re-ground material must not exceed a predetermined level.

• Designing for less (or minimal) use of material is expected of a good approach to design [BIB].

• Packaging designs are often 'greener' than consumer products because they contain higher quantities of post-consumer waste (e.g., card, plastic containers).
'Green issues' were not a major factor in the author's design project. Attention was limited to an acknowledgement that Forex-EPC material was recyclable and that, therefore, some components of the guitar had the potential to be recycled. The undergraduates made no mention of 'green issues' in either their diaries or their post-diary interviews.

The range of materials and processes that are able to be specified

Overall, industrial designers work mostly with plastics, occasionally with metals but rarely with other materials. Injection moulding dominates.

In-house

The variety of materials and processes that are able to be specified is limited primarily to those that the company has used in the past. This results overwhelmingly in relatively short lists of track-proven materials (mostly plastics) that are used for all new products. These lists include both commodity and more exotic plastics.

Consultancy

Consultancies are involved with a diverse range of design briefs and this necessarily results in the specification of a wide range of materials and processes. This can make consultancy work especially engaging but, at the same time, provide additional pressures of designing for unfamiliar materials.

The timing and sequence of attention and the ultimate level of detail reached

Industrial designers' attention to materials and processes can be tied to different phases of NPD, as in Table 12. The attention is evolutionary and spans across all phases of NPD, including testing and refinement (in contrast to Ulrich & Eppinger [1995:169], where industrial designers' inputs are shown to cease prior to production ramp-up). The ultimate level of detail to which designers are involved will be discussed shortly. Designers' progression through the phases is not wholly linear: decisions of detail are intertwined with general ideas, notably in cases where a novel design detail is proposed [Kenwood]. For this reason, Table 12 represents only a guide to industrial designers' practices in relation to materials and processes. In the author's project, manufacturing issues were most dominant during system-level design. For the undergraduates'
skydiving helmet project, a condition of further client support was for design ideas to be worked-up to a high level of feasibility early-on in concept development.

<table>
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<tr>
<th>IDEA GENERATION</th>
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<tbody>
<tr>
<td>The product image is established. [Grey Matter]</td>
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<tr>
<td>The merits of different materials are compared (e.g., plastics, metals) and outline ideas for manufacture are entertained.</td>
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<th>CONCEPT DEVELOPMENT</th>
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<tbody>
<tr>
<td>Basic manufacturability and assembly are determined.</td>
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<tr>
<td>The merits of different processes are compared (e.g., vacuum forming, injection moulding).</td>
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<tr>
<td>The need for side action injection mould tools is assessed.</td>
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<tr>
<td>Special requirements for materials (e.g., reinforcement, additives) are established.</td>
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<tr>
<td>For injection moulding, the general material (e.g., polystyrene) needs to be decided upon so that, in the next phase, tooling can be detailed with appropriate draft angles and compensation for shrinkage.</td>
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<th>SYSTEM-LEVEL DESIGN / DETAIL DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFMA. The chosen concept is refined so that it is suited to the needs of the chosen manufacturing and assembly routes.</td>
</tr>
<tr>
<td>Production details are added and tool design is undertaken.</td>
</tr>
</tbody>
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<tr>
<th>TESTING AND REFINEMENT / PRODUCTION RAMP-UP</th>
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<tbody>
<tr>
<td>Products are 'policed' to first production samples, to ensure that the product form is as intended (especially in cases where detail design has not been carried out by the industrial designer).</td>
</tr>
<tr>
<td>For injection moulding, the choice of precise material grade (e.g., percentage filler, melt viscosity) may be revised after the evaluation of first production samples.</td>
</tr>
</tbody>
</table>

Table 12: A guide to the general sequence of industrial designers' attention to materials and manufacturing processes
The interviewed professional designers were agreed that their attention to the constraints and opportunities of materials and processes was given from the outset of a project. This approach is in contrast to that of the author's designing, where there was a planned avoidance of materials and processes issues at the commencement of the guitar project. The avoidance was to concentrate on determining the features of the guitar and on how the instrument would look. Such avoidance was also shown by the undergraduates working on the skydiving helmet. There was agreement amongst the professional designers that their time was too short to concentrate on idea generation without parallel assessment of the practicalities of those ideas.

The ultimate level of detail reached
Whether industrial designers are involved with system-level and detail design are matters of professional experience and of making good use of employees' strengths, as well as involving people with what they like to do. As a member of a NPD team, the emphasis of responsibility on the industrial designer will depend upon the competencies of other team members. At Pentagram, engineering expertise is sometimes bought-in to complement industrial designers' work.

The interviewed in-house designers at manufacturing companies generally cease their involvement with a design once the external product surfaces are determined to be suitable for manufacture and assembly. Production engineers and toolmakers then detail the design for manufacture and determine the exact material grades and suppliers to use. The ultimate level of detail reached in the author's guitar project was written recommendations for the manufacturing routes of individual components [Pedgley, 1999]. This was on two accounts. First, the prototyping of a fully working instrument was set as the mark for the project's completion, to prove the underlying technology; detail design was a phase on from this. Second, the author was not experienced in DFMA.

The undergraduates working on the skydiving helmet project concluded their work with presentation boards that included short statements on product manufacture. Details of manufacture and assembly were not in evidence.

Speculative product design
Speculative product design refers to projects where a company or consultancy looks at possible product futures, characteristically the implementation of new or not-yet-available technologies. The achievement of a production manufactured product is not, at the time, an aim. The work is exploratory in nature, as described overleaf.
...to look at markets and (...) to entice people to their products. Or work that's
to explain how a project could be done but isn't actually a project itself (...) It's
never going to see the light of day.
[Chris Forecast, Grey Matter]

This kind of work might notionally have involved little or no consideration of manufacture
but this was found not to be the case. Production details for these projects are generally
not determined, but due attention is given to propose a feasible manufacturing route
(especially if prototypes are to be produced). Some important comments were made
during the interviews with the designers at Flymo and Kenwood that put speculative
design work into context. Their view was that speculative work is similar to the work
involved at the initial idea generation phase of a routine design project, when design
ideas are, by definition, speculative. As such, speculative work should be considered
integral to an industrial designer's everyday practice and not a separate issue [Kenwood].
PART B

The use of information

The interviewed professional designers identified a large range of information sources as helpful for decision-making on the manufacturing route for a product. These will be listed shortly, combined with the information sources used for the undergraduates' and the author's design projects. Both Chris Forecast of Grey Matter and Andy Rogers of Johnson Haigh Rogers stressed the importance of information use, not just for stimulating new ideas for products but also to gain critical commentary on emerging ideas. Designing in isolation, they asserted, should be strongly avoided.

An important source of information in the author's guitar project was experimentation. This was essential for the investigation of construction methods not previously used in guitars (and can be considered equivalent to research and development work in a professional context). Internet sources were used only in the author's guitar project, to acquire materials data and design advice from the GE Plastics web site and to perform a web search of U.K. material stockists.

The author's diary of designing was analysed to reveal how information use evolved over the length of the guitar project. Information use was most concentrated during system-level design, when manufacturing issues were considered in depth (74% of days involved information use). Information use fell to a low of 12% of days during the testing and refinement of prototype 3 (reflecting a change in the project away from modifications of the design and towards final prototyping). A total of 43% of diary entry days made some reference to the use of information sources, showing that the author's designing was not dominated by the use of prior experience. Overall, information was sought by the author on a need-to-know basis and, particularly, in subject-focused information hunts that spanned many days of concentrated investigation. Information searching on a need-to-know basis was also a feature of the interviewed professional designers' work practices. Very little of the information used in the author's designing was 'happened across' (category one information) or offered by people without prompting (category two information). Most information was actively sought (category three information).
Client/colleagues

Clients and colleagues can provide expert advice on materials and processes choices and constructive criticism of design ideas and details. At Samsung, an engineering department determines which materials will satisfy utilitarian requirements for a new product and forwards its advice to the company's industrial designers.

Designed artefacts and the wider world

The interviewed professional designers were agreed that there was no substitute for hands-on examination and handling of products to learn about design. The varied applications of materials and processes can be learnt this way, especially from competitors' products. By disassembling products, knowledge of detail design (e.g., wall thickness, assembly details, internal webbing) can be instilled. Broken products are a useful source of information for noting how materials fail [Dartnall Design Associates]. There was a feeling amongst the interviewees that industrial designers should be naturally inquisitive about designed artefacts and other forms in the wider world. Both the author and the undergraduates working on the helmet project used existing artefacts as information sources. On a few occasions, the undergraduates made reference to 'Formula One visor' material, 'Oakley sunglasses' and 'Sunglasses' material, showing that designed artefacts can 'become' materials.

Experiments (R&D)

Experiments can be undertaken to uncover currently unknown characteristics of processed materials.

Internet sources

The author used the world wide web to gather materials performance data, recommendations for design details and contact information for materials suppliers. A free database can now be accessed to assist designers in their choices of materials [MATWEB, 1999].

Liaison with end manufacturers and material suppliers/manufacturers

Companies can provide design advice and advise on the availability of new materials. Direct liaison with companies overcomes the problem of relying on out-of-date literature.

Physical samples

A library of processed material samples is often kept at a design firm. Andy Rogers of Johnson Haigh Rogers stated that it was imperative to make use of such samples. As with
designed artefacts, material samples can be handled and this helps to envisage their use in an emerging design proposal (or can spark ideas for new products).

Printed sources

Professional industrial designers make use of a wide range of literature, including:

- leaflets and brochures of material ranges;
- manufacturers' design advice (especially for injection moulding);
- directories of materials and manufacturing companies;
- the design press (e.g., Design Week, Blueprint), showing materials and processes implemented into products;
- in-house material specification sheets containing performance data [Nokia, Samsung].

A problem with literature is that it can quickly become out of date. For the author's guitar project, different printed sources were used at different phases of the project. During idea generation, guitar sales leaflets and books were consulted. Technical books, directories, and materials sales leaflets were used during system-level design (to be alert to DFMA issues and to gather materials properties data). One of the undergraduates working on the skydiving helmet project consulted his lecture notes for information.

Specialists/specialist services

Designers will sometimes gather information on materials and processes at exhibitions and conferences. The Institute of Materials Materials Information Service is used by designers at Pentagram.

The use of computers

It was found that computers do not assist the decision-making on the combinations of materials and processes to be adopted in a product. That is to say, computers are not used to provide explicit advice on whether to opt for one manufacturing route or another, or provide suggestions for suitable routes. The designers at Dartnall Design Associates, Flymo and Samsung stated that their work did not include use of mould flow simulation programs. At Johnson Haigh Rogers, finite element stress calculations were not undertaken. Computers were used by the interviewed professional designers to (a) generate photo-realistic renderings to show to clients what a product would look like in
different materials and finishes, and (b) perform searches of material databases to identify materials with specific properties.

**Industrial designers' materials and processes knowledge and values**

The interviewed professional designers outlined what would constitute 'core' knowledge and values for an industrial designer to possess, and what was better left for on-the-job experience. Their comments are contained in Part C of this chapter. Overall, wide experience of designing for different manufacturing processes was seen as beneficial (because it provides a stock of heuristics) and was not mentioned as a hindrance to creativity. It was stated that, ideally, there should be 'no boundary' to knowledge [Johnson Haigh Rogers, Samsung], that designers should know 'as much as possible' [Pentagram] and that designers 'could not have enough' knowledge [Flymo].

The author's varied use of existent knowledge and value judgements was demonstrated most effectively in diary entries describing cognitive modelling. The post-diary interviews with the undergraduates were successful in revealing something (though not a great deal) about the nature of the students' materials and processes knowledge. Similar to the author's diary, some of the students' accounts were given in the context of cognitive modelling. This subject will be examined shortly.

**Ways of knowing**

Knowing that was prevalent throughout the author's designing, shown by the abundance of diary entries that made explicit the author's decision-making. Experiments were also commonplace. They were central to the generation of knowledge on the performance of materials and construction combinations. Pointers to tacit knowing (knowing how) were given very infrequently in the author's diary. Entries describing the evaluation of the resonant acoustic properties of materials were one example. Vague descriptions of the surface finish on the Forex-EPC material were another example, highlighting the difficulty of describing how a material looks attractive: "...matte but with an intriguing surface pattern..." [78]; "[Black Forex-EPC] has a really appealing overall visual quality... The black version really is special..." [225]; "...it looks great" [239]. Two other pointers to tacit knowing were contained in the author's diary: "1.5mm thickness [sheet metal] 'felt' right" [197]; "[Design A was a] visually 'correct' (in my eyes) design" [292].

Little more can be concluded beyond a simple statement that tacit knowing, as shown, featured in the author's designing and that, for the evaluation of resonant acoustic properties of materials, tacit knowing was central. The interviews with the professional
designers and undergraduates included no discussion of tacit knowing or the qualitative status of knowledge.

**Classes of decision-making**

The author's diary of designing did not have the reporting of different classes of decision-making as one of its goals. As a result, entries that point to the use of intuition, as below, cannot be treated as more than isolated incidents.

- "...immediately thought..." [120]
- "...sprung to mind..." [135, 234]
- "...'automatically envisaged'..." [193]
- "...immediately linked..." [197]
- "The idea just seemed to arrive..." [291]

Accounts of analytical decision-making were evident throughout the author's diary of designing.

**The importance of cognitive modelling**

So far this chapter has presented the web of considerations that lie at the heart of industrial designers' attention to materials and manufacturing processes. This section now addresses how, through cognitive modelling, designers can go about putting these considerations into practice and make design 'moves'.

The interviews with the professional designers and undergraduates had only limited success at revealing the structure of cognitive modelling, primarily because the data from these sources were not documentary data. The conclusions in this section are therefore formed mostly from the findings of the author's diary of designing. There are no claims in this section that the functions of cognitive modelling identified in the author's guitar project are universal amongst designers. That is something that requires further research. However, the findings from the interviews with other designers do point to strong similarities in the general use of cognitive modelling. These similarities are used to strengthen tentative theories on the structure of industrial designers' cognitive modelling in relation to materials and manufacturing processes.

Cornish [1987:18] has said that designers needs to visualise materials and processes when generating design ideas. Throughout the author's designing, modelling 'in the mind's eye' was the process by which product materials and processes were proposed. Examination of the author's diary of designing revealed cognitive modelling to have two
key features. First, cognitive modelling had specific functions. Second, cognitive modelling was essentially a hidden, personal activity, which may on occasions become externalised in, and extended by, work in 2D and 3D media. That is to say, design rationale was sometimes 'embedded' in drawings and models.

Functions of work in 2D and 3D media

It was found that during the author's guitar project, 2D and 3D media acted both as passive and active contributors to the modelling process. As passive contributors, 2D media were used for illustration and 3D media were used to make a physical artefact to a predetermined plan. As active contributors, 2D and 3D media provided feedback for further design ideas (in a manner, it can be supposed\(^\text{46}\), similar to Schön's [1983] 'reflective conversation'). Overall, however, the activities of model-making and prototyping had very little impact on materials and processes choices. This was in contrast to pen-on-paper activities.

In the 2D media identified in the author's diary entries, both 'private' markings (intended only for personal use) and more complete 'public' drawings (for intentional outward communication) were present. This finding corroborates Garner's observations of designers' uses of sketch sheets [1997]. The following functions of 2D modelling with respect to materials and processes were identified in the author's diary. The last of the listed functions was the primary function of 2D modelling.

- Illustrations for communicating design ideas to colleagues.
- Illustrations and textual reminders of existing products for oneself.
- Project co-ordination.
- A record of ideas and decisions from meetings.
- The generation and development of product ideas in relation to (a) utility, (b) expressive qualities, and (c) manufacture and assembly.

Cognitive modelling was found to be initiated by a number of different kinds of primary generator. For the most part, the primary generator was one's direct thoughts. However, the activity of drawing, contact with already-drawn artwork, the activities of model-making and prototyping, contact with already-made models and prototypes, and contact with information sources (mostly printed) were also identified as primary generators in the author's designing.

\(^{46}\) The elements of Schön's [1983] 'reflective practice' could not be identified in the author's designing since the diary of designing did not record decision-making in real-time.
Cognitive modelling of a product's utility

A process of deduction was identified as a common element in the author's cognitive modelling of materials to satisfy a product's utility. The cognitive modelling had the following structure: reasoning from a modelled scenario (held in one's 'mind's eye') in which a product component needed to perform, to the proposition or elimination of materials on the basis that the materials will or will not perform satisfactorily within the modelled scenario. A similar process of deduction, though not explicitly tied to 'mind's eye' images, was described by Johan Santer of Kenwood. For designing, he stated, it is necessary to know the constraints of materials and to ask "...could we achieve this [desired utility or expression using this material]?" The interviews with the other professional designers failed to provide further insight. In the interviews with the undergraduates working on the skydiving helmet, however, the interviewees' accounts revealed a structure of reasoning that was equivalent to the author's (except that no explicit reference was made to 'mind's eye' images). The strongest evidence in this study to support a claim that the 'mind's eye' is central to industrial designers' decisions on materials to meet product utility came from the pilot interviews with two second year undergraduates (see Chapter Three). Both of the students gave several accounts of how materials were selected on the basis of satisfying envisaged scenarios, but Adam also made direct reference to 'mind's eye' images.

...I visualise how the product's actually going to be used; ...guitar strings are really sharp, they're like cheese wire, they're going to cut through a material if it's not suitable; ...lighting and UV degradation needs to be looked at as well, if you're going to be using it for a lighting system. I suppose that's true for products in the home too, because it's going to be exposed to sunlight I think.

[Adam]

A fitting description of the chain of thinking that an industrial designer engages in might be as follows. A product component will experience conditions x (determined through a scenario modelled in the 'mind's eye'), therefore a candidate material will need to exhibit y (material properties), therefore a suitable material is z (based on heuristics). The general applicability of this model needs investigation.

Cognitive modelling of a product's expressive qualities

It seems reasonable that the structure of cognitive modelling previously described (i.e., attending from a modelled scenario to a candidate material) should also apply for attending to a product's expressive qualities. However, there was only limited empirical evidence in this study to corroborate such a description. Proposals for materials for expressive use could be identified in the author's diary entries (e.g., aluminium powder
impregnated epoxy resin, transparent finish polycarbonate) but the scenarios to which
these choices applied were not explicitly stated (or stated at all). This might have been
inevitable, however, given that expressive qualities of materials are often known tacitly
and, therefore, are beyond precise verbal expression.

In the author's designing, decisions on material choices to meet desired expressive
qualities were led by personal preferences rather than the consensus of potential users.
That is to say, decisions were self-centred rather than centred on the preferences of
potential users or a defined marketplace. The author's approach to designing was
criticised in this respect in Chapter Eight. Self-centred designing was considered not good
practice in industrial design [Grey Matter; Johnson Haigh Rogers; Samsung].
Nonetheless, the exercising of personal preferences when attending to a product's
expressive qualities was far from unique to the author's designing. Such preferences
were present in the decision-making of the undergraduates working on the skydiving
helmet project and in the decision-making of the injection moulding students. The two
quotations below indicate personal preferences to be present in wider industrial design
practice also.

When the alternatives proliferate without increase in cost or reduction in
efficiency the designer's decision is aesthetic. He draws the line where he will
because it gives him aesthetic satisfaction, he relates plane to plane and form
to form to produce relationships which satisfy an inexpressible sense of what is
'right'.
Black [1976:221]

I did a series of objects, the Tango radios and Tempo clocks... In them the
structure was separated from the [internal] components... It was about
geometric arrangement. The objects were simple, made out of squares and
triangles, so you could rearrange them and get new ones, very different ones.
(...) For the radios, I created sandwiches of silk and plastic and made special
textures with high-frequency welding. I developed this whole new language
of materials, which I felt was quite important. The radios subverted, some-
how, the conventional sense of value because silk and plastic do not normally
meet. One is a valuable material, the other is not. One of the issues I felt I
wanted to address with the radios was the idea of value, because unless that
is changed we will have the same dictatorship of convention forever. As long
as the way we arrange things in hierarchies does not change, we will be stuck
with, say, the idea that heavy things are expensive and light things are cheap;
or the idea that things made out of plastic are cheap and things made of gold
are expensive. So I set out, deliberately, from then on to do a series of objects
all around the notion of value.
[Daniel Weil, a partner at the Pentagram Consultancy, quoted in Mitchell,
1996:16]
Cognitive modelling of product manufacture and assembly

A common element in the author's attention to product manufacture was a concern that the shapes of designed components were achievable. A process of deduction was identified in the author's designing, for which links were made between the following elements.

- 'Mind's eye' images of a desired component shape.
- 'Mind's eye' images of shapes that are known to be possible from manufacturing processes.
- The proposition of a chosen manufacturing route.

There was insufficient evidence in the author's diary to identify the precise structure of the links between these elements (that is to say, the precise structure of the cognitive modelling). It is speculated that the modelling involved a process of juxtaposition of the two categories of 'mind's eye' image and a subsequent proposition of a manufacturing process after comparison of the juxtaposed images. This description requires further investigation to determine its validity. In the interviews with designers at BIB, Flymo, Grey Matter, Kenwood and Samsung, the same underlying process of deduction was offered as a description of how proposals for manufacturing processes are reached (though the descriptions were not explicitly tied to 'mind's eye' images). With regard to product assembly, the cognitive modelling of scenarios was evident in the author's diary but, for lack of evidence, a pattern in the structure of this modelling could not be identified.

Use of 3D media

The use of modelling foam was stated to be especially useful for resolving queries over the manufacturability of a shape because potential trouble spots are made readily apparent by a physical model [Flymo].

Tasks (other than modelling) for reaching decisions on materials and processes

A number of tasks, other than modelling, were identified in the interviews with professional designers as important for attending to materials and processes.
• Forge links with manufacturers.
• Understand the peculiarities of the intended market of a product and, within a consultancy, understand the strengths and weaknesses of the client company [BIB, Flymo, Grey Matter].
• To aid idea generation and concept development, create a lifestyle mood board (a visual aid containing illustrations of prospective purchasers and photographs of products that potential purchasers are associated with using). The images on a mood board serve to illustrate potential materials and processes for use in a new product. Physical samples can be used to accompany a mood board. At Grey Matter, a written report on the prospective marketplace, the merits of existing products, and the opportunities for design is produced prior to the construction of a mood board. Such a report contains the results of what is termed ‘brand mapping’.
• For the author's guitar project, the writing of a PDS, design reports and a product costing clarified design issues and aided further decision-making.

Evidence that rigid design procedures are followed
Mark Delaney of Samsung commented that designers at the U.K. office use many modelling media together in a fluid, non-regimented way. This was in contrast to the work practices of designers at the Korean headquarters, where a sequential process (sketches, then soft models, then CAD) is rigidly followed. In none of the studied design practices in this current research was mention given of the use of concept screening matrices to aid decisions on materials and processes.

Can industrial designers’ ‘distinct way’ of expressing and generating materials and processes knowledge and values be identified and described?
This question was the second of the chief research questions. The distinctiveness of industrial designers' attention to materials and processes lies in diversity rather than specialism. Elements of both artist-designers' and engineers' work practices are displayed in industrial designers' work practices. The industrial designer shares the artist-designer's principle that, in addition to providing utility, processed materials have qualities that can be used to enhance a person's satisfaction with a product, whether in use, ownership or
simply as an object to behold. Similarities to engineers' practices arise primarily because industrial design is practised within a commercial, industrial environment.

**Similarities to artist-designers' practices**

- The industrial designer considers the properties of materials and processes from a humanistic perspective. Processed materials are proposed, in part, on the basis of providing visual, tactile and other sensations. The industrial designer is also responsible for upholding the identity of a company's products through the use of appropriate processed material forms.
- Through hands-on making of models and prototypes or through workshop experimentation, knowledge is derived of how materials and processes can satisfy utilitarian and expressive functions of a product.
- The activity of constructing models and prototypes provides an opportunity for designing-whilst-making.

**Similarities to engineers' practices**

- The needs and desires of a client or an employing company underpin design projects (rather than self-satisfaction).
- The use of homogenous 'engineering' materials is dominant in industrial design because: (a) products are normally manufactured by industrial processes requiring consistent and predictable material; and (b) end products are normally required to be exact copies.
- Production is the responsibility of an industrial manufacturer; the industrial designer is not an artisan. The final specifications of a proposal therefore need to be made explicit ahead of manufacture so that production can be planned.
- The use of quantified materials data is entirely appropriate, especially for use in mathematical calculations relating to utilitarian performance.
PART C

Introduction

Part C of this chapter addresses the third of the chief research questions and sets an agenda for information providers and tertiary education, based on the conclusions so far presented.

Implications for information providers

There currently exists no literature (or other information source) on materials and processes selection that is targeted to an audience of industrial designers (whether students or practitioners). Such a resource, were it to be produced, has the potential to be a great stimulus for designers (particularly novices). It could aid designers' materials and processes selection by alerting attention to operational constraints and opportunities and, in so doing, make decision-making more thorough. Many of the findings presented in this thesis could be transferred into such a resource. The format and structure of the resource would need be carefully thought through by the information designer. It is likely that sections on product utility, product expression and product manufacture and assembly would need to be included in the resource.

Product utility

Norman [1998] has put forward a case that materials data presented as written or numerical information may not be conducive to manipulation in the 'mind's eye' and that, presented this way, the data may not be particularly suited to industrial designers' decision-making. From this perspective, the worth of images illustrating utilitarian uses of materials (to complement materials data) should be considered in any new materials and processes resource for industrial designers.

Product expression

There is a need to categorise processed materials by: (a) their potential effects on people's senses; (b) their use in high and low end products; and (c) their use in different world-wide markets. Very little guidance is currently available for industrial designers on
these three subject areas. The findings of research in these subject areas would form the basis of valuable design advice, with the specific intention of replacing supposition.

**Product manufacture and assembly**

In Part B of this chapter, industrial designers' cognitive modelling of product manufacture was tentatively proposed to involve a process of juxtaposition of a desired component shape against achievable manufactured shapes. If this description were to hold good for general industrial design practice, a suitable format of information presentation to industrial designers may be a visual library of manufacturable shapes (and other elements of form).

**Implications for materials and processes elements of industrial design education**

At a most basic level, this current research has established that, first and foremost, an industrial designer needs to know of the combinations of materials, processes and finishes that can be combined to create a desired component form. Two points stem from this finding.

- Materials and processes for industrial design students should be taught from a product design perspective (rather than from the perspectives of materials science or process engineering).
- Although students' design proposals are on the whole not destined for production, students should still be thoroughly familiar with the opportunities and constraints of professional practice. Many of the opportunities and constraints also apply to students' client-based projects.

It is the author's opinion that materials and processes are too important to industrial design students to be left to undirected self-study. An emphasis needs to be placed in university curricula on the formal development of students' cognitive modelling for: (a) product utility; (b) product expression; and (c) product manufacture and assembly. Two key aims of a university module focusing on materials, processes and the industrial designer are seen by this researcher to be: (a) dissuading students from the invention of manufacturing routes; and (b) explaining to students how treating materials and processes as an afterthought has detrimental effects on both a final design and on the process of achieving that design.
An outline of a new curriculum

A good starting point for any new university curriculum focusing on materials, processes and industrial design may be the tentative descriptions of cognitive modelling provided earlier in this chapter. For a new curriculum with emphasis on cognitive modelling to work, students must possess a suitable level of graphicacy (although it may be a specific aim of such a curriculum to nurture graphicacy). In any event, a new curriculum needs to develop in students an ability to attend in parallel to idea generation and manufacturability. In so doing, students may develop intuitive decision-making, something that appears to be a hallmark of professional practice.

Designing for product utility

One would expect foresight and imagination to be crucial for modelling realistic scenarios in which a product needs to perform. The properties of materials that provide a product with utilitarian function need to be known to students. To help propose or reject a material, it would be advantageous to have knowledge of prior applications of the material.

Designing for product expression

To replace personal preferences and supposition as the basis of design decisions, students need to investigate market trends and users' preferences for the expressive uses of processed materials.

Designing for product manufacture and assembly

For a given material family, different manufacturing processes offer ways of achieving different component shapes. Also for a given material family, different semi-finished forms of material are available (e.g., sheets, billets, tubes, rods, foams, laminates, granules for melt processing) with different specifications (e.g., thickness, colour, pattern, surface finish). To act as heuristics during designing, students should develop a wide library of 'mind's eye' images of the forms that are achievable from different manufacturing and finishing processes. Students need also to understand the inherent constraints of different processes for creating desired forms. Peter Tennant of Pentagram suggested that, in addition to injection moulding and other plastics processing, students should have knowledge of sheet metal processing, casting (in various materials) and extrusions (in various materials). It would be advantageous for a university to maintain a library of existing products (disassembled and assembled; in working order and broken) so that students can develop their manufacturing knowledge by first-hand acquaintance.
Workshop practice
If prototypes, rather than MDF or similar composite-based block models, are to be produced by students, skills in working with end-product materials (e.g., plastics, metals) need to be developed. Through working with end-product materials, workshop practice can be used to develop first-hand experience of the 'truth to materials' maxim. For block modelling, students need to know how to simulate different manufactured forms, materials and finishes using model-making techniques.

On-the-job experience
Several of the interviewed designers recommended that detailed DFMA knowledge and knowledge of plastic melt flow was better left to on-the-job experience, as part of a junior designer's professional development.

47 A block model is a visually convincing analogue of a prospective production item but has no working parts.
Bibliography and Appendices
Bibliography and Internet Sources

A simple classification system has been added to this bibliography as an aid to future researchers. Sources are classified into six categories, according to their primary use in the literature reviews of this thesis.

C Collection and analysis of data
D Design decision-making
E Epistemology for industrial design
G Guitar design
M Materials, manufacturing processes and NPD
R Research methodology


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APPENDIX I

Injection moulding project interview notes

LOUGHBOROUGH UNIVERSITY
DEPARTMENT OF DESIGN AND TECHNOLOGY

A pilot study of the consideration of manufacturing processes and properties of materials by Year 2 Injection Moulding Project students

Owain Pedgley
Research Student 30 October 1996

The pilot study is concerned with two candidate students' consideration of:

- properties of materials (technical and visual);
- manufacturing processes

in both the context of other design considerations and as 'isolated' design work. The study is concerned both with more successful and not-so-successful interactions of information, knowledge, skills and values when addressing manufacturing processes and properties of materials.

It requires that the students do the following:

- date all their design sheets as and when they are produced;
- attend an individual, videoed tutorial with OP (approx. 1/2 hour) and attempt to answer a set list of questions;
- allow OP to photocopy their design sheets

Questions to be asked during a tutorial discussion of design sheets

0. Have you designed a product and its injection mould tool before? Are you apprehensive at all, what are your concerns?

1. Identify points in the design sheets where materials/processes were raised;

2. what wanted to be found out; what was the problem; was it easy to pinpoint the problem/what needed to be found out (cognitive ability)?

3. was experience or external information used to provide answers?

4. in the case of external information:
   - what, descriptively, was the information consulted? (e.g. a certain book)
   - where did the information come from? to hand? (if no, e.g. library)
   - in what format was the information? (e.g. diagram, flow chart, text param.)
   - did you find the information useful? if not, why not?
5. in the case of experience (i.e. knowledge/values/skills):
   • what was your experience telling you (descriptive); what was your train of thought? (e.g. injection moulded parts always have an injection point, therefore my product must have one, therefore it needs to be on a non-visually important edge)

General

6. ask the student: has a particular (drawing style, model..) made it 'easier for you to address materials/processes design considerations'—what styles and in what ways?
APPENDIX II

**Concurrent diary of designing entry chart**

This chart provides details of when entries were made into the concurrent diary of designing.

Column 1 refers to the date and starting time of a video recorded episode of designing.
Column 2 refers to the start time of an entry.
Column 3 refers to the finish time of an entry.
Column 4 refers to the time gap between consecutive entries.
Column 5 refers to the time spent writing an entry.
Column 6 refers to the total number of entries made on a given day.

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<td>Daily entry count (mode)</td>
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### APPENDIX III

**Concurrent diary preformatted stationary**

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<th>DIRECTOR F. PEDGLEY - DEPARTMENT OF DESIGN AND TECHNOLOGY - Loughborough University</th>
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<tbody>
<tr>
<td>DAILY REPORT ON DESIGN ACTIVITY</td>
<td>22 May 1994</td>
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#### 1. WHAT HAPPENED TODAY?

<table>
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<tr>
<th>AM</th>
<th>VIDEORECORDER DESIGN - CONTACT MEDIA V10-C00</th>
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<td>PM</td>
<td>SCANNING FOR WEB PROJECTS</td>
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<tr>
<td>EVE</td>
<td>WEB DESIGN DEVELOPMENT</td>
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#### 2. ENTHUSIASM LEVEL

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<th>(Designing)</th>
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<tbody>
<tr>
<td>(Research)</td>
<td>RESTRAINED</td>
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</table>

#### 3. REPORT

- Determining product features: looking at existing models, extracting information from the visual form. (Cross)
- Use design "Guide Handout" to be made aware of technological issues.

Launched at structural interface "need" from designer, then copied exactly what it was.

- Some of the "checklist" of technical notes on PSD have been printed off actually from initially encoded with "cadet" design work, others getting "technical" instructions which are fragmented to our product may be distracting.

- ROSETTE SENSATION: considered problem with JSON call-out: necessity to find a different way of just an idea left at this stage.

- Flexing of this section more experience tells me about loose functional sections of material.

Looking at "The Guide Handbook" has certainly been worthwhile in making me aware, very quickly, of the technical aspects of the guide. Less complicated, more on good intentions...

The "most recent" was presenting me most novel design work of the day. (Cross)
## APPENDIX IV

### Unused concurrent diary preformatted stationary

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<td><strong>DATE</strong></td>
<td><strong>DATE</strong></td>
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<td><strong>TIME</strong></td>
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</table>

Self-report of design activity

Version 2.0 12 March 1997

352
APPENDIX V

End-of-the-day diary preformatted stationary

Had a telephone call and email from Chris Hall at 3M Technical Centre, regarding adhesives for the polycarbonate joints (in response to a fax I sent in November). Details are on 18.1.45. He will send some samples for me to try out.

The joints from MTW systems are fantastic. If I make the RC bridge this week I shall arrange a visit to examine that onto prototype 2. The adhesives from 3M could be so good; it looks like I should be able to give the components in the Department workshops.

I have noted down a rough plan of the final 3 months on this design project. In particular, I intend soon to make final mechanical calculations for key structural components on the guides, so that these can be used in detail design relating to the final prototype and for the purpose of deciding what industrial manufacturing process we are suited to each product component. Also on these notes (18.1.45) I have noted my intention to use CRIMPED wire joints, in the construction of the final prototype.

My plan this week is to produce the RC bridge and to examine prototype 2, which needs to be finished very soon.
possibly like this
\[ a \]

ellipses. (angle)

from D520

DS43
<table>
<thead>
<tr>
<th>day</th>
<th>month</th>
<th>year</th>
<th>day's main activity</th>
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<tr>
<td>17</td>
<td>10</td>
<td>98</td>
<td>Clinic meeting with Ed Astone.</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>98</td>
<td>First meeting with additional collaborators Dave Hocken.</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>98</td>
<td>Second meeting with additional collaborator Dave Hocken.</td>
</tr>
<tr>
<td>24</td>
<td>11</td>
<td>98</td>
<td>Preparing guinea sandbox for DH to offer each (today: black).</td>
</tr>
<tr>
<td>29</td>
<td>11</td>
<td>98</td>
<td>CAD/CAM work for guinea neck blank.</td>
</tr>
<tr>
<td>30</td>
<td>11</td>
<td>98</td>
<td>CAD/CAM work + planning to sandblast.</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>98</td>
<td>Setup up CNC machinery + material for warm machine.</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>98</td>
<td>Blue-tack and (paint) of new block on CNC machine.</td>
</tr>
<tr>
<td>15</td>
<td>12</td>
<td>98</td>
<td>File new (paint) of new block using CNC machine.</td>
</tr>
<tr>
<td>18</td>
<td>12</td>
<td>98</td>
<td>Preparing of block to cutout.</td>
</tr>
<tr>
<td>19</td>
<td>11</td>
<td>99</td>
<td>CNC routing + milling of top plate (top 1).</td>
</tr>
<tr>
<td>20</td>
<td>11</td>
<td>99</td>
<td>CNC milling of final block.</td>
</tr>
<tr>
<td>21</td>
<td>11</td>
<td>99</td>
<td>CNC milling of final block.</td>
</tr>
<tr>
<td>23</td>
<td>11</td>
<td>99</td>
<td>Final preparation of block; work on back &amp; sandblasting.</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>99</td>
<td>Work on back &amp; sandblasting.</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>99</td>
<td>Soundboard sanded - complete.</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>99</td>
<td>Jig for cutting soundboard + face - complete.</td>
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No detailed entry to be made.
APPENDIX VI
Undergraduate diary of designing instructions

1. Background

I am interested in tracking your work as it progresses from design brief to design outcome, to examine how you develop materials and manufacturing processes into your proposal. I value what you have to say about your designing.

2. What I need from you

At the end of every day that you have worked on the skydiving helmet project, you need to fill in at least one of the supplied pre-formatted diary sheets. For most days this will probably take no more than a few minutes, but expect it to take nearer 15 minutes for a materials/process intensive day. You need fill nothing in if on a particular day you have done no work on the skydiving helmet project.

In addition you will need to:

- clearly number all of your development sheets and CAD printouts;
- make sure your diary entries are legible;
- take photographs of models and prototypes that you produce.

When your project ends I will need to have from you:

- a completed diary of designing;
- development sheets and CAD printouts which are referred to in your diary;
- photographs of models and prototypes.

To summarise, the content of your diary will be based on only one design project and solely on the subjects of materials and manufacturing processes.

3. Using the pre-formatted stationary

If the day’s work did not touch upon materials or manufacturing:

- fill in the ‘no detailed entry to be made’ sheet, making a note on what the day’s main activity was (e.g. ‘writing a PDS’, ‘form development’, ‘model-making’).

If the day’s work did involve materials or manufacturing:

- (and the work is on development sheets or CAD printouts) use the ‘tracing sheet’ for your account; also fill in the ‘formalities’;

- (and the work is not on development sheets or CAD printouts) use the ‘standard sheet’; also fill in the ‘formalities’.
4. The questions and prompts

1. Strategy
If you have a plan for how you will address materials or manufacturing issues in this project, please explain it. If your plan changes as the project progresses, please give details of how and why.

2. Details: 2-D and 3-D work
(For development sheets and CAD printouts, indicate on a tracing sheet where you gave consideration to materials or manufacturing processes. For 3-D work, make direct reference to the model or prototype.)

What have you considered regarding materials and manufacturing processes? How have you gone about it (what knowledge have you applied?) and why have you looked at it in this particular way?

3. Information sources
Give details of any information sources you have made use of to help you address materials or manufacturing issues. Did the information help? How?

Example information sources:
- looked at a chapter in Materials and The Designer (book);
- held a discussion with SBA Ltd, Leicester (materials supplier);
- had a chat with a friend;
- dismantled a product;
- saw something whilst walking down the street.

The giving of your time and effort is warmly appreciated. Many thanks.

You will be offered a complete set of your diary sheets soon after your involvement with this research project finishes. Any expenses incurred by your participation will be refunded.

Owain Pedgley
Department of Design and Technology
Loughborough University
Loughborough
Leicestershire LE11 3TU

room: Bridgeman Centre, XX1.07b
telephone: 01509 223045
telefax: 01509 223999
e-mail: o.f.pedgley@lboro.ac.uk
web: http://www.lboro.ac.uk/departments/cd
APPENDIX VII

Pre-formatted stationary for diarists' details

Diary of Designing

O.F. Pedgley Ph.D. 1999

Private & Confidential

Loughborough University

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<td>Email Address</td>
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<td>Portfolio/Experience (e.g. some examples of past work)</td>
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<td>Anticipated outcome from the designing</td>
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<td>(e.g. rendered proposal, block model, prototype)</td>
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<td>What confidentiality agreements are in place? How can they be worked around?</td>
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22/10/97
APPENDIX VIII

Sample post-diary interview transcript

Interviews with undergraduate industrial designers

© Owain Pedgley 17 June 1998

Zachary: Freefly Skydiving Helmet

Topics presented as they appear on the tape.

1. First sketch sheets (1-6)
   "...these are really initial ideas, concepts, things like that. Not really thinking about much materials," Zachary notes, apart from strapping and the need for a hard shell for the main body. Focusing on the form; getting ideas out on paper.

   Sheet 4, adding visor: "I suppose I was thinking visor... just clear... not glass; a plastic one. I didn't actually think that 'ooh, that could be that' or 'this could be that' at all this stage."

   Client did not specify the use of any particular materials- left it down to the student "I think he wanted it, not traditional, but so that skydivers can look at the hat and, you know, know that it is hard; you don't want something like jelly or something like that But then he [the client] was a bit of a character and was into a lot of [wacky ideas, hence 'Cool and Groovy Fudge Company']."

   Sheet 7, casing to protect camera- was thinking maybe metal.

   Sheet 9 has a section showing foam head protection.
   OP: "Where did you get the idea for the foam?"
   Zachary: "Just thinking of soft, impact resistant / absorbent material really."
   OP: "Did you think about it as a bit of a cycling helmet?"
   Zachary: "Definitely, yeah, that's where I was getting a lot of the idea." [points out the ribbed construction bottom of sheet 9- and acknowledges that it's come from a cycling helmet.]

   Sheets 11 to 28- revisiting the overall shape and styling, which Zachary was not happy with yet. He was thinking that the main shell would be a single-piece formed plastic. "I initially thought it could be done like cycling helmets, where you have the compact cell foam and then you have just the vacuum-formed thin plastic. Don't actually know what it is- at the top, just to protect." He dismissed this combination of materials and construction because he didn't think it would be "strong enough to be bashed around continually".

   OP: "Did you have in your mind at any stage how you were going to assemble this product?"
   Zachary: "Erm, not really. Mainly I think the helmet shell would be made in one- not made in two halves."

   Again, product shape and styling was the priority- "...definitely the materials selection of it came second. Only at the end did I really think 'ahh, what can this be made out of'."

   Zachary: "Ah yeah, I suppose, it's always in the back [of your thoughts]. I don't really like sit down and think directly about it, but you have ideas in your head, even if you don't write them down or investigate them at all."

   Sheet 29- looking at the mounting system for the camera- "Thinking metal, I suppose because it's stronger, to protect [the Sony camera that will fit inside]." Looking at how it might assemble onto the main shell by way of a bracket.
[Note: the client asked for the camera bracket to be detachable, so that the helmet could be used normally, free of any recording devices (NB allowing the helmet to compete on the normal helmet market).]

Sheets 31 onward—working-up the preferred form some more; Zachary was happy that he’d found a styling route that he liked. Renderings on sheets 31 / 34 show the kind of shiny, coloured surface finish he was looking for.

[Note: Zachary never stated how this would be achieved.]

OP: “What was driving your decisions on colours and that sort of thing?”
Zachary: “Mainly the colours they use in skydiving are very kind of primary.” [I infer that he wanted to have the boldness of this come through in his own design]

Back to Sheet 29—mounting system.
OP: “Did you have any idea on how that was going to be made at that point?”
Zachary: “I suppose machined, cut metal; stamped out or something like that.”

Back to Sheet 30—camera protection.
The design looked at here is a metal box in which the camera would be mounted. One of the questions Zachary was asked at his presentation examination was ‘why didn’t he make the shell and the camera bracket/protection system out of the same material’—to make it “more with it” (Zachary)—[Note: translation: ‘a more coherent form as a single product in its own right’]. Zachary: “It was one thing I didn’t look at because it didn’t cross my mind— I thought of it as two completely separate bodies. It didn’t really matter if they were of the same material or not. And I wanted metal around the camera, so it was actually stronger than the helmet. Even though the helmet was strong, I wanted [the camera protection] to look like it was stronger. I just wouldn’t be happy sticking the camera in just a mould on the side of the helmet.”

Zachary saw stability and protection of the camera as major issues to deal with.

OP: “Did you look at the conditions that it’s going to be used in... are there any particular adverse conditions that might have effects on the materials?”
Zachary: “Erm, not really. I see the force of the wind acting on it as one... so it will have to be rigid.” (plus Zachary notes that they generally don’t tend to go out in the rain). Zachary says that he was looking at an aluminium casing, particularly because its low weight meant that it wouldn’t add discomfort or imbalance to the helmet. He knew he wanted metal (for the reasons stated) very early on—but “didn’t really think about manufacture”.

The 3D prototype
Modelling the prototype and getting your head around the 3-D forms on paper was difficult—Zachary found himself making adjustments to the shape when he got working in 3-D [because the medium requires the form be worked out as a whole, rather than dealing with separate elevations on paper which are tricky to tie together in the ‘mind’s eye’, or tricky to draw in the first place as accurate representations of the ideas that you hold in your ‘mind’s eye’].

Zachary: “For the helmet, I was looking around at other helmets [on the market] and chose GRP; it was easy to manufacture.” Zachary states there are (apparently) no British Standards covering the design of skydiving helmets.

Zachary: “Basically [the client] said the impact resistance was about the same as a bicycle helmet, that’s why I initially looked at bicycle helmets—about 12mph. ... but basically they [the client] were saying ‘don’t worry about that at all because it’s not much of an issue’... basically it’s got to stop someone being knocked out.”

[Note: the company had produced a low production run free-fall helmet already, laid up from Kevlar, which Zachary had a look at. The design brief set was for an anticipated production run of around 5000/year.]

OP: “Did you get to then link the fact that you’d gone for GRP to any particular mass-manufacturing process?”
Zachary: “No— that was one of my errors.”
Sheet 35/36- Thinking about how you'd go about testing the helmet for its performance under an impact force (which he never got around to doing- lack of time). Zachary notes that you're doing it to determine a safety factor, so to do it properly you need a mannequin head so that a physician can assess the kinds of injuries that might occur after a crash using the helmet- testing the helmet without a head is not so useful.

[Note- the prototype that Zachary made was based around a hand laid-up one-off GRP shell]

OP: "The bicycle helmets you looked at... were they GRP lay-up?"
Zachary: "No. Climbing helmets- some of them are GRP. [designed to withstand blows against rocks]. The thickness of those are about 3mm- quite thick."
OP: "Did you conclude, then, from the fact that those helmets can withstand that, that yours was obviously going to withstand it as well?"
Zachary: "Yeah." [wincing]
OP: "Sensible."
Zachary: "Saves a bit of time I suppose."

Sheet 40- Returning to the camera protection system. As it stood, the lens was protruding out of the main holder, in order to provide a full frame of vision. Like this though the lens was unprotected, so it needed rectifying.

Zachary: "Didn't want it to be aluminium [OP: and hence, perhaps, part of the main housing] because I thought it would bend, so I put that as steel."
OP: "Right. So another component really to go onto it..."
Zachary: "Yeah...yeah."

But points out...

Zachary: "I could have had the box around it as well, but it begins to look too big."
OP: "Did you arrive at a decision on how that casing would be made then?"
Zachary: "Er, it would be cut and you know... I'm not totally sure on the manufacturing processes, but cut from a sheet and then folded. I imagine it would be pretty basic to make up."
OP: "What about attaching the [lens protection part, made out of the different material]?"
Zachary: "On the model is was Araldited on... probably more like bolted on."
OP: "Were those sort of thoughts running around in your head when you were doing this [the designing around sheet 40]?"
Zachary: "No. Well, in a way.... When I was deciding on this bit- the frame- [sheets 48/49] ... I was thinking about simplicity to manufacture- you know, sheet [bending]- quite easy. So yeah, I was at this stage."

Sheet 56- looking more at the inner lining, "mainly it consists of nylon strapping, because you want it to pull around everywhere. I did think of elastic too, but then once you've [pulled it tight] it stays there."

[Note- the client wanted the helmet to be a comfortable fit for different sized heads- so this needed to be looked at.]

Zachary: "... I thought it would be... simpler to manufacture one-sized outer shell-, like they wanted, and then at the time of purchase (or you order it) [you would be measured-up to determine what quantity of foam would be needed to 'pad out' between the standard-sized outer shell and standard-sized inner straps and lining; the foam would then be fitted to the helmet to suit your individual needs]."
Zachary: "You'd go into the shop... and [the foam] would be glued in permanently."

[Note- Zachary's design was therefore constructed as an outer shell, a foam layer and an inner strap and lining.]

Sheet 57- looking at changing the density of foam used according to where it is in contact with the face:
OP: "What's the significance of the soft and the hard?"
Zachary: "Um, because I thought you didn't want the same density of padding used in all of it, because like on some cycle helmets you get soft and hard foam. Some areas where you want it slightly more... you didn't want it squishing in and out- you needed stability in some areas." [Zachary notes that the annotations indicating hard foam should refer to the white area; the areas in contact with the face and neck should be the [more comfortable]
softer foam]. "The areas to fill-out [between strapping and shell] you use the harder and the softer you use for comfort.... The harder is for the impact."

OP: "What about attaching these three layers then- your bit holding the straps, your foam and then your outer?"
... we move on to sheet 61 to serve as an illustration....
Zachary: "Yep, they'd be glued into place... the strapping and the plate at the back would be made beforehand."
[Zachary points out that there are two layers of padding- a base layer which provides the main protection (glued in place), and pieces which are shaped to the face and adjustable, which would be Velcroed in].

OP: "Did you have any idea how the foam might be manufactured?"
Zachary: "I know it is mass-manufactured in big sheets...."
OP: "Is it malleable enough to sort of bend it to the curves you want?"
Zachary: "Yeah, yeah. A lot of them [the foam pieces] would be just straight punched out, they're very straight [but piece marked X was thought more problematic because it wasn't a simple cut-out- no positive statement given for how it would be produced].

Sheet 62- returning to the camera protection unit. Zachary pointed out that the same low-density foam as used in the face padding would be used inside the metal box, to prevent metal-on-metal rubbing, damaging the camera- keeps "a tight fit" between the box and housed camera.

Sheet 63- Zachary identifies two metal bolts with internal screw threads that are added to the assembly to take the camera unit mounting bracket, to prevent screwing directly into the GRP. [Note- He obviously doesn't think this is a good idea- maybe not long-lasting enough or perceived to be not strong enough?]

Zachary: "The visor was a last-minute thing. I knew I wanted like sunglasses material - nothing special like scratch-resistant. Because I mean they normally generally use goggles anyway."
OP: "Are the goggles a pretty standard material?"
Zachary: "Yeah, they're just simple, really flexible, clear sheet material..."
OP: "Right, so it's not a rigid plastic?"
Zachary: "The one that you can clip onto your helmet is, but the ones they use are a lot more flexible [the lens part]." "Yeah, I chose to have it hard because when we had a meeting with the client, he was saying that the top world guy, what's really cool about him is he wears a visor which pulls down- a hard one, almost like a motorbike helmet... and that's really tricky to... You look good, but no-one else can do it, wear it, because you can't really see out of them very well... but it's 'the thing to wear'."

[Note- the image factor is major in this sport... the client stressed this- the helmet had to look 'cool and groovy').

[Note- There is no evidence in Zachary's designing that materials and processes were worked-up in a detailed design of his proposal]

[Note- At the end of the interview, Zachary offered a few comments about his attention to materials and manufacturing processes.

"You tend to be thinking subconsciously about materials and processes"- backs up the notion that materials and processes are at the heart of industrial design activity. Materials lecture notes were used later on in the designing to confirm what materials would be used.

Zachary considered materials and processes to be one of the least fun elements of industrial design- he likes to concentrate on the form of the product being designed. He felt that his materials and manufacturing techniques knowledge was lacking, and therefore it did not feature strongly in the project.
APPENDIX IX

Questionnaire for feedback on diary-writing

Post-Diary Interview

Name ________________________________

1. Comments on using the diary

Did you manage to regularly fill in the diary of designing at the end of each day?

☐ yes ☐ no

If NO please describe

(a) why you were unable to.

☐ lack of commitment ☐ insufficient instructions ☐ not enough time ☐ it was intrusive

Other / comments:

(b) when you did actually fill in the diary

☐ days afterwards ☐ when I had time ☐ at the end of the project

Other / comments:

Tell me about the length of time it took to make an entry.

☐ too long ☐ OK ☐ other / comments:

How easy was it to decide upon what you were going to write?

☐ difficult ☐ OK ☐ easy

Other / comments:
Did you get to memorise the main questions?

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<td>yes</td>
<td>sort of</td>
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Suggestion / comments:

Do you think the diary asked for too much?

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<td>yes</td>
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Suggestion / comments:

2. Comments on the format of the diary

What could have been done to make the diary easier to use?

Comment:

What could have been done to improve the briefing on how to produce a diary and how to use the pre-formatted sheets?

Comment:

Did you yourself get anything out of writing the diary? (in what way was it useful? did it help you in your designing?)

Comment:

Many thanks for taking time to respond to these questions.
APPENDIX X

Question list used for the interview with Nokia

Interview with Nokia, Camberley, UK
25 March 1998

(D) = descriptive / factual questions
(A) = attitudinal questions

1. Structure of ID in the company

Can you describe the responsibilities you have for Nokia industrial design, and how you fit into Nokia's product design teams? (D)

Can you describe the scope of the design work that industrial designers here at Nokia are asked to tackle? (D)
(e.g. what kinds of products? what kinds of briefs?)

When (during product development) are industrial designers involved? (D)
(e.g. members of a core team throughout the project? brought in at specific times for specific purposes?)

2. Scope of materials and processes in ID

What importance does the company place on materials and manufacturing processes, as a part of its industrial designers' work? (D)

Can you explain the significance of materials and manufacturing processes? (A)
(e.g. looking at a spectrum; the subjects could be peripheral or central to the industrial designer's job)

What are the kinds of properties you look for in a material when you are assessing whether you might use it in a design? (D)
(e.g. ability to create a shape and surface which will have certain qualities, tying in aesthetically with a family of products; aesthetics- does it look good?; tactile; quality surface finishes; mechanical properties; chemical properties)

I'd like to gauge something of the constraints and opportunities you have with regard to defining what materials and processes will go into a product.

Firstly, can you tell me about when materials and processes are looked at in your design work? (D)
(e.g. right from start; after playing with ideas; when get onto detail work...)

So how wide is the range of materials and processes that you are able to specify? (D)
(e.g. what categories do they fall into? kinds of thermoset? or more general, able to specify metals, plastics, ceramics, woods, rubber-based materials etc.?)

What opportunities do you have for specifying materials 'out of the norm'? (D)
(e.g. bringing in unconventional materials to the product group?)
Where do you get ideas for suggesting new or unconventional materials? (D) How does that work? (D) (e.g. evaluate competition; keeping awareness of products generally; inspiration; sensitivity to everything around ...)

Are there occasions when attention to materials and processes is deliberately put to one side in a project? (D) Why? (D) (e.g. industrial designer's job is to propose exciting ideas early on, then 'come down to earth'? shape exploration, ergonomics evaluation, user needs assessment, establishing electro-mechanical layout, internal component layout, examination of market).

Has the company's designers worked on speculative products which have never been intended to be put into production? (D) In these projects, how important is it to still consider materials and manufacturing processes? (A) (e.g. speculative- products not intended to be put into production still need their manufacturing feasibility checked?)

→ I'd like to ask about the level of detail that you look at with materials and processes.

How far into the details of 'design for manufacture and assembly' does your work go? (D) (e.g. injection moulding processing, is it common to look at...) • location of mould weld lines? gate locations? ejector pin location/marking?

• dealing with potential sink marks?

• stiffening and assembly ribs?

• stress analysis?

• sprue location and design; cavity mould flow in plastics products?

• tool design?

If the industrial designers do not deal with DFMA and exact materials choices, who does? (D)

With regards to determining exact materials, how quickly might you go through, say: (D)

• talking in general terms, e.g. 'transparent hard thermoplastic'?

• through to identifying 'polycarbonate'?

• through to tradenames, e.g. 'GE Lexan' (NB from a known supplier)?

• through to resin grades?

3. Information and knowledge

What printed matter like charts or formal written procedures are used to help in the selection of materials and processes? (D) What kind of information do these provide? How do they help? (D) Are they used frequently? (D) (e.g. databases? reference texts? optimiser charts?)

Do Nokia's industrial designers use computers to assist with choices of materials and processes? (D) If so, how do computers help? (D) (e.g. technical details of processing, renderings in different materials, databases of material mechanical/physical properties, mould flow analysis, finite element analysis?)

Do you think there is something to be gained by actually handling processed materials rather than relying on text books or databases? (A) Do you have material samples around the office? (D) Can you elaborate on the significance of experiencing processed materials first hand? (A) (e.g. sensitivity to human-material interface and all that entails; satisfying the five senses)
4. The act of designing

→ least understood, potentially difficult to talk about

So within all that we have mentioned... can you describe in basic terms what might be called your 'chain of reasoning' which you would follow to arrive at a material and process combination for an emerging design? (D)
(e.g. general phases of evolution and specific tasks: evaluate brief - what properties required of material? say how are we going to achieve this?)

→ reword: What is the relationship between materials and processes? How do the two interact in the design work? What drives you towards one combination of materials and processes rather than another? (D)

This is really at the heart of the matter... how, in your mind, do you go from an idea for form or shape, to being able to say 'the product will require this particular manufacturing process'? How do you think that works? (A)
(e.g. linking? a bank of stereotypes in one's head, to think in processed forms? knowledge of what you can and cannot do with particular processes? or rely on looking up in literature?)

Is there a hierarchy of your consideration (similar to level of detail of materials)? (D)

e.g.
- general: match to desired form?
- middle: injection mould?
- detail: tool design for specific process?

Do you think that concern for technological matters like materials and processes can constrain an industrial designer's creativity? (A) Why? (A)
(e.g. in early concept work it 'gets in the way' of the free flow of ideas / brainstorming and is in some way in opposition to flamboyancy? or it provides the arena for being creative?)

Are 'green issues' such as 'design for disassembly', 'design for recyclability' and the use of recycled materials having an increasing bearing on the company's product proposals? (A) When during a design project do these come into play? (D)
(e.g. coding products with plastic types)

What bearing do fashions have on swaying the use of particular materials and finishes for Nokia's products? (D)
(e.g. look at how materials in cameras and personal stereos have evolved through trends)

If boundaries of knowledge were set on materials and processes, where do you think these would lie for an industrial designer? (A) What do you consider 'out of bounds' and what do you consider a 'speciality'? (A)

Are there any other points relating to materials and processes that I have not covered that you feel are important? Please explain...

What do you see as important to research? What do you think is missing that would, if it were available, assist you in your designing?
APPENDIX XI

Authentication of the author's diary of designing

Declaration of authenticity with respect to Owain Pedgley's diary of designing

We have witnessed Owain Pedgley writing the aforementioned diary of designing at the day's end and as the guitar project has progressed.

Eddie Norman (Supervisor)  
Date 20/4/99

Dean Bates (Colleague)  
Date 20/4/99
APPENDIX XII

Coded transcript of the interview at Samsung

Intervews with professional industrial/product designers at design consultancies and in-house design departments

© Owain F Pedgley
18 March 1998

Meeting with Mark Delaney, Samsung Design Europe, at Samsung, Great West Road, Brentford, London, 16 March 1998

Interview transcription - 70 minutes

Bold type = Owain’s questions
Normal type = Mark’s responses

What I’ve got really are some set questions which I’d like to go through and just see what your responses are to them.

Okay

Erm, firstly to gauge something about Samsung - can you describe some of the scope of the work industrial designers do here?

Um, basically we’ve got a huge industrial design department [at Samsung]. Here [in Brentford] there’s only me and Mr Shin- in the past this department’s been as big as seven, but recently... because of the economic crisis in Korea, all overseas development has been scaled-down quite a lot. But Samsung as a company is absolutely huge, and people know it for the electronic goods, and in Seoul there are 200-odd industrial designers working on all ranges- ranging from white goods, right through to AV, cameras, videos, all sorts. Here we work on things mainly for the European market- we’ve worked on white goods, hi-fi systems, televisions, mobile phones, washing machines, vacuum cleaners, all sorts. But also within the Samsung group there are things like digging machines and super tankers...

Things you don’t normally associate with...

Things you’d never think are Samsung. They’ve just launched a car... I don’t know if it’s going to come across here, but I guess that will be their hope.

It’s a huge range of products then.

Yeah. And like you know the two twin towers in Malaysia, in Kuala Lumpur... Samsung built one of those... Samsung Construction. So it’s just like a huge wide range of things. Obviously I work for Samsung Electronics, so that’s pretty much focused on consumer goods.

When, during product development, are industrial designers involved?

Erm, it varies, but in an ideal situation we’re involved right from the very start. We have... I mean I work in the European section, so we have European product planning teams...
consist of engineering experts, industrial designers, marketing people, sales people. And maybe once every three, four months we have a meeting somewhere within Europe, and we'll discuss current projects that are going on and we'll present new design ideas. It's a good chance to get to the sales people what they want—what their customers are asking for. So that's like a forum for new idea generation— it's a forum for critiquing work that's on-going, and for work you get is just tweaking old products - changing control panels and you might get the chance to change a moulding and update colours.

Are the rest of the design team members at Samsung Europe in this building too?

Well, at the moment I am. Yeah, basically because of the Korean crisis we were told we had to close down all overseas design departments, so I'm in the process of wrapping-up the Samsung Europe design centre, and what we hope to do is... they hope to take me on as a consultant, so they still keep some sort of design [person with knowledge of the European market].

So that will mean a switch back to Korea will it?

It will go back to Korea, but they realise that pretty much to... they need some sort of foothold within the European market. So in a couple of year's time, once... the Korean currency has just plummeted, and has reached the bottom, and it's just beginning to sort of go through the bottom of that curve, so they realise if they close down the entire European design centre now, in a year's time when they want to start it up again, they've got another three year's work to do to get it up to the stage it's at now. But if they keep me on for a year or two years as a consultant, I can get in going again much quicker when it comes back on-line.

What importance does the company place on materials and manufacturing processes, as part of your work?

As part of my work, Part of my job is to identify new materials and new processes and, as part of briefings we sometimes get from Seoul, they also identify new technology. We spend a lot of time researching products—we create these reports—haven't done one for a while, but we send these back to Korea. We create design trend reports for Europe, where we find new products and innovative things.

Right, you'd be looking at different materials, and what you could possibly put in your own products?

Yeah, yes, certainly. And design industry colour trends, and recently one over the past year or two, one of the big things has been translucent materials-they've made big in-roads, especially in the kitchen. So that's been a trend we've kept a very close eye on.

So you're looking at keeping an eye on fashions then, to make sure you're not sort of behind... or well, to make sure your ahead really...

Sure. Well it's a difficult game. I mean often people will want to say well, what's the next big trend going to be. You can't really tell. Often I wish we were more like Philips, who tend... I don't know if you've seen their 'Vision of The Future' project. Philips set a group of designers to work, I think it was 8 to 10 people, and they gave them a huge budget. They briefed them all on
new technologies that were coming, new social trends that were coming up, and said 'go away and design sets of products'. They spent about a year making all these products - they made a beautiful book and they made little videos of how these things would work. Then they published it, maybe two years ago, and Philips did a very clever thing - rather than sitting and waiting, trying to predict what the future was, they literally went out and made the future. Because now the visual trends and materials trends that you saw in Vision of The Future are everywhere - every designer who's seen them has ripped them off.

Do you think it's partly because they've seen that it's Philips, so that it's got a sort of 'stamp of approval' on it?

Yeah, and it's partly because it looks so great and Philips have gone out and made the future. They've said 'this is our vision of the future', but in reality what they'd done, everyone then had to play catch-up with Philips. It's the way designers work - they sort of look around, see what's around, take bits of this, little bits of that, and you keep seeing this Philips stuff being regurgitated again and again and again.

...but you know where it's come from...

You know where it's come from, and often when I go to student shows you can tell the people who have seen the Vision of The Future because they've got that style.

Do you think that comes through both as the style of the product and the style of the materials they've used, and how they've used materials?

Yeah, I mean Philips were the first people to start using translucent materials, and you see very much in their future work these shapes coming, and these translucent materials, and metal and plastic combined, and designing for tactile experience - like handles and soft-touch textures. You see this in quite an extreme form in Vision of The Future. And then a couple of months ago I went to a trade show in France, and there was the Philips stand, and although it wasn't as extreme, there were little touches of translucency appearing, there was this nice soft-touch. You can see how all the other designers at Philips were learning from this little team that was set up.

So that's appearing in their mainstream products?

Yeah.

Could you explain the significance of materials and processes - if your work didn't involve it, would it all collapse?

I don't think it would all collapse - I think it would be a lot duller. I mean materials and processes are where you can add some spirit to your design. Often we have to design ranges, so you have things which are good entry-level products and then you have the next step up and the next step up - how are you going to differentiate that? You can keep adding buttons and features and things like that, but that's a very dull way to do it because people now... I think there's a big trend away from hi-tech products. A trending back towards more simple but better-made products. So often the way we will do it is by use of materials - by adding in soft-touch...
materials, transducers and metals or rubber-type things. You can raise the perceived value of a product, probably without adding too much cost.

In the past it's all been technology-driven. If you were going to buy a top of the range video, you got one which has got a great ream of knobs and buttons on it, but now if you're going to buy a top of the range video, you're going to get a fairly simple-looking machine, but you know all the technology's in there- you know it's going to have four heads and surround sound and Dolby and all that.

It's the way it's being presented to you...

What are the kinds of properties you look for when you are assessing if you might use a material in one of your designs?

I mean basically the way I do it it's just things that catch my eye, things that make me stop and go 'wow'. Things that I've been recently are the Dyson vacuum dealer... where here's this again in like clear plastic- you've got all these beautiful shades of blue and the yellow inside showing through. Now I don't particularly like Dyson's design, but that one's just stunning- looks amazing. The grey and yellow one, which I thought was an OK piece of product design, a bit aggressive, a bit like a gun... to this one, which suddenly just by changing the materials it's changed the entire character of the product- and that's great.

They're probably coming off the same mouldings but...

Sure, just different material. In the past we've fought very hard to hide all fixings and hide all ribs, sink marks and things, and somehow on this one you can see all that- it just makes it more... more beautiful, and I think fits in with Dyson's technical image... shows off his technology. And always when I'm out shopping and things like that at weekends, if I see something that makes me think sort of 'oh, shit, you know, wow, that's good', then I'll make a note of that. I think as a designer you're constantly like cataloguing ideas that you want to use.

You've just got to keep your eyes really open?

Yeah, I mean I can't think of any other way to do it. I mean sometimes you'll go to a meeting or visit a factory and you'll see something that sparks off an idea for how you can use that technology in a way that you're working, or maybe there's another product. Recently we did a washing machine- for the buttons I wanted a silicone rubber sort of feel, because I felt that rubber and a washing machine and water all went well together because, you know, you want something safe when you're pressing the buttons, it was a top of the range washing machine, so you wanted to add some texture, wanted to add some tactile experience. So rather than just having a white plastic front with white plastic buttons, it had a white plastic front with soft-touch very light grey buttons or blue.
You're adding to the experience that the user gets?

Yes, it's a tiny thing, but often... I was quite surprised... about six months ago we did a focus group with a group of just normal people on phones. We got them in, you've got like a lot of phones in front of them, got them to use them, comment on them. It's amazing how sophisticated their critique was.

Just people off the street?

Yeah, just people off the street, you know. We got them in and said 'we want to talk to you about phones?' Often they don't know why they like phones more - they could say 'well, it's something about the buttons'. We put like a Siemens phone in front of them which was beautifully engineered, high quality plastics, and we put like a cheap (some other make) phone in front of them, and they could tell the difference without like... because they both have a quite similar visual style to them - they're quite Germanic, quite straight - but they knew the Siemens was higher quality, because of the level of finish on buttons, the click of the keys...

Were they getting to manhandle them all?

Oh yeah, yeah. And they were getting down to how the buttons felt, you know 'ah this click is the perfect click and this doesn't feel like it's...'. It's all that tactile experience, even if people don't actually know perhaps what they do like more.

They get a feel for what they do like...

They do pick up on it, yeah.

I'd like to know something about the constraints that are placed on you when you are having to design your products, as regards to materials and processes.

Well generally at the start of a project well have a brief which will say the price point that this is going in at and the kind of constraints that we're going to come up against. Sometimes it's a particularly complex project, I've had to go out to Seoul for a briefing and meet the engineers and spend an hour or two hours crashing through all the points of what I can do and what I can't do. Obviously there's no point in designing something if you find you can't fit the PCB and batteries inside, so I like to get as close to the internal dimensions as I can. And from there on it's just production processes. After you've been working as a product designer for a bit, you get quite au fait with draft angles and how you have to design, but it's always good to try and push things on, because often engineers are very good at engineering but not so good at innovation. I find often with engineers, if you can put a product [proposal] in front of them and say 'this is how we want to do it', they can take that to bits and they can improve upon it. But if you try and explain an abstract thought to them, you can just forget it. So, there's no point in... that's the hardest thing about being a product designer, is trying to be creative within the limitations of production processes. Any form can be created with sculpting out of marble and adding bits of leather and wood and things but...
big is the range of processes that you could specify in a product- I mean, does it have to be one of a particular list because that’s available?

Erm, often... 95... 98 percent of things I do are injection-moulded plastic. That’s all you get, I’d love to... I won’t even try to specify wood or something. But on some things like televisions or things like that, you can get a bit of wood in there, if it’s a high-end product. But the moment you do something like that, the costs just go through the roof because all the... most manufacturing places are just set up with lines of injection moulding machines, chucking out injection mouldings, trundling along in tum televisions and VCRs.

So all you’ve got to do is change the tool and it’s back on and you can keep churning it out...

That’s right, and if you’re going to start trying to convince a company to spend thousands, if not millions of dollars on getting some wood in, to put a wood strip along something, you better have a bloody good reason. And if you’re going to do something like that, you have to work almost twice as hard to get it through as you would normally. You really have to fight and push it through. I mean often the longest fights we have are to do with shape. I mean I want very soft, ergonomic forms with very complex curving surfaces, and that’s very difficult for the engineers to do. They’d much rather I’d put a single radius or something...

... straight line or a radius?

Yeah... so you have to fight very hard to get... make sure that the model that you supply and the drawings that you supply are what’s actually turned into reality. Seymour-Powell have a really good slide show that they give to clients- sort of take a picture of Claudia Schiffer- put her up on the screen and say ‘oh she’s beautiful isn’t she’, and they’d say ‘oh yeah, yeah, she’s beautiful’. They put another picture up and they’ve just changed her slightly in Photoshop- they’ve just moved her eyes slightly more apart, and they say ‘ah, it’s alright, she’s still beautiful’... then they do another one and they’ve changed her a little bit more, and then they do another and by the end she’s looking really weird. And they say ‘all we’ve done is move her eyes by a mill, and made her nose 3% bigger’, and they say ‘if completely changes her doesn’t it?’ and the clients are going ‘yeah, yeah’... ‘well this is what you’re doing to our products’. Because often engineers will just add a mill here, add a mill there, take a bit away, take a bit, sort of interpret the shape or the form, and the product completely changes. It’s very difficult to police things like that, but that’s where the effort really has to be put in.

So you’ve got to act a bit like a policeman on that one?

That’s right, you’ve got to. I find that you have to be very firm with the engineers - it’s no good being a prima donna and throwing your keys out of the pram and demanding you get this, even if it’s going to... I mean there are some things, certain types of tooling where it will save thousands of dollars, and if you can do that then you save thousands of dollars on... make thousands of dollars more profit. So you’ve got to be realistic, but you’ve also got to work very hard to push them to get what you want. And sometimes you don’t make many friends working that way but you do tend to get a bit of respect once they realise that you can do it.
do you start looking at materials and processes, if you’re given a brief?

Um, there’s no like set stage. What I basically do is… when you get a brief you immediately start to think… what I try and… if possible, I always like to get a brief a month before I actually have to physically start the project because that gives me time to just chew it over… have it ticking over in the back of my head, and if you find ideas coming to the forefront, make a quick note. Or there might be a project where I haven’t done, or where I haven’t worked before… when I did my first phone, I’d never designed a phone, so I immediately had to get, gain knowledge of what was happening in phones at the moment… what was the best selling phone, what was the best designed phone, you know that sort of thing. So you have to do a bit of research, and in doing all that research you come across interesting things, like ‘oh, they’ve done it that way, they’ve back-sprayed, they’ve put texture’, and you get a feel for how companies are raising their brand image, or raising this product’s perceived value—and it might be by putting some chrome on it, or changing the shape of the buttons or something like that. And with that, certain materials tend to suggest themselves. As a product designer working in consumer goods, most of what I do is plastic—well, all of what I do is plastic. So it’s basically different types of plastic, different finishes, em, different finishes on the plastic like spray finishes and things like that. And once you’ve been working for a while, you tend to get a feeling for how, whether the product can absorb that cost, if it’s a little mobile phone then you can start playing with really nice touches and things like that because the market demands it… but if it’s a microwave or something, they’re very cost-conscious products, and the cheapest method is going to be the one that’s going to be taken; there’s no point in me suggesting ‘we’ll put some real chrome in here’ and ‘we’ll put some gold trim around here’ and things like that, because they’ll just throw it straight out.

Is that really just down to experience in knowing what you can and can’t do for the particular product ranges?

Yeah, I think so. But there’s things using materials to add perceived value is very different from market to market. One thing you’ll find is things that are perceived as being stylish and high-brand image in Asia are very different to things that they perceive here. They think that in Asia very hi-tech products with lots of buttons and flashing lights… that’s like really hi-tech, ‘wow, that’s really great’, whereas in Europe it’s sort of simpler, more austere almost design is considered more hi-tech. So that’s very difficult—for different cultures to come to terms with, if you’re designing to sort of work out what market you’re designing for...

That’s why you need to be kept on then?

That’s why I need to be kept on, to keep that European input going on.

Are there occasions when you deliberately put materials and processes to one side. If you’re sort of being treated as, um, what you effectively end up with is a processed form in a particular material, are there occasions when you put that aside and you say ‘well, I’m actually not too bothered about whether it can be made just yet’, and concentrate on something else?

Oh yeah, certainly. I mean at the very initial stages, it’s very bad to censor yourself. You can’t start thinking… when I do an initial sketch I don’t start thinking ‘how can it be moulded?’. I’ll do a sketch and then try and synthesise that into something that can be made. Generally, most things can be made—it’s just a question of cost, and maybe it’s because I’m getting old and bitter.
you just tend... I've been working for five or six years now, you're constantly working on things that have to be made. You just find yourself telling... I find it very difficult to design things that can't be made now, because you just don't have time in a working environment, you don't have time to sort of go right through all these big long spiralling loops that you go through as a student. You just have to come up with the idea very quickly and get it out very quickly, because you'd rather spend time policing that design through, and doing as much work as you can at the front end to make sure that the design that you hand over is as producible as possible - so that it doesn't get messed-up, rather than going... spending a lot of time at the sketching phase, going through millions of different ideas. I mean, the maximum you'll ever present is three ideas, and that's...

What sort of things do you pick up on, with regards to manufacturability then?

Erm, basically, how you're going to put things together, part lines, fixings. I mean you've got to make sure when you're designing something that there isn't going to be a great screw-boss right in the middle of the main fascia or anything like that. Um, there's also a lot of things you get used to how to use mouldings interestingly. Like to have two mouldings, and one moulding goes through and appears again through another one, so you get like sort of different colours coming through and things like... It's just how to be creative within. Because you know that when you get to the end, you get your model made and you go to present it, there's going to be all these engineers there who want the easiest life they can possibly have and they're going to want to shoot your design down so they can say 'well, we know what's best'. It sounds like a war, and often it is, but often it isn't. Often you get engineers who are excellent and are really in to making... once you get a certain degree of respect going between you, you can do some really great work. There's no point in being an arty-farty designer; you're not going to get an ounce of even mould... Engineers will want to change things because they can mould it cheaper, and you have to say 'yes' you know, unless it's really going to ruin it, it's sort of 'OK, that's fine', because we are in a cost-conscious market sector. So costs are everything. We'd all love to design the perfect products and have these beautiful bits of art product, but in reality you don't get to do much of that.

So it's a matter of going in with some good ideas but also knowing full well how it's going to be manufactured?

Yep, you've got... I mean all the products that I make I am sure can be moulded. Often engineers will want to change things because they can mould it cheaper, and you have to say 'yes' you know, unless it's really going to ruin it, it's sort of 'OK, that's fine'... because we are in a cost-conscious market sector. So costs are everything. We'd all love to design the perfect products and have these beautiful bits of art product, but in reality you don't get to do much of that.

I was just looking at the Daewoo catalogue [a design brochure on the desk in front of me, featuring some very odd looking designs for consumer goods].

Yeah, God, what are they playing at?

There are some funny things in there aren't there?

They're bloody awful, aren't they. Aren't they? That was from this trade show - I couldn't believe that they put those out on show and said 'this is what we're doing as our future'. I just think it's absolute bullshit and should be broken and thrown out. But Samsung also do a lot of future stuff, but we try and do... recently we did... two years ago we did these three in this office [points to boards showing three designs on the wall, which were three... the 'junior' TV is like a little...
remote, a little child's portable, so it looks basically a bit like a fish, and it's quite good fun. But you could make it; well, you couldn't really because of the tube- the shape at the back comes in right around the tube, so it's very difficult to make. But if they did want to make it, we'd just put all the running gear in a different box and have a cable going to it.

Yep, yeah...

So you could conceivably make, so it is real. In those more speculative projects, are the materials and manufacturing processes still specified?

Em, basically...

...or still worked-out, anyway?

They're still worked-out to a certain extent. Perhaps it wouldn't be as in-depth as if I was spending a television just for normal, then I would have all the parts and the costs they would go, and I'd have a pretty good idea of how it would all fit together.

I mean these are like real initial sketches for a vacuum cleaner, and I'm like working out how it would all fit together. This was... the whole idea of this was reducing costs to a minimum, so it was two big mouldings, a motor cover and... that's the sort of level. So I could present that to an engineer, and he could immediately have a good discussion on why he didn't want to do it this way- why he wanted to change this, why he wanted to change that. But if you can present something at that sort of level... I mean it's a scrappy sketch, but the moment you show that to an engineer, they can sort of go 'oh yeah, I see where he's coming from, I see why he wants to do that'. But if you go in and just sort of arty-farty around, it doesn't gain any respect at all and that's the hardest thing. Too often in the past product designers haven't understood... they've either been very good engineers or very good stylists, and I think the real talent comes in merging those two. Not being perhaps the best stylist in the world, and not being the best engineer in the world, but being able to flip between the two camps and that's when you're going to get a reasonable product.

Do you think that's where you're most useful as well?

Yeah, especially in a company like this, which is dealing a lot with very high end things, right down to £79 microwaves. So there's no point in being a perfect stylist on a £79 microwave, it's all about how can you reduce the costs. But then maybe when you get to a hi-fi, then you're talking about something a little bit different because you have got a little bit of cost set aside for styling and playing around.

People are willing to pay out a little bit more money for something interesting...

Certainly, yeah, yeah. And that's the kind of project that people would pay for. But a microwave- how cheap is it? is the main thing most people want to know.
Keeping on 'level of detail', how far into design for manufacture and that sort of thing do you go into?

Erm, not that far. I know some companies do go very far into it and some product designers are absolutely excellent at it. But I myself am not very good at that and I don't find it's a good use of my time because it isn't my strength. Samsung as a company has millions of these design engineers around, and that is their strength... and I feel my strength is coming up with the creative, realistic ideas and handing them over in a form they can understand and work with.

And what I have done is the past as... with projects, I've gone Over to Seoul or Korea and stayed over there for two weeks working with the engineers, gone down to the factories and sat with them on their CAD stations, sort of helping them with problems, with perhaps my drawing doesn't meet up with the model, because I'm only making 2-D model making drawings, and I give that and a model, and they have to try and interpret these two things and turn them into a 3-D producible model. So it's a teamwork thing, but it also depends on the strengths of the individual designer.

Right, so would you look at things like the weld lines on an injection moulding, where they're going to appear and that sort of thing...

Yeah, I mean...

...even if you didn't look at the tool design itself?

No, I wouldn't look at the tool design. I just don't know enough about it, it's such a huge field.

And often when I get into situations where engineers say to me 'well, have you thought of how this will be made?', I have to say 'well I've thought a little bit and I think it can be made but... that's what you're here for if I could do that, then I wouldn't need you- I could just take this straight to a toolmaker.' So it's levels of...

...using your skills to your best...

Yeah, I don't feel that, personally I don't want to spend all my time on tools and working out how things fit together, but I feel there's no point in me handing over things that can't be made.

So, still treading that middle-line, but it depends, as I say, where your strength lies.

How quickly might you go through from talking in general terms, sort of like 'transparent, hard plastic, thermoplastic' through to then saying 'well, it's going to have to be polycarbonate, or whatever' and then right through to the exact grade- what sort of level do you pitch materials at?

Generally the engineers know what they are going to use, so we get told, you know, 'we're using ABS.' Or we say we want to use clear materials and they say 'oh no, you can't use that' or... So...

That again is very much dictated by the product that we are working on. Generally the engineers know what they are going to use, so we get told, you know, 'we're using ABS.' Or we say we want to use clear materials and they say 'oh no, you can't use that.' So...

Generally we don't have too much input into that, because it is such a cost-driven thing. I mean if I was working as a smaller batch designer or a one-off designer, then I would have a lot more input into the materials I was doing. Because you are designing for mass-production, you generally don't have too much choice, and generally the factories are stocked, massive stock piles of these materials, so they want to use them.
Sure. If you're going to do anything a bit different, you've basically got your work cut out.

You've really got to push for it and fight for it and you've got to prove it a lot more than if you go in with something that's very standard and very usual and uses all the same materials as they're used to using, all the same manufacturing techniques, all the same graphics and colouring, it's easy. But if you decide, for whatever reason, that you want to push it, you've really got to be prepared to go in and tell them how they're going to do it. Make sure... be willing to police it all the way through, right through...

Otherwise it could just come out of production a complete mess, or just side-lined?

Yep, sure, they will literally just change things without telling you and the product... What has happened in the past with a consultancy we've used before we had a European design centre, they've given in their drawings, gave their presentation, Samsung said 'thank you very much', gone away and manufactured it and then brought it out two years later and looks nothing like the thing that the consultant gave them. But they're still attaching this consultant's name, especially when they used to use really famous design consultants like Porsche, and they got this phone out and it's a right dog's arse of a phone. And I said 'but this is awful' and they (Samsung) said, the model was beautiful, but our engineers couldn't do it... So...

Defeats the purpose!

Defeats the purpose, so when you're in... but because I'm in-house I can police things a lot more, because I have quite good relationships with people at the factories because I've worked quite hard to build-up those relationships. They want... tend to work a bit harder to please you... if it's somebody who's gone away, and they know this person's never coming back, they can sort of say 'ah, let that go, let this go', but they know that I'm here and next time I'm in Seoul I'll be down to see them and say 'right, what's going on with this, what's going on with that?'.

Is there any manufacturing base in the UK?

Yeah, there's a big factory up in the north east, up at Winyard, where they make microwaves and televisions.

Do you go up there occasionally?

Er, until now I haven't had a project that's been made there, but currently I'm working on some microwave projects and that probably will be made there, so I guess I will have to go up.

Have you had any projects on the monitors, Samsung monitors?

No I haven't no. Those are all done by IDEO in the States.

Right- a bought in consultancy?

Yeah.... I wish I had because they were good fun, really nice as products.
What printed matter, like charts or written procedures, if any, do you use in your work?

Erm. What I tend to do is, because of the language difference and the time difference and the far side of the world difference, when I present things I tend to write a written report on it with pictures and explaining what I've done and why I've done it, because often I find you give a presentation, it will often have simultaneous translation as well, so sometimes the translator isn't a designer, so he doesn't know how to translate certain words, so they make it up and somehow the points don't come across. You have to make sure that people are getting your point. So for all the main guys there, I'll give them a copy of this report. So when... if there are any comebacks, I'll say 'no, sorry, in my report so-and-so it states this date or that... From Korea, often we get briefings that are sort of spec-sheets and charts and button layouts, but there's no actual standard briefing form. It's something that we should really get round to... I think maybe if I was a Korean designer there would be because it's all... the stuff I get comes from whoever can speak good enough English to translate it for me.

So if you were over there, then maybe it would be...

I think if I was over there it would be very different. I think there's a far more formal structured approach over there. Here we tend to be... they find it strange because in Seoul the designers work very differently— they're very methodical. They do sketches, present sketches, someone chooses a sketch they think is good, they do models. Someone chooses the models they like, they do better soft models. And it sort of progresses that way and there are very definite stages, but as designers in the UK and Europe, we tend to work in a fairly haphazard way. I'll have a CAD drawing on the go, sketch book and a box full of foam models.

All on the same project?

All on the same project all at the same time. When I first worked here, they found it very difficult, when they said 'can you show us the first stage sketch presentation', and you'd say 'erm... there you go' and they'd say 'no, no, no... just sketches' and you'd say 'we're not doing just sketches, you know, here's a model of this sketch'. So I think in Korea, as I said, it's a lot more structured, but as designers here, we're taught to be a lot more fluid in our design process. Often I will try to document that as I go along, or document parts of it, at least.

Do you use computers at all for materials issues?

Erm, not for materials no. I know they do in Seoul, obviously when they get to 3-D CAD and things like that.

They render-up in different materials?

Yes they render-up and there's flow diagrams and things like they can do, and by doing it they can show where weak points will be and things like that. So there's obviously all that but I myself don't do it. We have got a 3-D CAD system here that they use in Korea that I should learn, but just since I arrived, we're talking two years now, it's been absolute bedlam.
Well these things take a lot of time to learn don't they...

Sure. The way I... they keep telling me that I should learn it, and I say 'OK, if you can give me six months off from the on-line work, I'll learn it and come back good at it, but until you can do that, I'm not banging my head against a wall trying to meet your deadlines.'

You couldn't fit it in?

No. All our stuff is Mac-based, so we use Vellum and transport that into Illustrator for graphics and... so it's all very easy, I don't need to move from my desk. In Korea they use CORS ideas, which is quite an in-depth CAD system.

Do you have samples of materials around that you manhandle?

Yeah. We will have... often when I'm trying to propose a new process or new material, I'll try and get some of that material. Recently for a vacuum cleaner project we were doing, I wanted to do a perma-bag inside. My previous job I worked for Electrolux, so I knew we could get these perma-bags, so I got the name of the company and I got the materials, got material samples sent to us. So then I took all that out to Seoul and actually showed them, rather than just buzzing in and saying 'oh yeah, that's a perma-bag, there's the name of the company', I actually got it and got the rep to come in and give us some... give me a briefing on it and get lots of test results - so that was a way of introducing Samsung to a new product and a new material. Also, here we have keypads and things that we like - like buttons and things like that...

Keep a stock of...

...we keep a stock of old nonsense and things like that.

Bits of broken product?

Yeah, we've got loads of broken products through there [points] and often when we're doing a project, if there is a particular product within the existing market that we think is doing something very good, we will buy it, take it to bits, send it out to Korea, find out how they're doing it. That's a very standard way within design... from car design, right down to...

Taking competitors' products apart?

Yeah, you take them to bits.

Can you elaborate on the significance of experiencing materials first-hand?

Basically anything that stops me in my tracks and makes me say 'wow'. You see a product and you think 'wow, that looks bloody good!'. I want to know how they've done it and... Electrolux released a vacuum cleaner recently that's got nice soft-touch rubber handles on it, so you think 'wow, what's this material?' and try and find out what it is, and maybe take it apart and have a look at the labelling inside and try and track it down. We sometimes get from Seoul every now and then we have these workshops in Seoul that are all to do with the on-going design issues, and like we get lectures on new materials, technologies for product finishing. So like this shows me a series of impressive looking data sheets on new / emerging materials and...
finishes, showing both visual and mechanical properties, costing and benefits / drawbacks compared with alternative methods/materials. ...I dunno [picks up one example]. ‘vibrating adhesion’, and then they sort of give an idea, examples of what it does and they have this quite interesting graph that sort of... the closer it is... the further way, the more it is... so like this is medium cost, it’s quite an easy process, it’s medium elegance, it’s very workable, it doesn’t save on many parts...

Is this research by Samsung Korea?

Yeah. So we will get things on occasion, we’re trying to put things like this in place whereby this is on-going, and other things that are coming up are like an intranet site, so within Samsung you’ll be able to go on the net and surf within the Samsung web site and get hold of information like this.

How common do you think it is that product design companies will have this sort of thing? [pointing to the data sheets]

Bloody rare. This is only the first stage and I would hope it would go on, but with all the troubles in Korea with its currency, it’s... stuff like this costs a lot of money and it’s the first thing that gets cut when there’s troubles.

...but it seems like a really useful resource, fantastic.

Oh yeah it’s brilliant to get things like that. But generally the way you do it is you find products that you like, and in Seoul they have like whole cabinets just full of like materials and finishes and that sort of thing... taken to bits and they label them how they’ve been done, so designers there can go, when they’re making a presentation... you can take that and say ‘look, this is what I’m thinking of and you’ve got something real to hold on to’. And I try to do that as well. If I’ve got a specific process that I’m looking at, I will try and find something that has that process already, because often you will present it and all the engineers go ‘naaah, naaaah’- and you say ‘there you go, they’ve done it- now, for the price, match it’. When you do that they can take it to bits and say ‘ah wow, you know, that’s how they’ve done it’. It’s such a huge field, there’s no way you can keep up with it. As a product designer you’ve got so much on your plate anyway just keeping up-to-date with everyday work. So the only other way to do it is to keep abreast of things in the design press- Design Week, Design magazine, id, Blueprint, you know, you just look at products, see what catches your eye- try and work out how the hell they’ve done it.

It sounds like Samsung are really ‘up with it’ on that one though.

They realise they’ve got their work cut out. I mean obviously we’re trying to compete with Sony and Philips and all these very established brand names, so our products have basically got to be better than theirs. So you’ve got to do a lot of research and it’s a long process and I think three years ago our products were bloody terrible, but now I think thet’re only bad, so that’s a good step and if we can keep those steps going then that’s great, but if we take a step back we fall back down. We do have certain products that are excellent, like the Samsung monitors- they’re really nice, beautiful design, good performance. Some of the televisions we do... I mean one of the things most people don’t know is we make a fifth of the world’s television screens, so quite a lot of the televisions that people are watching that are Sanyos or something- they’ve got a Samsung screen in it.
That's all hidden away, though...

It's all hidden away and people think, if they had two televisions together, they'd probably go for the one with the higher brand image. That's all the power of brand image, so we've got to design products that are better and perhaps mould-breaking in a way, to try and move things on.

Do you have a look at the graphics on your products?

Yeah, we try. That's another thing which is very difficult. You can't get a decent graphic designer to work full time on product graphics because it's bloody boring; they all want to do books and things like that, which is perfectly... You know, it's like asking a product designer just to design knobs: it's just not...

...they're just not going to do it are they...

They're not going to do it. So you tend to find that product designers with varying degrees of success in the graphics, and sometimes that's great because graphics on a three-dimensional product... So when that works out it's great, when it doesn't you get these bloody awful graphics, and you often products have too many graphics on them I think.

I think it's a very important part of the product...

Yeah, definitely very important and often I think on graphics 'less is more' sort of thing, but that's another cultural thing, like we find that Korean products, within the Korean market they love things with like 'super high bass' or 'super-iron magic system', whereas like Europeans may like a very subtle 'super bass'.

...or just the company logo and that's about it...

Yeah. So, you know, again there are cultural things to overcome here, but graphics are very important and I tend to be quite good at graphics so I tend to try and work them in right from the very start, have an idea of where they're going to go because there's nothing worse than designing the product and forgetting to do 'shit, the logo... can't fit it in, so you get this logo squeezed in and it just looks crap, so it's something you do have to consider. At the very least you have to consider where the brand's going to go... but if you can consider all of it, then so much the better.

What sort of processes do you use to put printing on, graphics on?

Erm, there's 'tempo' printing which is like a big rubber, and they print it and it just comes out on top of the piece and prints. That's a very cheap process.

Does that produce white-on-black if you want it to?

Yeah, it can do, but what often happens is it comes out very grey-ish. (I point to the Sony Dictaphone that has grey printing on it- "yeah, that's tempo-printed"). The other thing is you can silk screen- that's a bit better, and then you can do like printed panels that you drop in, give you better again. There's also a lot of in-mould graphics you can do- you know, you see these
mobile phones with fake wood effects on them and all shit like that- there's a lot of stuff you can
do with that. And you can incorporate graphics into that as well. There's also processes like
vacuum-foiling, where you see the foil... shiny graphics that are almost part of the moulding...
that's foil, done within the mould. As the mould comes together that's all done. [I point to
the Sony again, this time the main logo- "I think that's foiling, on a bit of raised thing"]). And then
obviously there's the badges that you can like drop on, that tend to get like higher quality like
televisions and VCRs and things.

[Referring to the Sony foiled printing] That one tends to sort of rub off after a while...

Yeah, yeah. Again, it's very cost-driven. To do foiling costs more than to do tempo-printing, so
if it's a cheap product, you're going to get tempo printing.

Do you get transfers as well that you'll use?

Sometimes, but it's quite rare because it's quite labour-intensive to put them on.

Do you think that concern for things like materials and processes can constrain your
creativity?

Er, at times when you're initially sketching, you come up with something beautiful and you
can't think of a way to mould of it but that's just part of your job, you've just got to be realistic
about how you're going to make things. It can constrain you, if you let it, but as I said earlier, the
skill comes in being creative within the boundaries of the production processes and the costs that
you've got to meet.

There's no point I suppose being creative and... Being imaginative rather than creative...

Yeah. I mean, any fool can come up with a beautiful design. Any product designer who's done
a year or two's training can come up with a beautiful looking product, but it probably costs
thousands of pounds to buy and it's just not realistic. I think when you leave college and start
looking for a job, I think that's one of the things people are looking for when they look through
your portfolio. They're looking for that spark of creativity, but they're also looking for a realistic
creativity that they can immediately put to work on products. There's no point having someone
whom you have to completely train from scratch in the ways of draft angles and part-lines.

Are green issues like 'design for disassembly' and 'design for recyclability' - do they have an
increasing bearing on the company's work?

Yeah. Ah they're going to have... At the moment it's still in this in-between stage, where
companies are realising they've got to do it, but they're sort of 'oh well, maybe, maybe', but
there's a lot of people, there's a lot of countries introducing things like 'take-back' policies, where
large companies have to take back their old products and recycle them. So obviously that's a
huge cost and in Germany, for instance, there's a lot of... there's this 'green point' mark that
products have to pass, where they've got to hit a certain set of environmental criteria, before
they're allowed to be sold in Germany.
That's to do with being able to be taken apart is it?

Yep... and labelings, mouldings. And there's things like not sticking two different types of plastic together; working with the minimum amount of screws... That's legislation isn't it?

That's legislation yeah. And it's coming in all over Europe. At the moment Germany's being a bit naughty really... they're saying that they're doing all this, and holding up all these things saying you know 'we're the leaders in ecology in Europe'. But all they're doing... all their companies are doing are taking back all these products, driving... putting it in a truck, driving it across the border into France and dumping it there. So until all of the world gets its act together, that's always going to happen. Companies are always going to move until... so once all Europe gets... Eastern Europe will start to get all the shit. When I was at Electrolux we did a lot of work on all this 'design for disassembly' and we had workshops, and we had companies come in and speak to us about it.

We had this quite interesting thing with BT phones. The way that BT work is they get product designers to design their phones, then they tender out to companies to make phones for them. So we had two identical-looking phones made by two different companies- one was a European company, and one was made in Malaysia. From the outside you couldn't tell the difference- materials were the same... it was only when you started looking at where the screw bosses were and the fixing points were very different... What they said to us was we had to take these two products apart. So we took the European one apart in minutes, it was literally five minutes and the thing was all in bits, a nice pile. The Malaysian one took about fifteen minutes, and they had things like two different pieces of plastic glued together, they'd sonic-welded two things together, they had a big lump of lead glued into the handset to give it weight... so that was appalling. That really brought it home to us how we couldn't do that any more. As a result of that, we went through all our products, all our vacuum cleaners, found all the problems with them and tried to fix them. There's a lot of things you can do. We used recycled material for non-visual parts- untreated recycled, so you got this sort of jazzy... it's called 'jazz plastic', all speckled and marbled... for motor housings and bearings and things like that that you couldn't see from the outside- that weren't visual- just reused all the old shit. That was good, and we looked into replacing the PVC in the cords... because PVC isn't very good but there's nothing that can replace it apart from this very expensive material, so at the moment it's too expensive for such a cost-conscious product.

Do you... could you specify recycled materials in products at Samsung?

I can try... Whether I can police that at the factory... Until it becomes a larger issue- a global issue, and it's important from a Government level, I can try as hard as I want, but in the end, it often works out cheaper just to bit a new bit out because they've got to collect all the old mouldings, they've got to regrind them, get them to the right consistency... you've got to have someone sorting them, you know, PP, ABS... so it does cost more. So until it's on a Government level, you can try as hard as you like but it's just not going to happen.
Do the recycling codes get put on to the components?

They should do... because I've only been here a couple of years, I haven't had much produced yet, so I haven't had a chance to check on that, but I would hope that all of our mouldings are labelled, and that we are adhering to that sort of thing. But again it's just such a cost thing the companies, until they're forced to do it by law, they just won't. Many companies will make attempts at it and make half-hearted efforts and make a big stink about how they are making these efforts, but in general no company I've seen is really making any big in-roads.

It's got to come from the top?

It's going to have to come from the top or no-one's going to adhere. Until everyone's doing it, what you'll get is if one company starts doing it, their costs will go up and everyone else's costs will stay down... so people will say 'well why should I buy them?'. It's a very cost-driven market at the moment.

If boundaries of knowledge were set on materials and processes for an industrial designer, what would you say was definitely something to know and what might be slightly 'out of bounds', if there was anything out of bounds? What would be the core?

Well it depends on where you're targeting your career. Obviously working for a consumer goods company like Samsung, I got to know plastic mouldings because 99% of what I make is plastic mouldings. But when I was a student designer on placement I worked for a company called Atkinson Design Associates- and there I was doing a lot of furniture and chairs and things, so there you had to know a lot about castings- aluminium castings, and wood finishing technologies and things like that.

A completely different ball game?

Complete different, and I think the only thing you can do at college is, within each project, research that project- because all college really teaches you to do as a product designer is to learn quickly enough to be able to talk knowledgeably about it. A project may come in here tomorrow where it's a television and they want a wood fascia, so suddenly I'll have to find out about wood production techniques- mass-production techniques. So...

You'd have to get up back up to speed on that?

I'd have to get up back up to speed on that, there are no limits. There's also basic... there's also other things that come in... There was one project where we were thinking about putting a neoprene case on it, so I'd have to learn about neoprene and how that was going to be produced. So there's always... as a designer you're never going to be finished learning- you're always going to have to understand new things or... And I think that's good... I think that's part of the appeal in many ways...

Yeah- you're constantly changing and you're constantly finding new ways to do things and... I know when I'm out shopping, my girlfriend gets furious with me... because I see something and I'm going 'what the hell have they done there?...' and I'm looking going 'look at this part-line', and she's going 'put it down, put it down! you're embarrassing me, you idiot.'
mean I'm sure you're the same... And that's how you find out, you file that away in the back of your brain and you think 'oh, yeah, that's how they did that, that's how they made that interesting sort of finish'. And you may not ever have used that material before, or you've just learnt about how to get the best from it.

Build up a huge great palate in your head... Yeah, that you can draw upon. And like at the moment because I'm working on 200 plastic mouldings, I'm pretty au fait with how to mould plastic and how to put part-lines in and how they're going to join up. But if I had to learn about something else, it wouldn't be too much of a problem to go out and find out about it.

Are there any other important points that I haven't really covered that you think are important to do with materials and processes?

Erm, no... I mean, what is this for... for your dissertation?

My thesis yeah.

Right, so you're doing a BA or is it an MA now?

I've done a BSc, this is at Doctorate level.

God you're a clever little sausage aren't you.

[Some conversation snipped out]

My main concern is that I'm not missing out some big issue that is really at the heart of things.

No, I mean the whole thing about being able to design within the constraints of materials and processes... Often in the past I've run projects with students and you go up and they give you a presentation and too often they're trying to be different... but they're too lazy to be different within plastic materials, so they start... One student produced a bloody vacuum cleaner in wood. So you're sort of saying... sitting down and say 'why?'... well, it's different innit, it's different.' And you say 'well, yeah, but is it better?', and you can tell it's never crossed their mind that perhaps being different isn't the best way... it's that way for a reason.

I think it's very good to come to projects with a fresh mind and have a completely fresh mind at the start, and try to challenge it- but not to be afraid to come back and say 'okay, I've been out here, I've come back now and, sort of, here I am... I realise now why you've done that- I've tried to challenge it and I can't do it'. So 'different' isn't necessarily better, and often when you're working, the changes you are making are tiny little things... tiny little adjustments. Whenever I start a project I try to think 'well what can I bring to this that makes the product better?... and it's all customer-driven, it's not...

It's not you designing for yourself?

It's not design wank driven! It's not 'oh, I'll make this the most beautiful toaster that's ever been made', it's 'how I can make the experience of making toast either more enjoyable, or easier'. 
Often a lot of rot is talked about—like there is a 'perfect solution' for a design, you know, for every design there is a perfect solution—and that's complete nonsense. You can get things like the Philips-Alessi kettle which is a very expensive kettle, but when you're buying that you're not just buying something that boils water, you're buying an icon—a product that says something about you, so you're willing to pay the extra £70 for it. So... and that all comes down to materials again, and the design. They've used design and materials to package a very standard piece of household equipment.

Yeah, when you look underneath it, all the technology is probably the same as...

Yeah it's all the same. And you can definitely get more hi-tech kettles cheaper. So it's all... understanding brand image and product placement and perceived value, and how people use design and materials to achieve those goals—that's where the tricky part comes.
Section One: General

1.01 Definition of terms
1.01a This PDS forms the core criteria for evaluating any final design.
1.01b LU refers to ‘Loughborough University’.

1.02 Conduct
1.02a All design work shall take into consideration the issues raised in the Product Background / Design Brief document.
1.02b Work should be carried out in accordance with the latest Timeplan.

Section Two: Development Prototype(s)

2.01 Guitar features (general)
2.01a Bronze wound steel strings, light gauge (e.g. Martin M540 .30mm - 1.37mm).
2.01b Standard EADGBE tuning.
2.01c 650mm scale length, joins body at 14th fret.
2.01d Cut-away for easy access to high frets.
2.01e Should be supported by a conventional guitar stand.
2.01f Stressed components need to withstand a total string tension of approximately 500N (140N downward component and 18N horizontal component at bridge) - based on Eddie’s test.
2.01g Assembly and construction should be such that the product becomes a solid ‘whole’ (Rob Armstrong).
2.01h For all components, show due regard for: styling, surface textures, colour, semantics, Rob Armstrong house style, graphics.
2.01i The possibility of assembly from three main components (soundboard, back/neck/head and fingerboard) should be explored.

2.02 Guitar features (others)
2.02a Strap eyelets.
2.02b Rosette graphics.
2.02c Other body graphics.
2.02d Serial number / (RA) model ID number / product name.
2.03 Ergonomics
2.03a Overall weight to be similar to traditional acoustic guitars (approx. 30N).
2.03b Comfortable to play both with a strap (whilst standing) and on the knee (whilst sitting).
2.03c If opting for a one-piece back and sides, investigate curved surfaces to make this comfortable.
2.03d No exposed features which may constitute a safety risk to the user.

2.04 Styling
2.04a License for styling is allowed so long as the shape is in keeping with the ‘visual essence of a guitar’, namely:
   (1) the instrument has two distinguishable bouts (upper and lower) and there is a distinct rise where the two bouts meet;
   (2) the distance between upper and lower bouts is not too great;
   (3) the upper bout must be of smaller diameter than the lower bout;
   (4) the lower bout must have a flattened base curve.
2.04b Relatively small body (Rob Armstrong) - lower bout width should be 15" (380mm). See design sheet for preferred shape of soundboard, back and sides.

2.05 Component: Soundboard and Bracing [to be detailed]
2.05a 100mm diameter (round) soundhole. Centre of soundhole to be located in line with guitar waist (OFP visual preference).
2.05b Rosette patterns and other graphics to be detailed and made.
2.05c 3mm soundboard thickness (Rob Armstrong).
2.05d Bracing patterns and material to be explored (assessed for sound quality and stiffness).
2.05e Assembly location holes to receive bridge plugs.
2.05f Edge finishing to be detailed.

2.06 Component: Back and Sides [to be detailed]
2.06a Combined back and sides or separate components should be considered.
2.06b The acoustic chamber depth need be no more than 100mm under bridge (Rob Armstrong).
2.06c Moulded-in ‘Armstrong’ logo on rear.
2.06d Binding (in polymer) to soundboard to be developed and detailed.
2.06e Shape according to design drawings.

2.07 Component: Bridge [to be detailed]
2.07a Should be placed slightly forward of the major axis of the lower bout for the best acoustic performance, in accordance with the specified scale length (distance from 14th fret to top E saddle for 650mm scale length = x mm).
2.07b Needs to withstand the pull of each string (50-100N per string approx.).
2.07c Strings should terminate at the bridge by means of the string barrels.
2.07d Strings need to terminate in-line with one another.
2.07e Built-in tremolo retainer slots (thin and thick).
2.07f 6° intonation angle for saddle (this is not critical - RA)
2.07g Assembly location plugs, to fit correctly into soundboard before gluing.
2.07h Shape according to design drawings.

2.08 Component: Neck [to be detailed; Rob Armstrong to make]
2.08a A stiffening member is required (truss rod).
2.08b Is a truss-rod cover required?
2.08c Width of the neck at the zero fret (nut) should be approximately 45mm.
2.08d Cross-section of the neck should be according to Rob Armstrong’s recommendation.
2.08e Neck should not form an acoustic cavity - needs to be of a material and construction that will dampen vibrations (Rob Armstrong).
2.08f Assembly to be detailed.

2.09 Component: Head [to be detailed; Rob Armstrong to make]
2.09a Should incorporate a 3-and-3 layout for bought-in silver machine heads (OP visual preference).
2.09b Machine head nuts should point outward rather than downward (OP visual preference).
2.09c Assembly to be developed and detailed.
2.09d Shape according to design drawings.

2.10 Component: Fingerboard [to be detailed; Rob Armstrong to make]
2.10a A zero fret should be included to make it easier to set the correct action (Rob Armstrong).
2.10b The scale length (zero fret to top E saddle distance) should be 650mm (Rob Armstrong).
2.10c 20 frets should be included on the fingerboard.
2.10d Look at fret marking types.
2.10e Look at fret markings on the top edge of the fingerboard.
2.10f Assembly to be developed and detailed.

2.11 Polymer requirements / adhesive requirements: run-down
2.11a UV stability to prevent discoloration over time.
2.11b No distortion or degradation due to surface temperature build-up between, say, -40 degrees C and 80 degrees C (product placed in very cold and very sunny environments).
2.11c No catastrophic plastic deformation due to high stresses from the strings.
2.11d Moisture resistance.
2.11e Humidity resistance.
2.11f Water resistance.
2.11g Surface finish resistant to scratches.
2.11h Surface finish resistant to spoiling by stains and dirt.
2.11i Suitably tough to withstand minor impact forces (knots).
2.11j Ability for material to be coloured.
2.11k Consistency of semi-finished material.
2.11l Materials should be suitable for reclamation/recycling and should be labelled as such.

2.12 Prototyping procedures: run-down
2.12a Combined back and sides
   CIBA Epoxy GRP lay-up in GRP mould (coloured; texture in mould)
   Vacuum-formed coloured Forex-EPC sheet (as an alternative)
2.12b Soundboard
   Machined Forex-EPC sheet
2.12c Bracing (and binding?)
   Machined clear PC (Lexan)
2.12d Bridge
   Machined coloured PMMA
2.12e Polymer adhesive
   ITW Plexus MA3940LH
2.12f Wood to polymer adhesive
   Epoxy
2.12g Rosette / other body graphics
   AVS Signwriting Printing / Screen Printing transfers?

2.13 Evaluation of guitar sound quality
2.13a Sound quality evaluation should follow the instructions laid down in the relevant documentation (spectral analysis; tapes made in recording studio; personal preference). Opinions from guitarists and composers will be sought.

Section Three: Product Placing & Modifications for Mass Manufacture

3.01 Product Placing
3.01a First prototypes are concerned with construction of a working guitar, with no particular marketplace bias. The option of a 'cheap and cheerful' (£100 mark) or an 'unusual and expensive' (£1000+ mark) product placing remains an issue to be tackled after the construction of a working guitar. Other marketplaces could be considered (for instance, as an innovative alternative to guitars in the crowded £200 - £500 market).
3.02 Marketing
3.02a Consider product name and marketing strategy.

3.03 Product Cost Break-Down
3.03a Reach decision on anticipated number of units to be produced.
3.03b Produce a cost break-down when the guitar reaches final prototype stage. Use this as information for product placing.

3.04 DFMA for a mass-produced version
3.04a What aspects of the design, materials choices and manufacturing routes need to be modified to suit mass-production methods and to produce consistent product performance? How?

   Soundboard: integral bridge, bracing and binding; injection blow moulded PC around PC inserts
   Fretboard: integral frets

3.05 Operating Instructions
3.05a Make clear in the operating instructions the conditions for how the product should be treated, handled and stored (e.g. not to be left in extremes of temperature, not to be exposed to solvents.).
3.05b Reach a decision on a product guarantee period.

Features removed from PDS dated 9.10.97
   hardware should match (electric version)
   adjustable bridge saddle height (to tweak action)
   adjustable intonation at the bridge
   scratchplate
   left-handed version
   built-in tuning device
   auto-tuning
APPENDIX XIV

Glossary for the polymer acoustic guitar project

Core project personnel mentioned in the polymer acoustic guitar diary of designing

<table>
<thead>
<tr>
<th>Name</th>
<th>Role and Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH/Dave</td>
<td>David Hodson, Collaborator, Loughborough</td>
</tr>
<tr>
<td>EWLN/Eddie</td>
<td>Eddie Norman, Supervisor, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>OP/Owain</td>
<td>Owain Pedgley, Research Student, LU</td>
</tr>
<tr>
<td>RA/Rob</td>
<td>Rob Armstrong, Collaborator, Coventry</td>
</tr>
<tr>
<td>RJH/Dick</td>
<td>Dr. Richard Heath, Collaborator, IFTME, LU</td>
</tr>
</tbody>
</table>

Ancillary project personnel mentioned in the polymer acoustic guitar diary of designing

<table>
<thead>
<tr>
<th>Name</th>
<th>Role and Institution</th>
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<tbody>
<tr>
<td>Dean</td>
<td>Dean Bates, Research Assistant, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>---</td>
<td>George Torrens, Lecturer, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>George</td>
<td>George Pickaver, Technician, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>Jo</td>
<td>Jo Derbyshire, Intellectual Property Officer, LU</td>
</tr>
<tr>
<td>Jon</td>
<td>Jon Allen, Research Student, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>Melanie</td>
<td>Melanie King, Research Assistant, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>---</td>
<td>Paul Hanson, graduate, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>---</td>
<td>Paul Wormald, Lecturer, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>Rod</td>
<td>Rod Page, Technician, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>Ruth</td>
<td>Ruth Randall, AVS Signwriting, LU</td>
</tr>
<tr>
<td>Sally</td>
<td>Sally, Laboratory Technician, ITW Adhesives, Kettering</td>
</tr>
<tr>
<td>Sean</td>
<td>Sean Kerslake, Technician, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>Tony</td>
<td>Tony Hodgson, Lecturer, Department of Design &amp; Technology, LU</td>
</tr>
<tr>
<td>---</td>
<td>Trevor Swindlehurst, graduate, Department of Design &amp; Technology, LU</td>
</tr>
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Trade names and miscellaneous abbreviations used in the polymer acoustic guitar diary of designing

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>3M</td>
<td>Minnesota Mining and Manufacturing Company, adhesives manufacturer</td>
</tr>
<tr>
<td>7T03</td>
<td>A grade of Perspex sheet manufactured by ICI Plastics Ltd</td>
</tr>
<tr>
<td>Airex</td>
<td>Alusuisse AirexAG, Switzerland, manufacturers of expanded polymer sheets</td>
</tr>
<tr>
<td>Araldite</td>
<td>Trade name for two part epoxy adhesive manufactured by CIBA-Geigy</td>
</tr>
<tr>
<td>ASAP</td>
<td>As Soon As Possible</td>
</tr>
<tr>
<td>AutoCAD</td>
<td>Computer aided design package developed by Autodesk Inc.</td>
</tr>
<tr>
<td>AVS</td>
<td>Audio Visual Services, a service division of Loughborough University</td>
</tr>
<tr>
<td>CAD/CAM</td>
<td>Computer Aided Design/Computer Aided Manufacture</td>
</tr>
<tr>
<td>CF</td>
<td>Carbon Fibre</td>
</tr>
<tr>
<td>CIBA</td>
<td>CIBA-Geigy, plastics resin manufacturer, Cambridgeshire</td>
</tr>
<tr>
<td>CMYK</td>
<td>Cyan, Magenta, Yellow, K(Black): the four colour print process</td>
</tr>
<tr>
<td>CNC</td>
<td>Computer Numerically Controlled (automated manufacture)</td>
</tr>
<tr>
<td>CS</td>
<td>Chopped Strand mat for fibre reinforced plastics</td>
</tr>
<tr>
<td>DFMA(A)</td>
<td>Design For Manufacture (and Assembly)</td>
</tr>
<tr>
<td>DPI</td>
<td>Dots Per Inch</td>
</tr>
<tr>
<td>DS or D/S</td>
<td>Design Sheet</td>
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<tr>
<td>E-Mu</td>
<td>Client for Owain Pedgley's undergraduate work</td>
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<tr>
<td>EPC</td>
<td>Expanded PolyCarbonate</td>
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<tr>
<td>Foamex</td>
<td>Trade name for PVC-based composite expanded sheet manufactured by AirexAG</td>
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<tr>
<td>Forex</td>
<td>Trade name for expanded polycarbonate sheet manufactured by AirexAG</td>
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<tr>
<td>FRP</td>
<td>Fibre Reinforced Plastic</td>
</tr>
<tr>
<td>GRP</td>
<td>Glass Reinforced Plastic</td>
</tr>
<tr>
<td>ICI</td>
<td>ICI Plastics Ltd, plastics manufacturer</td>
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<tr>
<td>IM</td>
<td>Injection Moulding</td>
</tr>
<tr>
<td>Interplas</td>
<td>Trade exhibition held at the National Exhibition Centre, Birmingham</td>
</tr>
<tr>
<td>IPO</td>
<td>Intellectual Property Office, Loughborough University</td>
</tr>
<tr>
<td>IPTME</td>
<td>Institute of Polymer Technology and Materials Engineering, Loughborough University</td>
</tr>
<tr>
<td>IR</td>
<td>Infra Red</td>
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<tr>
<td>ITW</td>
<td>ITW Adhesive Systems Ltd, Kettering, adhesives manufacturer</td>
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<td>K&amp;C Mouldings</td>
<td>Materials supplier, Coalville, Leicestershire</td>
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<td>Lexan</td>
<td>Trade name for polycarbonate sheet manufactured by GE Plastics</td>
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<tr>
<td>LU</td>
<td>Loughborough University</td>
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<tr>
<td>MA3940LH</td>
<td>A grade of adhesive manufactured by ITW Adhesive Systems</td>
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<tr>
<td>Manufacturing Week</td>
<td>Trade exhibition held at the National Exhibition Centre, Birmingham</td>
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<tr>
<td>MDF</td>
<td>Medium Density Fibreboard</td>
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<tr>
<td>MEK</td>
<td>MethylEthylKetone</td>
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<tr>
<td>Ovation</td>
<td>Manufacturer of guitars with polymer components</td>
</tr>
<tr>
<td>P38</td>
<td>Trade name for polyester filler manufactured by W. David &amp; Sons Ltd</td>
</tr>
<tr>
<td>PAG</td>
<td>Polymer Acoustic Guitar</td>
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<tr>
<td>PC</td>
<td>PolyCarbonate</td>
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<tr>
<td>PDS</td>
<td>Product Design Specification (document)</td>
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<td>Perspex</td>
<td>Trade name for acrylic sheet manufactured by ICI Plastics Ltd</td>
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<td>Pilkington Library</td>
<td>One of two Loughborough University libraries</td>
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<tr>
<td>PMA</td>
<td>PolyMethylMethAcrylate (acrylic)</td>
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<tr>
<td>Polybron</td>
<td>Materials supplier, Shepshed, Leicestershire</td>
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<tr>
<td>PP</td>
<td>PolyPropylene</td>
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<td>PS</td>
<td>PolyStyrene</td>
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<tr>
<td>PVC</td>
<td>PolyViny/Chloride</td>
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<tr>
<td>R&amp;D/R+D</td>
<td>Research and Development</td>
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<tr>
<td>RIM</td>
<td>Reaction Injection Moulding</td>
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<td>SBA</td>
<td>SBA Plastics Ltd, Leicester, materials supplier</td>
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<td>Thorogood</td>
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<tr>
<td>VT Plastics</td>
<td>Materials supplier, Nottingham</td>
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<tr>
<td>WR</td>
<td>Woven Roving mat for fibre reinforced plastics</td>
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<td>WRT</td>
<td>With Respect To</td>
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<td>WWW</td>
<td>World Wide Web (internet sites)</td>
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### Part 1: Concurrent format

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<tr>
<th>Diary date</th>
<th>Day</th>
<th>Figure</th>
<th><em>What happened today? (verbatim)</em></th>
<th>Day's main activity (translated)</th>
<th>Classification</th>
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<td>1</td>
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<td>&quot;Planning start of design project (videotaped)&quot;</td>
<td>Planning</td>
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<td>&quot;Workshop (card modelling)&quot;</td>
<td>Testing and refinement</td>
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*APPENDIX XV: Guitar project summary diary entry catalogue*
**Part 2: End-of-the-day format**

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<thead>
<tr>
<th>Diary date</th>
<th>Day</th>
<th>&quot;No detailed entry day?&quot;</th>
<th>Figure</th>
<th>&quot;Day's main activity&quot; (version)</th>
<th>Day's main activity (translated)</th>
<th>Classification</th>
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<tr>
<td>13.5.97</td>
<td>25</td>
<td></td>
<td></td>
<td>&quot;Mostly research-based, very little time dedicated to guitar project&quot;</td>
<td>NOT DESIGNING</td>
<td>&lt;undocumented&gt;</td>
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<td>14.5.97</td>
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<td>&quot;CAD/CAM work on guitar neck block&quot;</td>
<td>CAD modelling</td>
<td>CAD</td>
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<tr>
<td>30.11.98</td>
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<td>&quot;CAD/CAM work on guitar neck block&quot;</td>
<td>CAD modelling</td>
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<tr>
<td>1.12.98</td>
<td>202</td>
<td>YES</td>
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<td>&quot;Setting up CNC machines and material for imminent manufacture&quot;</td>
<td>Workshop (constructing final prototype)</td>
<td>Testing and refinement</td>
</tr>
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<td>10.12.98</td>
<td>203</td>
<td>YES</td>
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<td>&quot;Setting up CNC machines and material for imminent manufacture&quot;</td>
<td>Workshop (constructing final prototype)</td>
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<td>15.12.98</td>
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<td>&quot;Setting up CNC machines and material for imminent manufacture&quot;</td>
<td>Workshop (constructing final prototype)</td>
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<td>16.12.98</td>
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<tr>
<td>21.12.98</td>
<td>206</td>
<td>YES</td>
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<td>&quot;Setting up CNC machines and material for imminent manufacture&quot;</td>
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<td>31.1.99</td>
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<td>&quot;Final run (pneum) of neck block using CNC router&quot;</td>
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<td>208</td>
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<td>&quot;Final run (pneum) of neck block using CNC router&quot;</td>
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<td>8.2.99</td>
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<td>&quot;Final run (pneum) of neck block using CNC router&quot;</td>
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<td>&quot;Final run (pneum) of neck block using CNC router&quot;</td>
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<td>20.2.99</td>
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<td>YES</td>
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<td>&quot;Final run (pneum) of neck block using CNC router&quot;</td>
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<td>Testing and refinement</td>
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<td>21.2.99</td>
<td>212</td>
<td>YES</td>
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<td>&quot;Workshop preparing guitar and bridge&quot;</td>
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<td>28.2.99</td>
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<td>YES</td>
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<td>&quot;Gluing binding to guitar body&quot;</td>
<td>Workshop (constructing final prototype)</td>
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<td>2.3.99</td>
<td>214</td>
<td>YES</td>
<td>58</td>
<td>&quot;Final machining of bridge, by hand&quot;</td>
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<td>Day's main activity (translated)</td>
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<td>3.2.99</td>
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<td>&quot;Finishing guitar bridges in workshop&quot;</td>
<td>Workshop (constructing final prototype)</td>
<td>Testing and refinement</td>
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<tr>
<td>4.2.99</td>
<td>216</td>
<td>YES</td>
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<td>&quot;Final preparation of bridge, work on back and soundboard&quot;</td>
<td>Workshop (constructing final prototype)</td>
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<td>5.2.99</td>
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<td>YES</td>
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<td>&quot;Work on back and soundboard&quot;</td>
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<td>12.2.99</td>
<td>218</td>
<td>YES</td>
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<td>&quot;Soundboard struts- completed&quot;</td>
<td>Workshop (constructing final prototype)</td>
<td>Testing and refinement</td>
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<tr>
<td>15.2.99</td>
<td>219</td>
<td></td>
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<td>&quot;Gluing bridges to soundboard&quot;</td>
<td>Workshop (constructing final prototype)</td>
<td>Testing and refinement</td>
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<td>17.2.99</td>
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<td>YES</td>
<td>Figure 56m</td>
<td>&quot;Jig for gluing soundboard and back- completed&quot;</td>
<td>Workshop (constructing final prototype)</td>
<td>Testing and refinement</td>
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<td>19.2.99</td>
<td>221</td>
<td>YES</td>
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<td>&quot;Bonded soundboard onto back- completed&quot;</td>
<td>Workshop (constructing final prototype)</td>
<td>Testing and refinement</td>
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<tr>
<td>22.2.99</td>
<td>222</td>
<td>YES</td>
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<td>&quot;Preparation of guitar body for Dave Hudson- completed&quot;</td>
<td>Workshop (constructing final prototype)</td>
<td>Testing and refinement</td>
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<td>24.2.99</td>
<td>223</td>
<td>YES</td>
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<td>&quot;Client meeting with Dave Hudson; body handed over&quot;</td>
<td>Meeting with Dave Hudson</td>
<td>Meeting</td>
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<td>224</td>
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<td>Final R&amp;D report*</td>
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<td>Report writing</td>
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<td>Report writing</td>
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<td>8.3.99</td>
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<td>Final report</td>
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<td>Final R&amp;D report (draft completed)*</td>
<td>Final report</td>
<td>Report writing</td>
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</table>
APPENDIX XVI

Guitar prototype development

Figure 56(a-n): A visual record of prototype development
Figure 57: The final prototype, viewed from the front (top) and back (bottom)
### Part 1: Concurrent format

<table>
<thead>
<tr>
<th>Diary date</th>
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<th>Artwork</th>
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<th>Fn</th>
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<tr>
<td>16.5.96</td>
<td>1</td>
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<td>&quot;Early stages: consider technical issues less important. Want to explore creatively.&quot;</td>
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<td>DS1</td>
<td>Some technological issues raised as a checklist of features to be investigated.</td>
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<tr>
<td>21.5.96</td>
<td>3</td>
<td></td>
<td>All ideas at the moment are very much loose and visual—technological issues have not been considered yet, at least not in any great detail.</td>
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<td>DS2</td>
<td>Diagonal stripes: property of mail: sparked off by colour/pen property/whip of pen.</td>
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<td>5</td>
<td>DS2</td>
<td>Side structural elements: mechanical detail added as a reminder: do these need checking?</td>
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<td>DS2</td>
<td>How to connect top to bottom: sparked off by seeing my drawing flowing around.</td>
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<tr>
<td>22.5.96</td>
<td>7</td>
<td>DS3</td>
<td>Linings/structural interface is assumed from diagram then realised exactly what it was (..).</td>
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<tr>
<td>22.5.96</td>
<td>8</td>
<td>DS4</td>
<td>&quot;Rosette snapping-in: considered problems with soundboard decoration: necessity to find a different way, just an early idea at this stage.&quot;</td>
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<tr>
<td>22.5.96</td>
<td>9</td>
<td></td>
<td>&quot;Use Denny 'Guitar Handbook' to be made aware of technological issues.&quot;</td>
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<tr>
<td>22.5.96</td>
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<td></td>
<td>&quot;Looking at 'Guitar Handbook' has certainly been worthwhile in making me aware, very nicely, of the technical details of the guitar (less complicated than an initial impression).&quot;</td>
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<tr>
<td>22.5.96</td>
<td>11</td>
<td></td>
<td>&quot;Some of the 'checklist' of tech features on DS3 have been sparked off mentally from previous encounters with 'guitar design' work, others pertain to more 'general considerations which are appropriate to any product I may be designing.&quot;</td>
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<tr>
<td>22.5.96</td>
<td>12</td>
<td>DS4</td>
<td>Linings of this section for the rossette: Poor experience tells me about issues providing sections of material.</td>
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<tr>
<td>25.5.96</td>
<td>13</td>
<td></td>
<td>&quot;I consider the work being carried out now is for the benefit of formulating a high-quality, advanced, well-informed DS3 to work to...&quot;</td>
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</tr>
</tbody>
</table>
| 25.5.96    | 14        |         | "Using musicians' Yearbook to point out guitar features."

#### APPENDIX XVII: The guitar project detailed diary catalogue

**APPENDIX XVII**

The guitar project detailed diary catalogue
<table>
<thead>
<tr>
<th>Diary date</th>
<th>Entry no.</th>
<th>Artwork</th>
<th>Content (verbatim)</th>
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<th>Lr</th>
<th>Cn</th>
<th>Fn</th>
<th>In</th>
<th>Kn</th>
<th>Cg</th>
<th>2d</th>
<th>Ts</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.6.96</td>
<td>28</td>
<td></td>
<td>&quot;I have started work on the PDS because I feel that I have raised enough issues and that it is the right time. The PDS will focus my attention to start honing in on design details and to prioritise design work. Without it, design work would tend to float and the chance of doing mis-guided or mis-placed design work is much greater. Starting work on Report I also has the same function and allows me to form the most complete picture of design work as it stands - giving me confidence (and an appropriate level of understanding / planning) to move onto the second phase of design work.&quot;</td>
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<tr>
<td>20.6.96</td>
<td>29</td>
<td></td>
<td>&quot;Using previous design reports (degree show E-Mu keyboard and Thornwood) to add to requirements of the PDS, as stimuli. &quot;</td>
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<tr>
<td>20.6.96</td>
<td>30</td>
<td></td>
<td>&quot;Putting considerations into my mind when generating a PDS, off the top of my head; &quot;... potential manufacturer; manufacturing, recycling at materials, graphics, potential volume of production.&quot;</td>
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<tr>
<td>20.6.96</td>
<td>31</td>
<td>DS10</td>
<td>&quot;The fact that I am writing some spec under the test system at the bottom left and others in bubble boxes indicates a prioritisation going on. These in test are very specific statements, bubble boxes indicate 'general area' to look at. Also isolation and linking of PDS components. Very aware of doing this in order to aid my next stage of rationalising all these different spec. points.&quot;</td>
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<tr>
<td>20.6.96</td>
<td>32</td>
<td></td>
<td>&quot;This PDS sheet has now really become the hub of project development - it encompasses all the bits that need to come together.&quot;</td>
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<tr>
<td>20.6.96</td>
<td>33</td>
<td></td>
<td>&quot;Have made PDS so that one must consider the key design aspects of each component as well as the whole, will hopefully make me design a more thoroughly investigated / understood product.&quot;</td>
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</tr>
<tr>
<td>18.7.96</td>
<td>34</td>
<td></td>
<td>&quot;I have just started on 5.02 of Project Report I draft that concept works have used very little, if any, specialist input (on the technical side especially. This is a reflection of the way I have learnt designing. Results would bound to be different (..) if a specialist was brought in from the outset.&quot;</td>
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<tr>
<td>19.7.96</td>
<td>35</td>
<td>LB1.8</td>
<td>&quot;Acoustic seat. Rob Armstrong's idea, brought up by Eddie's mentioning of bowl-backs being acoustically dead.&quot;</td>
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<tr>
<td>19.7.96</td>
<td>36</td>
<td>LB1.8</td>
<td>&quot;Rob Armstrong is not overly concerned with the guitar shape w.r.t. the tone being produced (more concerned with the construction). This also goes for the size and shape of the soundspace.&quot;</td>
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<tr>
<td>19.7.96</td>
<td>37</td>
<td>LB1.8</td>
<td>&quot;Modified fretboard designs all Rob Armstrong ideas → suggested when going onto the subject of plastic fretboard design.&quot;</td>
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<td>&quot;[in relation to an acoustic seat to lessen the deadening on a bowl-back]. ... did a quick experiment playing tonewood on and off the floor, and noted the difference in tone.&quot;</td>
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<tr>
<td>19.7.96</td>
<td>39</td>
<td>LB1.9</td>
<td>&quot;The soundboard / back interface was again raised by me [at meeting with Rob Armstrong, 18 July 1996] - suggestions of a glued / removable / mechanical joint were made. Is it to be square or right?&quot;</td>
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<tr>
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<td>40</td>
<td>LB1.9</td>
<td>&quot;Overall design was considered: (i) soundboard, (ii) bowl/back/neck/head, (iii) fingerboard. OP/ENUN/RA mutual agreement.&quot;</td>
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<td>19.7.96</td>
<td>41</td>
<td>LB1.9</td>
<td>&quot;Bridge design using a 'floating saddle' was suggested by RA, thereby making it easier to mould the rest of the bridge into the soundboard.&quot;</td>
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<td>19.7.96</td>
<td>42</td>
<td></td>
<td>&quot;Moulded pick retainer [joint OP+ENUN idea; ENUN mentioning other things guitarists tend to have around them].&quot;</td>
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<tr>
<td>2.8.96</td>
<td>43</td>
<td></td>
<td>&quot;Acoustic guitar features. I shall look through acoustic guitar brochures and note down features (technical or aesthetic) which are possible design variants. It becomes obvious after 2 or 3 catalogues, the number of new features to be identified decreases markedly.&quot;</td>
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<tr>
<td>5.8.96</td>
<td>44</td>
<td></td>
<td>&quot;Currently transferring all pertinent info, regarding what has been learnt/designed upon, to the polymer acoustic guitar for writing up report. Particularly keen on noting down any technical features decided upon (primarily for PDS). This process is like a final sweep so that the report can be written and complete.&quot;</td>
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<td>&quot;Although this PDS (022) has not considered materials/manufacturing, I was aware of myself / reminding me that materials / manufacturing will be an issue, but also aware of a 'voice' saying 'no need to look at it just yet' - the correct time will come later.&quot;</td>
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<td>46</td>
<td>DS16</td>
<td>&quot;Top left guitar cutaway development. Thinking how neck will join onto the [new shape] guitar back. Sharp corners experience - maybe a problem. Resin build-up producing curved inside radius.&quot;</td>
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<tr>
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<td>47</td>
<td>DS16</td>
<td>&quot;Acoustic interface - how to join the two main body components (esp. different materials) - do not know - will find out later. This is potentially very important.&quot;</td>
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Appendix XVII: The Guitar Project Detailed Diary Entry Catalogue

15.10.96 48  DS16  "Considering what materials (types) the two main body components will be. Familiar that composites need 'laying-up', do not know if they can be 'moulded' - will have to find out. For now assuming that (for mass-manuf.) the bowl back will be moulded (blow, vacuum or pressure…). Aim is to have a clearer idea of how the guitar will be made (was thinking about the shape of existing bodies for inspiration)."

17.10.96 49  "For yesterday's work I was carrying out a styling exercise (the order of the day, which whatever configuration of shapes I came up with would not importantly have major design implications for the projected manufacturing process was considering that the design can be made anyway). Materials / manufacturing process decisions in greater detail will come soon, but not just yet (established existing related product)."

17.10.96 50  DS23  "Construction of the headstock - what pieces will be involved? How will they fit together? Are they moulded?"

17.10.96 51  DS23  "Headstock/fingerboard join - push fits (knowledge): considering assembly: important to stick to get to grips with how it may be possible made."

17.10.96 52  DS23  "Different types of compering material (resins) on neck - knowledge of different types: no need to consult at the moment."

17.10.96 53  DS23  "Considering that the neck/head may need some intricate detailing, not possible with fibre-reinforced plastic (not well enough vented in diff. manuf. techniques at the moment). Therefore wondering if it is perhaps best to make bowl back composite (acoustic, more importantly - neck and head i.e. not acoustic. Importantly - join will be difficult. Considering it because need to start thinking about manufacture/construction."

17.10.96 54  DS23  "Various configurations of manufacturing neck + body + head. Why? Probably most tricky area - lots of features to join on. Soundboard is just a board; these components need fitting with lots of other components and complex shape."

17.10.96 55  DS23  "Strengthening ribs on 3D view (experience). Fixing points for moulds (knowledge)."

28.10.96 56  "Design work up until now has been fine, but I feel now that I am now thinking about the particular material (i.e. plastic composites) more intensely, especially costs and manufacturing possibilities."

28.10.96 57  DS24  "To have bridge interconnecting with soundboard (i.e. 1 mould): would be tricky. Bridge = reasonably intricate = std. moulding with non-reinforced plastic (i.e. a different material to the soundboard, so, therefore, could not be integral). Fibre reinforced would not allow for such intricacies (also, means soundboard is no longer a flat sheet which it could, if appropriate, be cut out a lot cheaper then moulding)."

28.10.96 58  DS24  "Possible manufacturing routes for joining bridge to composite soundboard - just ideas."

2.12.96 59  EOD  "Having consulted EWN after my recent client meeting with EA (26/11/95), it has been decided to purchase a commercially-available bowl-back guitar. This way, design effort can be concentrated on exploring the success of different materials and construction techniques for the polymer soundboard, rather than attempting at this stage the time-consuming task of building a 'test rig' guitar from scratch. This will be a practical, hands-on way of considering the many facets of material/construction of a fully-composite/plastic guitar."

5.12.96 60  "By practically assessing the Ovation guitar, I have picked up assembly/manufacturing possibilities, and how in the process made some value judgements as to what I believe to be good/bad about guitar design. I am looking at the guitar to remind me…"

5.12.96 61  "Smooth feel to neck to aid playability, not even on finish. The Ovation painted finish scratches/dents too easily."

7.1.97 62  DS26  "60" Density change in foam: no idea off top of my head, to satisfy criteria for soundboard design; a blowing process (hence interest in foam); potentially easy manufacturing process to achieve (in one operation that is)."

161.97 63  DS26  "60" Getting back up to speed on the design. Have been away on vacation for 2 weeks. (…)…reminding myself of some of the materials properties of the soundboard, from my own knowledge initially."

65  "Reading Marsden, The Material of Invention. In glossary, 'Structural foam' (foams with a skin). These sound as though they might do the job for the guitar. I was reading this as part of my PhD reading, and it happened to stumble across it…"
Part 2: End-of-the-day format

| Diary date | Entry no. | ARTWORK | CONCEPT (webbing) | Win | Ly | Gm | Fn | In | Kn | Cg | 2d | Ts |
|------------|-----------|---------|-------------------|-----|----|----|----|----|----|----|----|----|----|
| 13.5.97    | 65        | "Looking through literature collected from Interplas and Manufacturing Week (composites literature)- not very good / useful resources (nothing to design yet, just concept ideas)."
| 13.5.97    | 66        | "Looking through George Torness’s composite file- has a design data book for composites; key points to note when designing. Could be useful for the future."
| 13.5.97    | 67        | "Collected some sample styrene and PVC-based foamex from Roh’s plastic store- for discussion about top-plate materials with EWL and RH/RA. (Based on a ‘rigid foam board’ of polymer composite material as a starting point for first prototype)."
| 14.5.97    | 68        | "Agreed with Eulen that the initial prototypes will be: (a) ‘a cube’ quick prototype in foamex-type material to see what ballpark the sound quality is in; (b) material/soundboard design based on calculations/acoustics literature."
| 14.5.97    | 69        | "Contacted Dick Heath (ITFME) on availability of materials similar to ‘Foamex’ (see attached e-mail printout)."
| 9.6.97     | 70        | "Some suggestions for donated materials in Murphy L. Reinforced plastics handbook: a design guide for such materials."
| 9.6.97     | 71        | "Contacted technician, ITFME. All this was to do with getting brochures/contact addresses for foam board suppliers to get hold of some materials for prototype."
| 9.6.97     | 72        | "Evaluated by flexible sample supplied by Roh (in plastics store)."
| 9.6.97     | 73        | "...I met with Dick Heath & he suggested a change of focus (looking at basic plastic sheet rather than foams). I met so that I could make a more informed choice on the first material prototype. He also provided some names and addresses for material suppliers. Also met so that I could make a more informed choice of adhesive."
| 10.6.97    | 74        | "Library visit to collect names/addresses of materials suppliers, so that more information on these materials can be gathered (and see what range of materials are available). Consulted ‘European Plastics Directory 1995’, listing such information."
| 11.6.97    | 75        | "Design consultation with Dick Heath, ITFME; in logbook L1:1-2:8. Aim was to find out what material the Ovation was made of (and how) so I can determine what glue to use in prototype mock-ups. Sample of bow/fretboard taken by technician for LR analysis. RP1 and myself performed a few basic polymer identification tests – RP1 reached a verdict. This information needed to be used so that prototypes with polymer sheets could be produced after coming back from Scotland."
| 11.6.97    | 76        | "Wrote all letters to materials suppliers so that I can have more tech info to use in further choices of material, and to see what materials are available to me."
| 23.6.97    | 77        | "Really like the finishing on the Forex sheet samples- mate but with an intriguing surface pattern (especially the expanded P.C.)."
| 23.6.97    | 78        | "Received some packages of example materials over the last week when on vacation. Will use the plastic sheets at a design meeting as a tactile way of looking at possible materials- perhaps the most immediate way for Rob Armstrong to see how a polymer acoustic guitar might be constructed."
| 24.6.97    | 79        | "Had a brief meeting with Eddie- showed him the Forex samples. We both agreed that the sound of the expanded PCB sample (slightly metallic) when blown by the hand and on wood sounded quite promising. I had a look at the tech spec, its ease of machinability is a bonus too, as is the ability to produce some good quality print on it (as per the sample)."
| 27.6.97    | 80        | "Contacted Dick Heath. The IR test on the plastic used on the Ovation back is not easy to identify; some internal debate within ITFME; Dick will email me results."
| 29.6.97    | 81        | "Quick discussion with Eulen, saying that I favour Almax material because it has RA description (air movement in material) and has more of a 'metallic' ring to it when struck-agreed. Just a thought in recent days: Dick said that by using foam I was introducing too many variables to start with. This is true of course, but I don’t see my designing progressing by choosing basic material first, evaluating this in the guitar design, and then modifying this slightly or only then progressing to a more advanced material. My designing is not meant to be scientific-material choices, at least at this stage, are more to do with using what sounds as though it would be right and testing it out. Progression can then go from there- rather than starting designing from the most mundane (and less likely to be appropriate) materials."
| 3.7.97     | 82        | "In the afternoon, whilst walking back from Loughborough, I envisaged in my mind two things. (1) Forex material really does sound as though it could be the right material to try and overcome problems to do with guitar sound by constructional details. Unlike all other polymer sheets, Forex-PC will be more rigid from the outset, less bulky and ‘rubbery’, and has an ‘intrinsic ring’ when hit. Looks like I might have stumbled across a suitable material very early on. The material is also scratch resistant and has a very pleasing finish. (2) A fully vacuum-formed mould (in Forex)."
| 3.7.97     | 83        | "This was drawn from a cross-section of the removed Ovation soundboard- purpose was to draw to my attention the constructional details of this area, as I might want to duplicate the details when I make prototypes. (I checked my early design sheets DS3 to remind myself of the reasons for this design)."
| 3.7.97     | 84        | "Haven’t thinking how to produce the thickness tapering effect using a conventional forming method. Thermofiling come to mind because I pictured drice cuts with different wall thicknesses (fjg)."
| 3.7.97     | 85        | "Producing a rough coating of soundboards)- so I can get an idea of this important aspect prior to meetings..."
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<th>Diary date</th>
<th>Entry no.</th>
<th>Artwork</th>
<th>Content (version)</th>
<th>Win</th>
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<tr>
<td>4.7.97</td>
<td>87</td>
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<td>&quot;Looked at Benchmark/Crawford, Mechanics of Engineering Materials, so I could compare Forex technical details with that of some woods.&quot;</td>
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<td>4.7.97</td>
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<td>&quot;Meeting with Dick. This was arranged to (i) discuss material choices and (ii) discuss adhesive choices (i.e. manufacturer) - especially in areas where I was unsure.&quot;</td>
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<td>4.7.97</td>
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<td>&quot;Meeting with Dick. Two starting materials for the soundboard were chosen: polystyrene (non-reinforced) and Forex-EPIC, basically because these two have a 'ring' rather than a 'deadening' when knotted. Forex suggests a resonating property. Also, both are available as a sheet which can be machined / formed by a variety of methods. They are a good starting point.&quot;</td>
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<td>4.7.97</td>
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<td>&quot;Meeting with Dick. The result of the I.R. test on the Ovation back now indicates that it is a vinyl-ester based resin (high performance).&quot;</td>
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<td>4.7.97</td>
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<td>&quot;Meeting with Dick. Adhesives were discussed, particularly the problems of gluing [sic] un-like polymers, which I was not too familiar with. We also had a brief discussion of: printing (e.g. rosette)- have to be careful because it may in fact weaken the polymer (cat's claw example polycarbonate); Struk: Dick very concerned it introduces more variables.&quot;</td>
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<td>4.7.97</td>
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<td>&quot;Meeting with Dick, referring to above entry. This is an example of our differing viewpoints on the designing. I am not treating it as a full R&amp;D project which is almost scientific in its approach. I don't have time for this, and I would question whether that is actually appropriate for my design work. My aim is to create a working guitar. It won't be the best first go. It's too early to acknowledge any 'variable that may alter guitar sound': but not to then jump a stage further and ask 'how' and 'why' each variable affects the design. Perhaps when a working guitar has been produced, then we can ask how can construction, material and manufacturing be changed on this design to improve sound quality? With help from me, Eddie, Rob Armstrong and Dick Heath. For now, I need to have something in front of me which I can touch, hear and get a feel for.&quot;</td>
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<td>5.7.97</td>
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<td>&quot;Washined materials supplier. availability of polymer sheets.&quot;</td>
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<td>5.7.97</td>
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<td>&quot;Drop-tested CF composite samples for 'good potential acoustic'. These are very still, may not need any bracing.&quot;</td>
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<td>&quot;Wanted to meet with Rob Armstrong (client) to discuss materials choices between polystyrene, expanded polycarbonate and CF composites with reference to construction of prototype soundboards to be fitted on the Ovation neck and end block&quot;</td>
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<td>The meeting was arranged for ASAP, so can continue making prototype boards.</td>
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<td>5.7.97</td>
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<td>D528</td>
<td>&quot;Decided to contact Rob Armstrong. Version of this idea came into my head a few days ago. Potentially interesting aesthetics - will consult RA about technicalities.&quot;</td>
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<td>5.7.97</td>
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<td>D528</td>
<td>&quot;Sent down notes from Trevor Swindon's dissertation: start to some of the materials properties of acoustic guitars for use in later design work / discussions.&quot;</td>
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<td>&quot;I checked through my first product design report (Aug '96) to see if I had stipulated some details for choice of material. I had not.&quot;</td>
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<td>6.7.97</td>
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<td>&quot;I also had a look at some various academic papers to do with guitar design (sound, ergonomics, stringing, materials). I concluded that these will be relevant at a later date, when we have something a little more 'concrete' to play with. It's a matter of educated experimentation at the moment: hence the inflow of information and RA from here on.&quot;</td>
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<td>6.7.97</td>
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<td>&quot;Meeting with Rob Armstrong, 15.7.97 (in 1.1.31) I presented the material samples to Rob- he agreed without reservation that the Forex-EPIC was the best material to use. It had a feel and sound quality that &quot;would work&quot;. I stated Dick Heath's position: that design parameters should be altered steadily and that we should use a basic PS sheet as the starting point material, but this was agreed between us as not really the way forward at this stage. The hands-on, going for a prototype that will have the most potential (using current knowledge) was agreed to be the way. Optimisation of the material and construction could then follow.&quot;</td>
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<td>&quot;Meeting with Rob. Rob explained to me how he should go about building the top plate, and gave an indication of the materials to use, giving the confidence and 'green light' to go ahead with building something that he was happy with. It had been a long time since I had seen Rob, so wanted to get his 'stamp of approval' on the work done and the direction now being taken, especially concerning what materials to start with. It had been up to me though, to find a design direction from the conflicting ways of working at a crafts-designer client (Rob) and a materials specialist (Dick).&quot;</td>
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<td>6.7.97</td>
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<td>&quot;Fixed SBA for quote. Will order Forex-EPIC material Monday morning.&quot;</td>
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<td>6.7.97</td>
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<td>&quot;As I was walking into University I had a thought about how the soundhole might be produced using a warmed male-female punch.&quot;</td>
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<td>29.7.97</td>
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<td>&quot;As I was walking into University, I had a thought about how the soundhole might be produced using a warmed male-female punch. This had crossed my mind in the light of some difficulties in creating a clean circular hole using a trepanning tool and jig.&quot;</td>
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<td>&quot;Consulted with Eddie: in order to reduce potential problems around the guitar bridge (and so that a 'standard' bridge can be used in the prototype), it will probably be necessary to add an intermediate layer between the soundboard and the guitar back (...). This has implications for making the prototype, but does not have a design implication for a guitar built from scratch. The decision was made after handling the prototype at its current stage (basic shape + soundhole cut out; no bracing).&quot;</td>
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<td>29.7.97</td>
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<td>&quot;To check whether Available bonds fine Forex-EPC to wood, I have made a test piece which will set overnight. If it does not bond, some re-thinking will be in order.&quot;</td>
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<td>19.8.97</td>
<td>108</td>
<td>LB1:34</td>
<td>&quot;Learned that the Forex EPC (or the configuration - lack of thinning members: that it is currently inj) is subject to stretching or a kind of polymeric creep, because the guitar went out of tune overnight.&quot;</td>
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<td>29.8.97</td>
<td>109</td>
<td>LB1:35</td>
<td>&quot;Meeting with Rob, 29.8.97: When he [Rob] first picked prototype 1 up, he 'just knew' that the material was right; that it had the correct kind of acoustic response, but that its construction would need to be modified (given that the prototype had failed).&quot;</td>
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<td>29.8.97</td>
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<td>&quot;Meeting with Rob; Rob's advice: Bracing: it may be beneficial to over-brace, since the poly carbonate sheet does not have any inherent directional strength (as in grain in wood); add more material than presently on the guitar, especially in the axis parallel with the neck. (Rob flipped the sheet of Forex that we had supplied him, and came to this conclusion). Or, somehow give some direction to the material itself (EWEN comment).&quot;</td>
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<td>29.8.97</td>
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<td>&quot;Meeting with Rob; Rob's advice: Discussed laying-up of fibreglass to form a bowl back (using a mould that Rob had in his workshop) - to try to use, after the gel coat, as much heavy balsa fibre as is possible to encourage some thickness and air rather than a dull, thudly resonant [sic] bulk. (For prototype construction, at this stage most of the materials/machining considerations are biased towards design 'R&amp;D' experimentation and practical testing, rather than definitely opting for one or the other. The designs so far are made using mostly of the R&amp;D nature of design work. When designs are approaching the success expected of RA and myself, then it will be time to 'tie down' to a particular material/s and process/es).&quot;</td>
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<td>5.9.97</td>
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<td>&quot;...I recollected during the day that the graphic and geometry of the guitar might be quite different to originally planned (bowl-back). It was at the last design meeting (Aug 29) that Rob suggested that we might want to produce a prototype using my original developed body shape, but using fabricated and jointed sheet Forex instead of vacuum-formed (bowl)-may be much more acceptable to many people. Will have to see- perhaps produce this as my 3rd prototype- not having a bowl-back, and using body and back pieces separate will have implications for a mass-produced design. May be more expensive and less easy to assemble.&quot;</td>
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| 16.9.97    | 113       |         | "As a result of poor adhesion of the sheet, I have consequently phoned Dick Heath for his advice on possible replacement adhesives/bonding techniques. I suggested hot-melt polycarbonate (if it exists- I am well aware of some other hot-melt adhesives), which may produce a better bond. I am now waiting on Dick's response."

16.9.97    | 114       |         | "Having pulled off the soundboard on prototype 1, it became obvious that a problem exists with the bend between the wooden strips and the polycarbonate sheet- the adhesive (cellulose) was peeling off under the high force of the strings." |    |    |    |    |    |    |    |    |    |
| 23.9.97    | 115       |         | "Although when I was redesigning the prototype form (the foam model mk.2 for a final prototype guitar) I was envisaging a similar construction method to traditional wooden guitars (i.e. strips/faces of wood bonded, simply replaced with polymer materials)- as per conversation with Rob Armstrong at the last meeting- when I showed the foam model to Eddie, he reminded me that we could have a single-piece moulding still from such a 'stout body', - I then remembered Paul Henson's guitar design which he produced from vacuum-moulding, which had shallow draw angles and small radiused [sic] edges. Aesthetically, though, I did not like the small radii sharp corners on the guitar just seem to look right. This will be a conflict to be resolved after prototype 2 has been finalised and evaluated." |    |    |    |    |    |    |    |    |    |
| 8.10.97    | 116       |         | "I see materials in this design project as critical to its success- simply because the innovation- making a stringed instrument from polymers- is on uncharted territory (sic). It is R&D work, dearly, and made more obvious by the fact that I am testing materials in prototypes. It is far from any kind of packaging exercise." |    |    |    |    |    |    |    |    |    |
| 8.10.97    | 117       |         | "Design work is not concerned with designing for industrial processes. They are being borne in mind, but whilst the short-term goal remains to be the achievement of a 'good sounding guitar', through workshop procedures, DFMA considerations will be left alone. Once a 'good sounding guitar' has been achieved, then attention will divert to development and detailing- where DFMA will certainly be considered. Because the regard for processes is light at this stage, decisions on potential quantity and costs have been delayed (purposely delayed)."

8.10.97    | 118       |         | "The existing PDS. pointed out that 'assembly' needs to be considered. I know this, of course, but have been delaying attention to much of the assembly design until work on the Ovation is over-ie. when I move on to designing and building prototype 3 from scratch." |    |    |    |    |    |    |    |    |    |
| 8.10.97    | 119       | DS30    | "Work on the guitar is a simple development from earlier work, only this time it is for the purpose of making a printed prototype. I know from a year 2 design project that AVS on campus could create coloured, printed stickers. I used this illustration as an example to ask then about suitability for making. The material I had seen and had in mind was printed, adhesive-backed film. A transfer could simply be pressed onto the soundboard, as an alternative to printing on direct. (Certainly the adhesive film can be used by me on my prototype to simulate direct printing)."

Appendix XVI: The guitar project detailed diary catalogue
<table>
<thead>
<tr>
<th>Diary date</th>
<th>Entry no.</th>
<th>Artwork</th>
<th>Content (verbatim)</th>
<th>Wn</th>
<th>Lv</th>
<th>Cn</th>
<th>Fn</th>
<th>In</th>
<th>Kg</th>
<th>2d</th>
<th>Ts</th>
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<tbody>
<tr>
<td>8.10.97</td>
<td>120</td>
<td>DS30</td>
<td><em>The stimulus for producing a large recycling log on the plastic body was sparked by me re-reading my PDS section to do with recycling. Paul Wormold had given me an information sheet on the standard logs and these two issues seemed to 'click' in my mind. I immediately thought of making the log as part of a moulding or press/ and wanted it to really shout out &quot;recyclable product design!&quot; the most suitable surface area without spelling the form of the product was on the back.</em></td>
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<tr>
<td>8.10.97</td>
<td>121</td>
<td></td>
<td><em>I do not like the layout of my current PDS regarding material property requirements. I have decided to go about listing these and will endeavour to put some figures against the requirements- this is a job for tomorrow. I had a quick glimpse at a listing of materials/processes properties that I had produced as part of my research work- this will come in handy in the designing and listing of desired material properties (and will allow me to formally check how appropriate Forex-EPC is, and act on the findings accordingly).</em></td>
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<tr>
<td>9.10.97</td>
<td>122</td>
<td></td>
<td><em>I have in my own mind fixed a major 'step-up' for materials/making processes and their role in designing. Phase 2 (production of prototype 3) which will soon be started, will involve no modification of an existing guitar. As such, I anticipate greater attention to design details and a more 'considered' approach to the design-and-make activities. By this, I mean there will be greater design work, rather than design-and-make. In essence, more paper-based designing, especially of joints and finishes.</em></td>
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<tr>
<td>9.10.97</td>
<td>123</td>
<td>Section 2.11 of PDS</td>
<td>Finished the revised PDS today- and used my notes on materials and processes (mentioned yesterday, a document I had produced through my research reading) to add a few more 'checklist' material properties to the appropriate section in the PDS. I basically went through the materials list (which is not comprehensive) and noted down which properties would be important in the guitar, based on my understanding of how/where the guitar will be used and how/where it will be stored.*</td>
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<td>9.10.97</td>
<td>124</td>
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<td><em>Checked with Eddie that his figures for a string tension test were applicable- they were, but the slightly heavier gauge strings that will be used on the PAG mean that the total string tension is likely to be nearer 50N.</em></td>
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<td>9.10.97</td>
<td>125</td>
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<td><em>I visited the University library this afternoon to gather information on design consultancy. When scanning the shelves, I stumbled across a reference book titled Structural Adhesives at R620. 1995/ST. I had a quick look through, bearing in mind that adhesives are an important design factor in the P.A.G. As a design resource this text looked simple but comprehensive. I shall go back to it in the near future.</em></td>
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<td>14.10.97</td>
<td>126</td>
<td></td>
<td><em>Took this design sheet to Ruth at AVS signwriting, she gave me a very useful description of the materials and processes available to me for producing the rosette. These I noted down here as I could refer to them again later.</em></td>
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<tr>
<td>14.10.97</td>
<td>127</td>
<td>DS31</td>
<td><em>Thinking in terms of workshop practice (prototype 2 production) here- and with a concern that over-gluing [h] is probably a better approach to this joint than under-gluing (the glue needs to spread out across all the different parts.)- I'm imagining what I would do in the workshops.</em></td>
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<tr>
<td>14.10.97</td>
<td>128</td>
<td>DS31</td>
<td><em>For the construction of prototype 2, again, where a good bend between the wooden bracings and EPC soundboard is essential. Prototype 1 was not heavily sanded- in fact it was not too easy to produce a rough surface on the EPC. I intend to spend more time roughening up this surface this time, hopefully it will allow any glueing that occurs when the guitar is stressed.</em></td>
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<td>14.10.97</td>
<td>129</td>
<td></td>
<td><em>Ruth at AVS was ultra efficient and able to give me a test-run rosette before the afternoon was out. I shall use this on the prototype 2 guitar when it is assembled. The test-run was produced using the vinyl-1 shall probably get test-runs for the other processes produced too.</em></td>
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<td>23.10.97</td>
<td>130</td>
<td></td>
<td><em>Plan to do some vacuum formings of the EPC to test how it performs. Also other hands-on material playing to get an idea of how prototype 3 might be made. Will do this soon after prototype 2 is finished (in a week or two).</em></td>
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<td>23.10.97</td>
<td>131</td>
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<td><em>Whilst writing this diary I have just recalled the possibility of using a polycarbonate-styrene mix which could be tougher (because of the styrene). This could be suitable for the 'integral' braces, if we wished to prototype them in the workshop. Would need to do a more in-depth study of the material properties required, though. I came across the PC-styrene blend when looking through a plastics directory at the Pilkington Library a few weeks back.</em></td>
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<tr>
<td>23.10.97</td>
<td>132</td>
<td></td>
<td><em>Materials/processes were looked at today when I went through my revised PDS with Eddie (dated 9.10.97), to check to see if there were any immediate issues of concern. The following issues were raised. (1) Scratchplate- originally used to protect the wood (Eddie). Suggestion that a textured material (OF) or a reinforcement (e.g. extra fibre or equivalent) could be used as an alternative. (2) 0.5mm soundboard thickness- this is the available thickness of the Forex-EPC, and RA had agreed this was fine. Eddie suggested that thinning of the soundboard towards the edges might be wanted- but I pointed out that RA did not consider this to be important when we talked about it. (3) Eddie noted that an 'integral bracing' feature might be used. I'm not sure I have mentioned this before but it seems I omitted this from the PDS. Eddie suggested that 'licking' on braces is perhaps a little close to manual/traditional methods of making rather than DPMA- which is what I should concern myself with. I agreed, mostly, but pointed out that I was still in an 'R+D' stage and that more work would be needed before I could really concentrate my efforts on DPMA- the considerations like this will come into play on prototype 3 (designing from scratch, with the knowledge of prototypes 1 and 2). (b) The bridge- similar to the bracing; this too could be integral and designed different to the conventional, according to structural loads. Will look at this when designing prototype 3.</em></td>
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<td>4.11.97</td>
<td>133</td>
<td>DS32</td>
<td><em>This 3D representation was used by me to visualise possible machining points (especially the groove where the strings sit).</em></td>
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O.F.Pedgley Ph.D. 1999 Appendix XVII: The guitar project detailed diary entry catalogue
<table>
<thead>
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<th>Diary date</th>
<th>Entry no.</th>
<th>Artwork</th>
<th>Content (recitation)</th>
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<th>LV</th>
<th>CN</th>
<th>FN</th>
<th>KN</th>
<th>CG</th>
<th>2d</th>
<th>Ts</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.11.97</td>
<td>134</td>
<td>DS32</td>
<td>&quot;With this illustration I was showing, to myself, the joints of the bridge and making explicit, to myself, the basic construction requirements.&quot;</td>
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<tr>
<td>4.11.97</td>
<td>135</td>
<td>DS35</td>
<td>&quot;Looking at how to fix string, using a shoulder method sprung to mind, much like a bicycle brake cable is supported in a lever.”</td>
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<tr>
<td>4.11.97</td>
<td>136</td>
<td>DS35</td>
<td>&quot;All along producing this design, and the possible designs on DS35/34, I thought that there may be too much material, especially when compared with the classical. Greater area means greater adhesive coverage (strength) and possibly greater distribution of vibrations, though this is perhaps dubious. Again, I intend to just ‘have a go’, in acrylic, attach it to prototype 2 and string it up.&quot;</td>
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<tr>
<td>4.11.97</td>
<td>137</td>
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<td>&quot;Looking through Bralla, Handbook of Product Design for Manufacturing, I was able to get a clearer understanding of plastic-to-plastic joining techniques (e.g. ultrasonics, gas welding), bearing in mind that the bond between bridge and soundboard (if they are to be different materials) will need to be strong and made by either: (i) melting local area; (ii) welding local area with additional polymer; (iii) application of adhesive. The table of adhesive types and compatibility (kit) was useful as was the table of plastic-to-plastic welding compatibility (kit). Current design (EPC to acrylic) requires epoxy or polyester adhesive.&quot;</td>
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<tr>
<td>17.11.97</td>
<td>138</td>
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<td>&quot;Over the weekend just gone, I completed reading bits of Bralla’s Handbook of Product Design for Manufacturing. From my reading I wanted to create a comprehensive list of material processes, assembly and joining and finishing (mainly for my own development, but also as reference reading for my PhD research). The contents of the book have opened my eyes to some new possibilities of processing and joining in plastics, which I will look at in greater detail in the next phase of work. I envisage using my ‘list of processes in product design’ for future design projects as well as finalising the design of the polymer acoustic guitar.&quot;</td>
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<td>17.11.97</td>
<td>139</td>
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<td>&quot;Created a sample of Forex-EPC bonded to PMMA (clear) using epoxy adhesive (araldite). Left this to set over the weekend. The result seems to be a surprisingly strong bond - on first inspection it looks as if it will hold on the guitar top-plate. My reason for producing this was to see what kind of a bond could be produced and if any material degradation would take place in so doing - it was also a check to see if it was worth my while producing an acrylic bridge on prototype 2. Verdict - go ahead with acrylic bridge, I will be able to explore its acoustic response only by practical experimentation.&quot;</td>
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<tr>
<td>20.11.97</td>
<td>140</td>
<td></td>
<td>&quot;Useless welding combinations (written down). Info got from Bralla DPM text.&quot;</td>
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<td>20.11.97</td>
<td>141</td>
<td>DS37</td>
<td>&quot;This is me presenting myself what the joint is, and annotating some of the properties of the Forex around the welding (there were taken from the information data sheet, supplied by SBA plastics). My purpose for considering the joint is because I want to move towards final designs, recommending the use of industrial processes. I am laying out the parameters to which I am working.&quot;</td>
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<td>20.11.97</td>
<td>142</td>
<td>DS37</td>
<td>&quot;Laying down (written) what manufacturing processes can be used with the Forex (a combination of my own knowledge. Helped particularly by my ‘list of processes’ which I produced a few days back, and information from the Forex data sheet). Again, laying out my options regarding the techniques of joining two plastic parts.&quot;</td>
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<td>20.11.97</td>
<td>143</td>
<td>DS37</td>
<td>&quot;Again, me checking the properties of the Forex, from the data sheet.&quot;</td>
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<td>20.11.97</td>
<td>144</td>
<td>DS37</td>
<td>&quot;Me externalising my reasoning for delaying the finalisation of prototype 2. In essence, I want to check the feasibility and practicality of joining methods other than adhesive. For this reason I have set up a meeting with Dick Heath. This design sheet will come in very handy to remind me of some of my constraints and lines of thinking.”</td>
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<td>20.11.97</td>
<td>145</td>
<td>DS37</td>
<td>&quot;The R.I.M. idea, don’t know whether it is feasible, could be used to form the whole of the soundboard in a single moulding, from the figured Forex, using a special tool. (Applying my own knowledge - would be an expensive tool though).”</td>
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<td>21.11.97</td>
<td>146</td>
<td></td>
<td>&quot;Reminding myself of another possibility (written down).&quot;</td>
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<td>21.11.97</td>
<td>147</td>
<td>DS38</td>
<td>&quot;This whole sheet is to do with processes (and materials). I want to lay out my options for detail design of the bridge/soundboard joint. It is a summary page which I can refer back to at a later date, without having to wade through the technical sheet again. Much of the information was arrived at through a useful meeting with Dick Heath today.&quot;</td>
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<td>21.11.97</td>
<td>148</td>
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<td>&quot;From my meeting with Dick Heath today, I asked him how an integral bridge/soundboard-bracing component might be made from a blow mould. He said injection blow moulding. (Not RIM as I had proposed).&quot;</td>
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<td>21.11.97</td>
<td>149</td>
<td></td>
<td>&quot;I used Bralla to eliminate polyurethane adhesives (too soft, flexible).&quot;</td>
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<td>21.11.97</td>
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<td>&quot;Dick gave me the contact information for a specialist adhesives expert at S.M.A.&quot;</td>
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<td>21.11.97</td>
<td>151</td>
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<td>&quot;Polyester adhesives - strong bond - I identified this from Bralla.&quot;</td>
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<td>21.11.97</td>
<td>152</td>
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<td>&quot;I went to the workshops to test out the thermo-forming ability of the EPC using a drip heater. The band on the opposite side of the heat application side was good quality, no major surface defects. The heated side was a little warped and rough-textured. May well make use of this knowledge when finalising the guitar.&quot;</td>
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<td>21.11.97</td>
<td>153</td>
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<td>&quot;(Thermal expansion/contraction, tendency [X] for the gas to expand when heated - distort the material surface) Limitations of heat processing [ Forex ], as identified by R.H. He demonstrated ‘bubbling’ when the polymer was over-heated, using a flame.”</td>
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<td>21.11.97</td>
<td>154</td>
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<td>&quot;Draft of fax sent to S.M.A specialist at the end of the day. [written down].&quot;</td>
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<tr>
<td>21.11.97</td>
<td>155</td>
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<td>&quot;Meeting with Dick. 21.11.97. Poly carbonate to EPC. Nothing else is likely to be compatible (UR). Therefore only worth manufacturing a polycarbonate bridge/strut. Conclusion reached through discussion with RH.&quot;</td>
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<td>21.11.97</td>
<td>156</td>
<td></td>
<td>&quot;Need to get hold of polycarbonate sheet of thickness approx 1.2mm. Statement of action is what I must now do.&quot;</td>
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<td>24.11.97</td>
<td>157</td>
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<td>&quot; Went to Polybran Plastics Supplies, Shepherds, who supplied me with a length of 10mm thick polycarbonate (Lexus, GE Plastic). This will be used to test different bonding methods for the Forum/IPC junction.&quot;</td>
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<td>24.11.97</td>
<td>158</td>
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<td>&quot; Went to the GE Plastics WWW site, through an infowise search on Lexus. I was curious to find out more about the precise properties of this material. Will return to the site tomorrow to note some of the key data.&quot;</td>
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<td>26.11.97</td>
<td>159</td>
<td>L81:40</td>
<td>The key properties of polycarbonate (both in Lexan and Forex) were noted on L81:40 so that I can make quick reference to them when discussing processing requirements with manufacturers. This is important information which needs to be portable, since I do not want to rely on remembering it. Most of the physical properties were taken from the text 'Mechanics of Engineering Materials' by Rankin and Crawford.</td>
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<td>26.11.97</td>
<td>160</td>
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<td>Made use of the GE Plastics WWW site (<a href="http://www-ga.com/plastics">http://www-ga.com/plastics</a>) which I had visited previously. Noted down some of the key points relating to designing and working with Lexan polycarbonate sheet. These are noted on L81:39. The notes on joint design using linear vibration welding were particularly useful and I could see how this might be the most suitable method for my application; I would not consider the design modification to implement this method.&quot;</td>
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<tr>
<td>26.11.97</td>
<td>161</td>
<td></td>
<td>&quot;Checked with Dad to see if he has any useful information for me about designing in polycarbonate. Found some useful basic data on the properties of reinforced polycarbonate, which may be noted at if non-reinforced polycarbonate does not perform well under 500N of loading.&quot;</td>
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<td>26.11.97</td>
<td>162</td>
<td></td>
<td>&quot;Checked in the Plastics Literature Guide to see if it had any useful information for me about designing in polycarbonate. Found some useful basic data on the properties of reinforced polycarbonate, which may be noted at if non-reinforced polycarbonate does not perform well under 500N of loading.&quot;</td>
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<td>27.11.97</td>
<td>163</td>
<td></td>
<td>&quot;Checked in the Plastics Literature Guide to see if it had any useful information for me about designing in polycarbonate. Found some useful basic data on the properties of reinforced polycarbonate, which may be noted at if non-reinforced polycarbonate does not perform well under 500N of loading.&quot;</td>
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<td>27.11.97</td>
<td>164</td>
<td></td>
<td>&quot;Checked in the Plastics Literature Guide to see if it had any useful information for me about designing in polycarbonate. Found some useful basic data on the properties of reinforced polycarbonate, which may be noted at if non-reinforced polycarbonate does not perform well under 500N of loading.&quot;</td>
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<td>28.11.97</td>
<td>165</td>
<td></td>
<td>&quot;Looked at Reinforced Plastics Handbook to see if it had any useful information for me about designing in polycarbonate. Found some useful basic data on the properties of reinforced polycarbonate, which may be noted at if non-reinforced polycarbonate does not perform well under 500N of loading.&quot;</td>
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<td>28.11.97</td>
<td>166</td>
<td></td>
<td>&quot;Sorted out my pile of literature relating to this project. Came across promotional literature from ITW Adhesive Systems. Have faxed them the same information about my joint requirements as the other recent mail. Hopefully they will be able to supply me with a suitable grade of sample adhesive (their range is based mostly on methylmethacrylate adhesives).&quot;</td>
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<tr>
<td>1.12.97</td>
<td>167</td>
<td></td>
<td>&quot;I have spent the last four days searching for manufacturers who can weld or work with two components together. Telephoning the companies identified in the Plastics Literature Guide and Leicester Yellow Pages was not profitable—these companies did not carry out the kind of work I was looking for (the information provided was therefore inaccurate).&quot;</td>
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<td>1.12.97</td>
<td>168</td>
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<td>&quot;In the morning I visited the library and spent some time looking at the Deby Yellow Pages, again, to identify plastic welders. I telephoned one company, A.B.C. Derby, who said that they would be able to do the job for us. I have arranged a visit to discuss the job and 'go there' in two days time (Wednesday). It seems that they use hot gas (welding rod) method. I might still have to track down companies using alternative methods so that I can make a comparison of the results of different welding techniques.&quot;</td>
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<tr>
<td>3.12.97</td>
<td>169</td>
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<td>&quot;My strategy at the moment is to test out the various bonding methods available to me and then apply the best one to the guitar bridge on prototype 2. The best technique might also be recommendation for the final design, but alternatives like injection blow moulding might be more cost.&quot;</td>
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<td>3.12.97</td>
<td>170</td>
<td></td>
<td>&quot;Visited A.B.C. Derby, today. The director there, Peter Radford, was very helpful. He was able to produce a hot plastic rod weld between the Lexan and the Forex, although this may not be a sufficiently strong joint... the process has raised the Lexan block a little so there is a small air gap between it and the Forex sheet... almost like the block is levitating on the welding rod. Peter pointed out that the plastic rod would be able to accommodate the block, but he did not have anything in clear welding rods for polycarbonate were also available. The Forex did not distort greatly, which was a surprise, and once the temperature was set correctly, the skin on the Forex did not burn. Peter noted that the difference in thickness of the two samples meant that the danger of burning the thinner (Forex) sample was always there because of the need to supply extra heat to the thicker Lexan block to get it to temperature.&quot;</td>
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</table>
| 4.12.97    | 171       |         | "Was looking at my prototype 2 thinking that welding each component (bridge and braces) onto the soundboard would be a very time-consuming task for a mass-manufactured version. Instead, I thought that making a skeleton, like this [drawing] could be vibrated/hot-plate welded as one piece on the soundboard. That way, only 2 (bridge) components would need to be assembled. This might be a more appropriate method than injection blow moulding of one full soundboard component." | Cn | Fn | In | Cn
<table>
<thead>
<tr>
<th>Diary date</th>
<th>Entry no.</th>
<th>Artwork</th>
<th>Context (verbatim)</th>
<th>Wn</th>
<th>Lv</th>
<th>Cn</th>
<th>Fn</th>
<th>In</th>
<th>Kn</th>
<th>Cg</th>
<th>2d</th>
<th>Ts</th>
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</thead>
<tbody>
<tr>
<td>4.12.97</td>
<td>172</td>
<td></td>
<td>&quot;Got a reply from Dick Heath. He says I should contact FFR Ultrasonics (Lincoln) for welding advice -&gt; will do this early next week.</td>
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<td>8.12.97</td>
<td>173</td>
<td></td>
<td>Telephoned Dick Heath. I will meet with him tomorrow to see if he can use ITPH’s hot plate welding equipment. If that doesn’t work, Dick has contacts that I can approach.</td>
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<tr>
<td>8.12.97</td>
<td>174</td>
<td></td>
<td>&quot;Gave some Lecon and Forex samples to Eddie to give to FFR Ultrasonics, to see whether the materials can be welded that way. Awaiting results... hopefully the end of next week.</td>
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<td>9.12.97</td>
<td>175</td>
<td>0539</td>
<td>&quot;Wanted a rough idea of how well the methacrylate adhesive from ITW would perform under the conditions experienced by the guitar bridge. I had established earlier in the project that the adhesive is under shear forces.”</td>
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<td>9.12.97</td>
<td>176</td>
<td></td>
<td>&quot;Received a lengthy fax from ITW Adhesives who have supplied me with much information on a suitable adhesive. They are also dispensing a sample to me to try out. I will put this adhesive into use and compare its performance with that of Araldite.”</td>
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<td>15.12.97</td>
<td>177</td>
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<td>&quot;Things are currently 'on hold' because I am awaiting results of the jointing methods to apply to prototype 2. I'd like to get on finishing it, but I simply am not in a position to at the moment. I am taking advantage of this 'quiet spell' to catch up on some reading and writing for my thesis.”</td>
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<td>15.12.97</td>
<td>178</td>
<td></td>
<td>&quot;Attempted to create a test joint with the adhesive from ITW. Turns out I need an applying gun so I have had to put this part of the work on hold.”</td>
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<td>16.12.97</td>
<td>179</td>
<td></td>
<td>&quot;Received the ultrasonically-welded test joint. The material has been pulsed: if this is the kind of result to be expected then it is a preferred route for the guitar on the grounds of very poor finish quality and structural interference. The sample is spot-welded, I originally thought that the material would be welded as a seam (continuous length). May come back to further investigation of ultrasonics if other methods prove doubtful.”</td>
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<td>16.12.97</td>
<td>180</td>
<td></td>
<td>&quot;Have arranged a meeting with Richard Heath for Friday to try out hot plate method at ITPH and discuss the joint samples that I currently have done. (...) On the phone to Dick I mentioned the ITW adhesive. He was sceptical that acrylic adhesive will give a good bond on polybutyrates: he couldn’t think why, yet ITW have recommended this to me as being suitable. Conflicting information here... so it makes it even more important to find out what happens by creating a test piece.”</td>
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<td>16.12.97</td>
<td>181</td>
<td></td>
<td>&quot;Tried to contact David Turr at ITW Adhesives: he will be in tomorrow so I will try again then. I wish to take a visit to him because that seems the simplest way to get this joint done quickly - it being such a small job and me not having the correct dispensing equipment. I might also be able to get some valuable advice from him regarding joint design.”</td>
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<td>17.12.97</td>
<td>182</td>
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<td>&quot;Last night I attempted to do my own hot plate bonding of the two samples but did not manage to do a good job - too uncontrolled, which resulted in a messy finish. Tonight I will try a different method.”</td>
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<td>18.12.97</td>
<td>183</td>
<td>LB1:44</td>
<td>&quot;...this drawing produced after Dean suggested to me that the fitting could be made on the underside of the soundboard... It produces another point of stress concentration, by having another soundboard hole, which is not desirable, but it could be looked at as a possible scheme for detailing.”</td>
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<td>18.12.97</td>
<td>184</td>
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<td>&quot;This was a quick representation I did of possible joint detailing to increase the effectiveness of an adhesive bond. I thought of it on my way back from ITW. The grooves could be mill out on the prototype, I thought, 'trapping' a great deal of the adhesive. The main problem I had learnt from today is that the two flat surfaces of the test samples tend to just squeeze the adhesive out to the sides - away from the area which needs bonding. Something would need to be done - preferably in the component design - to avoid this. &quot;Squeezing&quot; the bridge over the soundboard (approx. 1mm gap) could be another alternative, if two flat surfaces needed to be rejoined. All this needs to be borne in mind for the detailing.”</td>
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<td>18.12.97</td>
<td>185</td>
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<td>&quot;I attempted hot plate welding at home last night but did not produce a good job - the heated plate was not uniformly hot enough and my feeling from this 'rough and ready test is that both components of the joint need to be softened/alter (sic) in order to produce a good bond.”</td>
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<td>18.12.97</td>
<td>186</td>
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<td>&quot;The visit to ITW has been very informative. Sally, the technician in the lab there, produced 3 sample joints for me. Whilst doing that we had a chat about the merits of the different methacrylate adhesives and different dispensing methods. It provided me with some further insight into gluing and some of the considerations (such as working time/temperature/mixing systems). I am leaving the samples for 24 hours to achieve maximum strength; I will take all the test samples along to my meeting with Dick Heath for an evaluation / discussion on what action to now take / what else needs to be looked at.”</td>
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<td>19.12.97</td>
<td>187</td>
<td>LB1:44</td>
<td>&quot;Final comments on each of the jointing methods are filed in the logbook on LB1:44, in the light of today's meeting [with Dick Heath]. These are formal record for me to keep a tab on what design options are open to me.”</td>
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Appendix XVII: The guitar project detailed diary entry catalogue

O. Peddigey Ph.D., 1999
19.12.97 188

"Had a meeting with Dick Heath regarding bonding methods. We discussed these, as well as wider issues relating to the guitar design, and agreed that a team of designers would be able to put some figures onto the design work. e.g. if we have the soundboard half the thickness, treble increase but at the expense of making the soundboard a sound board rigid. I am conscious that my approach, whilst being planned, is far from scientific, but it enables me to be product-focused. That is to say, I can evolve full prototypes relatively quickly, rather than testing individual material theories to the detriment of overall design. I use the best of what I can get at the time and then implement that into my design. So, the findings from the discussion with Dick were: 1) No hot plate facilities in ITPHE; Dick will contact a plastics company in the New Year to see if I can use their facilities. 2) Dick's knowledge on the structure of adhesive joints was valuable, and gave me an understanding of some wider considerations to make regarding joint design. Particularly, Dick pointed out that the substrate surface on the EPC is called the adhesive-perspective test, rather than the adhesive. 3) Dick was impressed with the ITW methacrylate adhesive. This does the job, but he suggested that the rubbingness (sic) of the material may have implications for vibration dampening. Shows that the way ahead was to get stuck in and have a go!"

5.1.98 189

"I have noted down a rough plan of the final 3 months on this design project. In particular, I intend soon to make some final mechanical calculations for key structural components of the guitar, so that these can be used in detail design relating to the final prototype and for the purposes of deciding what industrial manufacturing processes are most suited to each product component. Also in these notes (LB1.45) I have stated my intention to use CAD/CAM, where applicable, in the construction of the final prototype. My plan this week is to produce the PC bridge and to assemble prototype 2, which needs to be finished very soon."

5.1.98 190

"Had a telephone call and email from Chris Hall at 3M Technical Centre, regarding adhesives for the polycarbonate joints (in response to a fax I sent in November). Details on LB1.45. He will send some samples for me to try out."

6.1.98 192

"DS40.41.47.9 have considered the material (Eorex) in the mechanical calculations (E.4, Young's Modulus)."

7.1.98 193

"DS43.6 was looking at the [design sheet] and, in the light of today's earlier work [strength calculations], concluded that it would require reinforcement. I automatically envisaged a sheet metal plate for this component."

7.1.98 194

"The mechanical calculations (DS42.5) were an advancement on yesterday. I now have a clear idea of what the Forex can/cannot do as a structural member of the guitar, through using the equations and working-through the design solution. I feel assured now, through the mathematics, that I can propose designs which are mechanically feasible in given materials. It has helped me picture the worth of steel as a superior stiff material to plastics, and, hence, in the designing of slim-line structural components. More than anything, the mechanical calculations have made the design issues clear to me and the importance mechanical calculations have in determining what materials might be suitable in a component."

7.1.98 195

"This was cleaning up, in my mind, how the build-up of components for the final design was going. I was thinking whilst drawing these that I would need to produce CAD models of each."

7.1.98 196

"When I was drawing this, I was envisaging a lean polymer bend which would be used using adhesive."

7.1.98 197

"I know the shape of the head reinforcement member, and that it would contain holes, and immediately linked it to pressed metal. 1.5mm Thickness fairly right."

7.1.98 198

"Started model-making the bridge. Hopefully will be able to continue this tomorrow. At the moment it is very weighty - it needs slimming and trimming. When it is placed onto the soundboard, just under its own weight, there is significant dampening of vibration when you tap the board. Don't know if this is a function of the weight of the material. Will just have to string the guitar up and see how it sounds."

7.1.98 199

"Have made a test sample of Lason-Fox using the 3M polyester adhesive. Will wait for this to cure, and then compare its performance with that of the ITW acrylic adhesive."

8.1.98 200

"I consulted Dean Bates (CNC expert) and Steve George (machining expert) about how to produce the curved radius-profile I wanted on the [prototype] bridge. (...) The mass-produced version might be moulded but, for now, the prototype version could be best realised through machining."

8.1.98 201

"The polyester adhesive is still curing. I shall give it a 'manual test' tomorrow afternoon. If it does not perform as well as the acrylic adhesive, I shall opt for the latter and make arrangements for the bridge + body to be assembled next week."

9.1.98 202

"Ian Allen (fellow research student) was consulted about achieving a high gloss polish on the bridge - his experience with acrylic was useful and I shall make use of all the techniques he described."

9.1.98 203

"The 3M adhesive has failed to produce a good bond on my first test piece. It cracked away similar to the nail. For prototype 2, I shall therefore use the ITW adhesive, pending further tests of the 3M mix."

Appendix XI. The guitar project detailed diary entry catalogue
<table>
<thead>
<tr>
<th>Diary date</th>
<th>Entry no.</th>
<th>Artwork</th>
<th>Content (verification)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1.98</td>
<td>204</td>
<td></td>
<td>Discussed prototyping facilities for the final version with Dean Bates. I am looking to make use of the Department's new CNC router for the mould of the guitar back (which will probably be vacuum-formed or similar). The CNC route will allow me to easily create the curves I require, but it is a new route for me so I will be learning as I go along. Dean pointed out the main working parameters of the machine to me, in order that I design for manufacture, for the particular facilities we have. One major restriction is the 30mm tool depth on the router. My guitar back is approx. 80mm in depth, so it is likely that I will have to build up my overall mould from several separately machined layers.*</td>
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<tr>
<td>14.1.98</td>
<td>205</td>
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<td>&quot;Painted ITW Adhesives. Sally applied the adhesive to the bridge and it is now bonding. Will leave for 24 hours to cure.&quot;</td>
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</table>
| 14.1.98    | 206       |         | "On the way back from ITW, Edie mentioned that I might want to make a fibreglass back rather than vacuum-formed, for this trial run."

*Strangely, now that the bridge is fixed in place, the sound chamber seems to be resonating quite well to ‘finger taps’, clearly resonating at different frequencies according to position on the soundboard. The dampening/hudly [sic] sound that I got a few days ago by just placing the PC block onto the soundboard has been replaced by resonant vibrations. Perhaps the adhesive has somehow formed the missing link between the Forex and the Lason, in terms of vibration transfer. I cannot help but be reminded, as I write this, of Rob Armstrong’s contention that the construction of the guitar is paramount, and that each component should come together to form a greater whole. Perhaps the adhesive is providing that very coherence?*

16.1.98     | 208       |         | Made a couple more test samples of the Lason-Forex (and a Lason-Lason) joint, using 3M’s polyester adhesive. These will cure over the weekend, allowing me to make a final judgement on their suitability – will probably make a small test rig and check the failure load of the joint (I’m sure that if this would find it useful to have a figure, I guess, since they were keen for me to provide feedback on the performance of the adhesive in my application. It would be hard if the adhesive performs well – it could be used in the Extst. by me, making the final prototype.* |

16.1.98     | 209       |         | Sprayed up a few samples of the Forex. Produces a quite good textured finish. Found that best finish came without the use of a base, just put the final colour straight on. I may well spray-point prototype 2 to give it the impression of a more finished final result."

16.1.98     | 210       |         | Did a test-run vacuum-forming to see how the Forex performs. The results were bad; in fact they have put me off going for a vacuum-forming on the final prototype. It may be better to go for a lay-up. Will attend to this point later on (hopefully next week).* |

16.1.98     | 211       | LB1:48  | Had a discussion with Ian Allen (fellow research student) on possible ways of forming the soundboard and integral bracing, initiated by ideas from Jon after playing prototype 2 (it is now strong up and is holding well out). Jon’s ideas are sketched by him on LB1:48. He has pointed out to me an idea where the ribs are formed from vac-formings, and inserts (perhaps casing, coloured) is poured in to provide strength and interesting visual qualities. All the details for this vac-forming could be done on the router (CNC). Unfortunately, we tested the Forex vac-forming capabilities after this discussion (point 3) and found that it did not form well. This is in contradiction to the manufacturer’s claims and obviously needs further investigation since (I regard it) as a fundamental stumbling-block for detailed design if we just take it for granted that our tests are right. I tend to err towards the manufacturer’s claims on this point - the Forex does vac-form well – maybe our tests were not conducted well enough! |

21.1.98     | 212       | LB1:49  | Design sketches of prototype 3 manufacture, for me to visualise what RA was explaining to me. I’ll find it easier to make use of this information in the near future when it’s in illustrations rather than memory.* |

21.1.98     | 213       |         | “The rest of the notes on LB1:49 and LB1:50 were notes made on the train. I did not forget some important points of the meeting. In producing these notes I was anxious in my mind to know the exact steps required to produce a high-quality GPR mould... and joined down that I intend to discuss this with Tony Hodgson (a lecturer in the Department who has the relevant expertise).” |

22.1.98     | 214       | DS45    | All the whilst whilst on DS45 I knew that I would be working with 8mm (10mm) deep polycarbonate and that the bridge would be machined using CNC methods because of the intricate/precise curves required. When working on the right-most drawing (marked ‘X’) I had in my mind an image of a block being machined to produce the shape I wanted - using the Department’s Workshop 1 machines. I found myself extending profile lines as if they were paths for the milling cutters to follow. I also imagined the milling machine producing the overall edge shape, then to a time. I concluded that the whole component could be produced on the CNC machine, save a few operations which cannot be performed in 2.5D machining.* |

27.1.98     | 215       | DS47    | “Thinking about choices for basic body colours (PB: GPR back), bearing in mind I am limited to just 3 colours for the Forex (peel: grey, black). I need to see samples of the grey and black before I can decide which to use, but here I am working up my preferred choices at the moment. At this point I was thinking that the GPR (back/sides) would be pigmented with the chosen colour. Later discussion with Tony Hodgson (GPR expert) alerted me to the fact that the surface outside will be very smooth, I didn’t really want a shiny/matt finish → see DS48 for some alternative solutions to this problem.* |

27.1.98     | 216       |         | “Remember to myself of aesthetic considerations of materials/processes looked at in the day and for tomorrow’s work.” |

27.1.98     | 217       |         | “Further exploration of colour choices for the materials (just using my own preferences for colours and limiting myself to the Magic Marker gamut of colours).” |
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<th>Diary date</th>
<th>Entry no.</th>
<th>Artwork</th>
<th>Content (verbatim)</th>
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<tr>
<td>27.1.98</td>
<td>218</td>
<td></td>
<td>&quot;Thickness of GRF back (determined from the Charlie bowl and its weight) should be (note when I was making the prototype).&quot;</td>
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<td>27.1.98</td>
<td>219</td>
<td>DS48</td>
<td>&quot;Possible different finishing techniques being put on the table. One possible edge solution is no 'fusy' material can be found?&quot;</td>
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<td>27.1.98</td>
<td>220</td>
<td>DS48</td>
<td>&quot;A drawing to explain to Dean (colleague) how the soundboard joins the body.&quot;</td>
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<td>27.1.98</td>
<td>221</td>
<td>DS48</td>
<td>&quot;Was thinking that this would have to be some kind of 'easy' strip. Don't know what to use. Had visions of shaping it down using hand tools to a smooth, level finish. Finishing this area is a question I shall certainly be putting to Rob on Friday.&quot;</td>
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<td>27.1.98</td>
<td>222</td>
<td>DS49</td>
<td>&quot;Here was assessing the visual qualities of different combinations of coloured polymer in relation to the wooden (natural) neck that Rob will be building.&quot;</td>
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<td>28.1.98</td>
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<td>&quot;Today wanted to check on the availability of materials to construct prototype 3. Telephone Polytron (material supplier, Shepshed), asking about obtaining coloured polycarbonate sheet. Negative reply - coloured sheet does not exist to buy. The counter, it would have to be bought-in (moulded) specially. I knew this was a problem as I was expecting to receive different hues, but was not willing to opt out for this at stage because it might not be as good. More trials (prototypes) would need to be made to investigate this. This means that I will have to work with the materials of the day (if present) and to avoid any painting the acoustically important parts because the effect that this has had on the tone, for one example, is negative. Painting the bridge on prototype 3 would just be for visual effect. Instead, I shall work towards a clear bridge for now. This also has implications which I have been thinking about...&quot;</td>
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<td>28.1.98</td>
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<td>&quot;The MA6940LH ITW adhesive, from the literature, clearly does not come in high-hold mini-cartridges (it is a 10:1 mix rather than 1:1). This means that gluing prototype 3 is probably best done at IFW, Kettering (Ita). Also, the adhesive is available only in blue, not in red, which is a bit odd since I am opting for a blue scheme. Will have to make sure the adhesive is properly covering all the bridge this time, not just parts of it as in the case with prototype 2. Jon (Allen) suggested that the adhesive channels may be changed to form the X-Armoning logo or my signature. This would be ideally suited to CNC manufacture, which is quite a novelty feature. Since the bridge will be clear, I shall make it as shiny on the surface as possible to highlight its visual qualities. Also, since also have enough in stock, I shall make the struts/other solid polymer components out of 10mm PC sheet (machine, etc...).&quot;</td>
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<td>28.1.98</td>
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<td>&quot;I took a visit to nearby Leicester to SBA Ltd, the suppliers of Forex-EFC, to compare the grey and black versions, since I want the final product to have a dark grey, sophisticated look but did not know exactly what the combination of colour and sheets was like for these two versions. I inspected the black and this suits my requirements exactly. It has a really appealing overall visual quality. HOWEVER: SBA only have run out of stock on this one, and I was advised that the last lot took 5 MONTHS to receive. This looks like a bit of a crisis, so as I shall get on to the manufacturers in Switzerland to advise me on other UK stockists or, failing that, of possibly directly sending me a sheet. The black version really is special, and since I cannot point the opal for fear of acoustic side-effects, I really need to get hold of some...&quot;</td>
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<td>28.1.98</td>
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<td>&quot;Thought, when discussing with Jon, that if the soundboard and bridge were all Forex-EFC (or equivalent), moulded, I would need some sort of insert (metal) - to withstand the pull of the strings (deforming the Forex). Experience shows that it is not difficult to dent...&quot;</td>
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<td>29.1.98</td>
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<td>&quot;Sent out a fax to Airfix Ltd, trying to hunt down some black Forex-EFC. Await their reply. Hopefully it will be positive. Also phoned another UK supplier of this material and also await their reply.&quot;</td>
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<td>29.1.98</td>
<td>228</td>
<td>DS50</td>
<td>&quot;Thought, when discussing with Jon, that if the soundboard and bridge were all Forex-EFC (or equivalent), moulded, I would need some sort of insert (metal) - to withstand the pull of the strings (deforming the Forex). Experience shows that it is not difficult to dent...&quot;</td>
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<td>29.1.98</td>
<td>229</td>
<td>DS51</td>
<td>&quot;Told Edie about GRF lay-up, since I've not done it before! Have illustrated the basic stages for doing this as a reminder to myself and to be used in design discussions in upcoming days, particularly for gathering comments on how to produce surface textures. I have added notes on vac-forming (using the different types of mould in the GRP process) because I have re-read that the Forex-EFC is subject to vac-forming, despite my earlier workshop trials. So, I am leaving the vac-forming route open, just wait and see what goes from there and then we can plan the glass fibre addition.&quot;</td>
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<td>30.1.98</td>
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<td>&quot;Design for mass-manufacture - PC or lasercut boxes (or pultruded glass fibre equivalent) could be added in the neck to provide the stiffness, rather than a metal truss rod (EVR).&quot;</td>
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<td>30.1.98</td>
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<td>&quot;Change of bridge material to PAMA is an accident that it can be bought off-the-shelf in a great range of colours, which will look great on prototype 3, with the acrylic adhesive. Also a swaying factor here was Dick's knowledge that PC should not be painted - it does not hold (hence, as Dick explained, PC Sierra bumpers were never painted). Rob did not think that changing to acrylic for this prototype would have detrimental effect on the tone. He checked up in Benham &amp; Crawford, 'Mechanics of Engineering Materials', and noted that the YM, tensile strength and density of PAMA are all of the same order as PC. A production version would use PC, however, because if placing a bridge and bracing as insert in a mould and injection blow moulding around them, the melt temperature needs to be close - but higher - than that of the required material (advice from Dick Heath). Also, chemically, it will help...&quot;</td>
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<td>30.1.98</td>
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<td>&quot;Details of the edge finishing on the soundboard. Rob thought my design with a separate 'bendy' plastic component glued-in was too tricky to achieve. Instead, he suggested a channel be cut into the soundboard and something, perhaps a coloured resin, be put in to add decorative effect. He also noted that any binding needs to run the entirety of the mould back to produce a good construction. For the soundboard, Rob suggested that I make it slightly over-sized and then shape it back (I thought with a router for a radius edge). Will consult with shaper techniques about how exactly this will be done since I haven't had experience with such model-making details.&quot;</td>
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<td>&quot;Rob thought that the hardwood sandwich in prototype 2 would not be doing the sound any favours and so it was not necessary to keep this component. The binding would need to be reasonably wide though. I think the exact distance will have to be determined by practically seeing what polymer binding works.&quot;</td>
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<td>30.1.98</td>
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<td>D551</td>
<td>&quot;This material sprung to mind because I looked at my drawing and thought 'bendy thin plastic' and linked that to the integral hinge properties of PP.&quot;</td>
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<td>30.1.98</td>
<td>235</td>
<td>D551</td>
<td>&quot;Again, the cue for this idea (making edging integral to a one-piece soundboard) was through looking at my drawing. All the details of this component are aligned so that it would be easy to pull out of a mould. This is the idea I had in my mind.&quot;</td>
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<td>&quot;The back and sides - Dick suggested using an epoxy-based GRP to create a more rigid 'tony back'. Rob pointed out that this was desirable since the 'bowl-backs' that he had personally worked with were too flaky and soft. He also said that they scratched a great deal - which is a good reason for adding mottled/matte surface texture. Surface texture, he agreed, could best be achieved by working it onto the mould. Colour would be added to the resin when laying-up. This combination avoids a great deal of finishing but is subject to future finish being able to be reprocessed in the mould-making process.&quot;</td>
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<td>3.9.98</td>
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<td>&quot;3-part mass-manufactured version was mentioned but everyone agreed that the immediate task was to get prototype 3 up and running.&quot;</td>
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<td>30.1.98</td>
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<td>&quot;For the rosette and other body graphics, I thought that high quality screen printing and use of transfers might be more readily because I saw how these had been made use of in a friend's Apple Powerbook portable computer and partly because the Forex-IPC sample from SBA has an high-quality printing. Will investigate this further too.&quot;</td>
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<td>9.2.98</td>
<td>239</td>
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<td>&quot;Fantastic! Received the black Forex-IPC direct from Switzerland today and it looks great.&quot;</td>
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<td>10.2.98</td>
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<td>&quot;Ask Rob to see if i have any 10mm angle strips. We don't have any so I shall seek some from an external supplier.&quot;</td>
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<td>10.2.98</td>
<td>241</td>
<td>LB1:52</td>
<td>LB1:52 (bottom right) shows an idea I had at lunchtime for placing the Armstrong logo on the soundboard. Aside from printing or transfers, I was thinking that it could either be (A) moulded by (B) as I was drawing the moulded-out it.&quot;</td>
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<td>11.2.98</td>
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<td>&quot;We measured the depth of the router to see if its size will have implications for the CAD model I produce to subsequently send to it for manufacture. Its 400mm x 400mm, so the guitar components will have to be routed in two halves, then joined together.&quot;</td>
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<td>11.2.98</td>
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<td>&quot;Looked through Leicester Yellow Pages for GRP and screen printing companies - noted these down in LB1:53 for future reference.&quot;</td>
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<td>12.2.98</td>
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<td>&quot;Talked to Leon about CNC manufacture of the FL plug, Forex soundboard and acrylic bridge, about depths of gutters, signing-up and saddle-like details.&quot;</td>
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<td>13.2.98</td>
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<td>D552</td>
<td>&quot;The bridge has been detailed up, including precise points for the bridge-to-soundboard location and with, with the aid of the section drawing showing where the string holes need to go, I was able to determine the distance back from the saddle where the strings should terminate. (...) I was thinking of machining considerations as I was detailing-up, making sure the thing would cope.&quot;</td>
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<td>16.2.98</td>
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<td>&quot;Made some test samples of Lexan strip to see if these would be suitable for the binding. At 2mm thick it is quite flaky. Thicker samples did not bend, so I added bandage interruptions at regular intervals (as wooden guitar making I think) to add flex. This seems to work really well. Taking Rob's advice, I pictured in my mind how I will construct this part of the guitar: separate lengths of binding, glued using TWF please adhesive and held together to the composite back with clothes pegs...&quot;</td>
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<td>&quot;I used a scanned-in image of the 'Armstrong' logo to create a vector graphic in AutoCAD for possible inclusion on the back mould of the guitar. If it reproduces through the modelling process, this could look great.&quot;</td>
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<td>20.2.98</td>
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<td>&quot;Phoned GRP suppliers (Polyfibre, Birmingham) to send me a price list of products with a view to discussing the exact moulding (epoxy) details with Dick Heath.&quot;</td>
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<td>20.2.98</td>
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<td>&quot;Phoned screwfit/fixings printers in Leicester (Darlington Ltd). I will send them some samples Forex and sample designs to work with - I can then evaluate the quality of the finished item and see if it is up to my expectations. I'm after the quality of printing on the Forex-IPC sample; I've seen some printed graphics rub-off, I definitely don't want this to happen. It needs to be crisp and not smudged. I'm also after high-resolution 4-colour process printing, higher than AVS (avantgarde) can offer. Will wait to see how it comes back and make a decision.&quot;</td>
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<td>&quot;Checked with my drawing on D551 to see how the Armstrong logo needs to be added to the wooden (MDF) plug of the back. As I thought; it needs to be inset rather than standing proud. Had a chat with Tony Hodkinson regarding the mould design. He pointed out that the 'A' logo needs to have sloped walls so that the mould will release easily.&quot;</td>
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Appendix XVII: The guitar project
detailed diary entry catalogue

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<th>Diary date</th>
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<th>Artwork</th>
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<tr>
<td>20.2.98</td>
<td>251</td>
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<td>&quot;The aim for the short-term is to complete the moulded back ASAP.*&quot;</td>
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<td>23.2.98</td>
<td>252</td>
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<td>&quot;Hold in my hand an image of what good quality printing on products can come out like—especially like the quite thick printing used on some beer bottles these days. If I remember correctly, Carlsberg ice is one in particular that I like the finish on.*&quot;</td>
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<td>24.2.98</td>
<td>253</td>
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<td>&quot;Received a price list from Polyflex (Birmingham) for FRP materials. Will use this as a resource for discussing the GRP layup with Rod, Tony, Dick, Eddie etc.*&quot;</td>
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<td>3.3.98</td>
<td>254</td>
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<td>&quot;Took a visit to Leicester this afternoon and popped-in to SBA Plastics, asking them whether they had any 10mm blue acrylic sheet. I was advised that ICI did not manufacture 10mm sheet (which I took with surprise). Whilst there, I noted down the code numbers for dark blue acrylics (using a simple match from ICI). The just slightly transparent blue (code 7703) was great. I shall ask around about availability of this in larger thickness—going to ICI first (probably via the web) to see if it exists.*&quot;</td>
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<td>4.3.98</td>
<td>255</td>
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<td>&quot;Haveussed ICI Acrylic UK direct, enquiring about the availability of 10mm blue perspex sheet, in small quantities. Await their reply. I asked that, if possible, they send me a sample direct of the dark blue slightly transparent grade (7703). I suspect that it's not too easy to get hold of many of the colours because (as SBA said yesterday), they have to order them by the pallet load (which one suspects is done for the most popular colours only).*&quot;</td>
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<tr>
<td>6.3.98</td>
<td>256</td>
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<td>&quot;Got a reply back from East Display screen printers. To my frustration, they say they are unable to help.*&quot;</td>
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<td>10.3.98</td>
<td>257</td>
<td></td>
<td>&quot;Have been pursuing screen printers who will print onto the Formex. Quorn Reps in Loughborough do not offer the service. Went to the library on campus and got the name of a few printers in the Nottingham/Derby area (assumption: Yellow Pages). Quorn Reps also pointed out a small screen printers in Loughborough.*&quot;</td>
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<tr>
<td>13.3.98</td>
<td>258</td>
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<td>&quot;Telephoned Perspex Screen Printers (Loughborough). The chap there alerted me to the fact that a 4-colour process printing would cost me approx. £500 (the process involves plates and separation). He advised me that, for a one off, it probably was not worth my while. Screen printing (single colour) would be around £50 per colour—so again, this is expensive. He said that printing onto polycarbonate was rarely straightforward and would need to perform a test run. The DPI for screen printing was approx. 300dpi, he said, which is not good enough, since my graphics were approx. 200dpi. I definitely did not want poor-quality graphics/printing on the prototype, since it would detract from the overall effect.*&quot;</td>
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<tr>
<td>13.3.98</td>
<td>259</td>
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<td>&quot;I have a hunch that what I really want is a high quality transfer (and I might be able to make this myself using Softmat. What I'd ideally like is...&quot;</td>
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<td>13.3.98</td>
<td>260</td>
<td></td>
<td>&quot;...response to my fax for ICI, I have some acryllic Perspex samples sent me in my three flavours blue/hue. Not 10mm thick though, so I proceeded to phone ICI and ask whether 10mm thick blue Perspex was available from stock. To my disappointment, the thickest available was 5mm; 10mm would have to be made especially—minimum order 20 very large sheets. Obviously this was well out of the question. The chap from ICI suggested I make a laminate sandwich from the two 5mm sheets. I have reservation over this regarding what it might do to the integrity/strength/visual response of the bridge, but it is actually the only way of proceeding, short of finding a supplier of 10mm non-ICI acrylic blue sheet, which, given that ICI are the major manufacturers, seems very unlikely. Creating a sandwich could have some interesting visual effects for the bridge (if the two colours were not identical). If they were exactly the same then some kind of split line would be visible—possibly a possible way forward. Either way, it's a prototype of what would be mass-manufactured from polycarbonate inserts and enclosed polycarbonate, so this little anomaly will add visual interest to the prototype which may or may not be carried through to a final design.*&quot;</td>
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<td>13.3.98</td>
<td>261</td>
<td></td>
<td>&quot;Got a piece of the black Formex-EC and placed the 3 Perspex samples onto it to compare the different colour combinations. I asked Dean and Malandro on their opinions. I am amazed by the brighter 7703 sample because it seems to fit in with the image I have in mind of the final design—eraring towards primary colours but still quite dark. In fact, it is noticeable how different the samples look at different viewing angles. The two darker samples are, I think, too little different from the black Formex. Will make a final decision next week, bearing in mind the 'sandwich' problem.*&quot;</td>
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<td>13.3.98</td>
<td>262</td>
<td></td>
<td>&quot;Asked Rod about suitable adhesives for sanding the acrylic. He said the Department didn't have anything, but the model shop on the Ashby Road stocked 'plastic-web' which would do the job.*&quot;</td>
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<tr>
<td>13.3.98</td>
<td>263</td>
<td></td>
<td>&quot;Faced Airfix/Airfix thanking them for sending the block Formex. I also asked them, again, whether the material was available in colours other than opal, grey and black (for possible future designs), and what places in the UK stocked it (again, for possible future designs).*&quot;</td>
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<tr>
<td>17.3.98</td>
<td>264</td>
<td></td>
<td>&quot;Received fax from Alusilise Airfix. Formex is available only in the three colours opal, grey and black (and the UK distributor is only SBA Leicester.*)&quot;</td>
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<td>17.3.98</td>
<td>265</td>
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<td>Discussed graphics issues with AVJ Signwriting. Ruth showed me some of the best-quality 4-colour process printing onto clear vinyl that they can do. It seems like it could be quite adequate (especially after some experimentation with different settings). The A4 sound logo would be best done using a vinyl transfer. I think this will come out really well. The text 'Millenium- Advanced Polymer Construction' could be produced using the black ink from the CAMYK process onto clear (sticky) vinyl. All of these processes are effectively producing transfers, but it seems that these should be fine for conveying the right image for the prototype. Mass-produced versions could then be printed on, using whatever method was appropriate.</td>
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<td>17.3.98</td>
<td>266</td>
<td></td>
<td>Over the weekend I was in London. One of the music shops had an original 1950s McCarty/ plastic acoustic guitar for sale (shop was closed so I couldn't go in and hear what it sounded like...). Shop was on Charing Cross Road. I thought it looked very 'polioy' in a bad sense—shiny material, cheap-looking. Also thought the construction and body shape looked too much like an enlarged violin.</td>
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<td>18.3.98</td>
<td>267 L8138</td>
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<td>Had a look at Bolla, FMFA look with relation to IM structural foam. I hadn't realized that it was used so extensively. Picked up the fact that the process creates a smooth skin (in contact with mould) with a foamed core. Made notes on L81:58 for future use in my section on mass manufacture in my final design report. Had notions in my mind about how the inserts might work and that holding a 'piddle' (see diagram) bracing pattern (one component, pre-injection moulded) would be a lot simpler than clamping each bracing member separately... I was thinking how to make the manufacturing process simple. The bending I thought could be quite quickly and easily fabricated by machine with a handdaw and appropriate jig (easily automated too).</td>
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<tr>
<td>23.3.98</td>
<td>268 D552</td>
<td></td>
<td>I had previously checked out the implications of a dou colour laminate on the bridge by making reference to the full-scale drawing (D303) and seeing where the joint line would lie. It will create an interesting feature on the scopped sides of the bridge, though of course not what a mass-manufactured version would look like, assuming it were injection moulded from a single coloured resin. My reasoning for choosing a light blue/dark blue tinted combination hinged on making most of a less-than-ideal situation. Using two different tones creates quite a visual interest and allows for some interesting design features which would otherwise be missed. I used the samples of acrylic I had sent to me to see what combinations were good together. I remembered Dean saying to me I might want to have two A Bramson logos in between the sandwich. I had a photocopy of the logo to hand, so I placed it in the sandwich to see what it looked like. The tinted blue made the white of the paper stand out exceedingly strongly in the daylight (bit like daylight paint). This was great, and would add value to the first prototypes of the guitar in final version. Hence, after experimenting with combinations, I opted for the following:</td>
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<td>30.3.98</td>
<td>269</td>
<td></td>
<td>Received e-mail from Dick Heath regarding laminating the acrylic bridge (L81:58). I'd agree with him that it introduces more 'unknowns' into the design, but since I've not taken an approach of controlling unknowns and progressing in a 'scientific' manner, it does not bother me quite so much. What I'm faced with is a practical dilemma between making the guitar sound good (keeping material choices simple and sticking with polycarbonate clear sheet) and making it look like a production item (laminating coloured acrylic)—or, as Eddie suggested today, simply coating (probably post because it's quick and easy) the clear polycarbonate on a temporary basis so that photographs can be taken of the guitar as close to what it would look like as a production product. My decision today, after looking at the options, is to allow greatest flexibility. Since two prototypes will be made, why not go for both materials? (I) clear polycarbonate bridge version could be temporarily sprayed for photographs; (II) laminated blue acrylic version (usually more arresting; unknown properties with regards to acoustics). Dick's technical advice on laminating the polymer should prove very handy. Confirmed my suspicions that a generic adhesives (as supplied by Hendal Shop) wouldn't be up to the job for bonding.</td>
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<td>30.3.98</td>
<td>270</td>
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<td>Received graphics back from AVJ Signwriting. The results are excellent and will be just fine for the final guitar. It will also be very easy to tweak colours/designs according to late changes in product colour scheme. I'm well pleased with the A-in-the-circle Bramson logo, cut out of matte blue vinyl. Licks the business! But Dean and I both noticed that even with this small area of construction on the surface of the Finex-PEC, the result was a marked change in 'ring' when the material is hopped and checked for acoustic response... But I then figured that adding the bracing would amount to significant changes to the acoustic response of plain Finex sheet, simply on the large area which is being constrained.</td>
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<td>31.3.98</td>
<td>271</td>
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<td>Phoneed VT Plastics, Nottingham... they have no affoix of blue acrylic 5mm. I will therefore have to buy a sheet @ £20... still the Dept, can use it afterwards. Since I'm having to buy it, I shall get just the one colour (7020) because I can't justify the extra expense of buying transparent as well. So, in effect, my design ideas for two-colour laminating and sand-blasting the A Bramson logo in the centre of two sheets will not be realised in the final prototype. Might retain it as a design idea for the final report.</td>
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<td>31.3.98</td>
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<td><em>Last night I had a bit of a think: if I was to say to somebody now: 'go and make my final design', they wouldn't be able to, because I've yet produced any drawings which are intended for anybody else to produce it. Some of the fine details of construction and material shape (such as thickness of bracing and precise location of struts, and how to produce the spokeshave [sic] finish on the guitar back) assist in detail (or 3/4 thought through) only in my mind. Why? Out of a lack of necessity to produce a formal description of the design or methods of manufacture at this stage... and also because the whole thing is still in a state of flux: not least because details of the neck and head, for instance, have been left to the control of Rob Armstrong.</em></td>
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<td>1.4.98</td>
<td>273</td>
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<td><em>Contacted IC about the same issues as yesterday.</em></td>
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<td>3.4.98</td>
<td>274</td>
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<td><em>Painted up some polycarbonate - You'll see that stick live for presentation purposes, will see tonight if it comes off easily with white spirit/methylsols/acetone/MEK.</em></td>
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<td>7.4.98</td>
<td>275</td>
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<td><em>It had been established some while back that I'd provide recommendations for mass-manufacturing route, as a 'drawing the line' under my realistic active involvement in the project (in relation to both skills and time)... I've just formalised this by stating that it will be in the form of a written report.</em></td>
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<td>7.4.98</td>
<td>276</td>
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<td><em>When you write down a job list like this, I think you can't help get images of final products and how you'll achieve them... I certainly did when writing the project completion plan.</em></td>
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<td>7.4.98</td>
<td>277</td>
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<td><em>LB1-63, at the foot of the page, is my disappointing efforts of tracking-down UK manufacturers of PMMA and PC. I've still not given up hope of tracking down 10mm-thick coloured acrylic sheet (non-IC Flaxton)... and possibly coloured PC sheet. These names/contact numbers were got from the Plastics and Rubber Weekly UK Plastics Directory 1997-1998, a printed directory listing plastics manufacturers, suppliers, and processors. Those selected seemed, on the evidence of their entries, to be the largest/most promising. I subsequently searched the web for similar information, and sent off 3 emails, also contained in the log book. I had no luck finding any info. on coloured semi-finished PC sheet... I'll take Polybrone's advice from way back that it doesn't exist. The email to Dick pretty well explains itself... I'm just trying to cover as many of the main lines of attack that I can, so I can justify (if I have to) using laminated 5mm acrylic.</em></td>
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<td>20.4.98</td>
<td>278</td>
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<td><em>I've been getting contact information for acrylics/PC sheet suppliers, for my last attempt at locating a stockist of dark blue 10mm sheet. The email from Dick (LB1:67) prompted me to make a final search for manufacturers and suppliers. Notes are written on LB1:67 and LB1:68 relating to this work, and made use of the UK Plastics Directory 97-98 (Plastics and Rubber Weekly) and a few web sites, most of which contained very little useful information for me, i.e. that they do not supply coloured PC/PMMA sheet.</em></td>
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<td>21.4.98</td>
<td>279</td>
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<td><em>I phoned around a few of the companies I listed yesterday (LB1:68). No 10mm coloured acrylic sheet... the bit [sic] I got was that this would be a specially-manufactured order if I wanted to obtain it, an account of very little demand.</em></td>
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<td>21.4.98</td>
<td>280</td>
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<td><em>I have asked VT Plastics, Nottingham to seed me a quote for 5mm sheet plus special laminating adhesive. I will try this method out for the bridge (lamination), but I'm thinking more and more that I may as well just go with the PC Lexum sheet I've already have and, for a presentation prototype, simply spray that up to the correct colour and temporarily attach it to the guitar for the correct visual effect for photographs etc. We'll see how the lamination goes...</em></td>
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<tr>
<td>22.4.98</td>
<td>281</td>
<td>D556</td>
<td><em>I have compiled a document (D556) which will help me finalise proposals for the mass-manufactured version recommendations. I expect this to be very much a working document, as an aid for discussion with people in the near future.</em></td>
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<td>22.4.98</td>
<td>282</td>
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<td><em>I decided today, with no fax coming through from VT Plastics, that I will produce all bridges from polycarbonate and then just spray one up for presentation purposes. Avoid all the hassle and concerns of laminating 5mm acrylic sheet. It's not the ideal, but I think it makes the most sense at this stage, where I really need to be pressing on.</em></td>
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<td>22.4.98</td>
<td>283</td>
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<td><em>As I write a draft report like D556, I clarify where I am going with my design and I also get revised design ideas come into my head. Some of the reasoning written down in this report is sure has not been written down before this is because I am now in anticipation of final presentations where my design reasoning needs to be communicated explicitly. Particularly, I had some views of how the bridge might be made in tandem with the soundboard. I will need to discuss these with Dick Hecht to assess their suitability/feasibility, and so forth (and for developing ideas) I shall work out manufacturing details/features graphically on paper soon.</em></td>
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<td>27.4.98</td>
<td>284</td>
<td>D555a</td>
<td><em>I used this left-hand drawing to remind me of how the prototype will be constructed around the neck. It lead me on to thinking about the same in the mass-manufactured proposal... the block was providing stability, and rigidity in particular, - how could this be achieved in the mass manufactured version, using lay-up/moulding? A web of walls I thought, rather like strengthening ribs in injection moulded components... The idea was then superceded [sic] on D555 main.</em></td>
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<td>27.4.98</td>
<td>285</td>
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<td><em>Stealing of an idea I had a while back, making use of some integral force when assembling the guitar- not sure how the idea comes to mind.</em></td>
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<td>27.4.98</td>
<td>286</td>
<td>D555</td>
<td><em>Whilst drawing this and the rest of the soundboard, it came to me that I ought as well mould the ribs and edging as formed material rather than inserts... will check with Dick.</em></td>
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<tr>
<td>27.4.98</td>
<td>287</td>
<td>D555</td>
<td><em>Was thinking that bridge could not be foam moulded because (a) visually it [the material] needs to be a different colour, and (b) the foam won't take the compressive force of the strings.</em></td>
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<td>27.4.98</td>
<td>288</td>
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<td>&quot;Material choices widened after talking to Eddie.&quot;</td>
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<td>27.4.98</td>
<td>289</td>
<td>DS55</td>
<td>&quot;I was thinking some adhesive could be used throughout.&quot;</td>
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<tr>
<td>27.4.98</td>
<td>290</td>
<td>DS55</td>
<td>&quot;Design went to design B because it's cheaper (per component); no painting and visually it looks fine.&quot;</td>
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<td>27.4.98</td>
<td>291</td>
<td>DS55</td>
<td>&quot;Similar to DS55s, I moved away from reinforcement. A block of foam would be easier to produce and is the same process as producing the soundboard, as explained. I think the only reason I thought of this way was because I had already looked at a similar problem in the soundboard, on the same page. The idea just seemed to arrive, anyway. Without reinforcement in this region I could feel in my mind the head twisting and creasing.&quot;</td>
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<tr>
<td>27.4.98</td>
<td>292</td>
<td>DS55</td>
<td>&quot;On reflection, my underpinning goal here on this sheet (DS55) was to see how I could minimize the number of components required, yet still achieve a machine-made and visually 'correct' (in my eyes) design. Hence, I know there have been some bumps from previous designs (reinforcement component particularly).&quot;</td>
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| 27.4.98    | 293      | DS55    | "Commentary on DS55. This is an important design sheet to me—I have set out how I think the machine-made guitar will be constructed, for the purposes of talking to Eddie and Dick, so that I can then go on to: (a) make firm recommendations and justifications for the manufacturing route of each component; (b) go ahead and complete the presentation CAD model, knowing exactly how components will be assembled. I have already had a meeting with Eddie to discuss the ideas on the design sheet. His suggestions are noted on the tracing sheet. We agreed at this meeting that it would not be necessary to provide exact dimensions for the components involved, but rather to communicate the proposed materials, production and assembly details in a joint graphical/text way. After all, final dimensions have not been decided upon... they would be meaningless at this stage."
130.4.98 | 294      | LB1/69 | LB1/70 | Today's meeting with Dick was to discuss my ideas for mass manufacture of the guitar and to gain some advice on what type of epoxy GRP I should opt for in the back/sides component. I wrote up my notes (from my head) after the meeting (LB1/69/70), and was pleased that Dick responded to my ideas and thought that they were well thought out. Dick alerted me to some of the characteristics of injection foam moulding that could produce differences in tone to the prototype hand-fabricated guitar. This was valuable, since I was not entirely sure how the process worked in practice. Most of the notes taken relate to details of the design for manufacture and its assembly; we held a conversation making constant reference to DS55 to discuss separate components. This was definitely a useful discussion. 130.4.98 | 295      |    |    |    |    |    |    |    |    |    |
| 30.4.98    | 296      |         | "At the end of the meeting the conversation came back to a topic raised quite some time ago in the project. After my natural involvement (for the PK3) ceased, which will take on, and how will the design work progress? Dick was firmly of the mind that an indication of potential sound quality can come from the prototype— and if it's a good quality tone than that bodes well for a mass-manufactured version, but you won't really know what you're dealing with until you make a guitar via these industrial processes. Dick sees future development work as (a) needing a lot of money being put up front and (b) testing of materials and manufacturing process combinations— a scientific approach to design in order to understand just what's going on and propose different, cheaper or more minimal combinations.
7.5.98     | 297      |         | "Working out dimensions for CAD modelling today, I couldn't help think about some more assembly details. In particular, I had more thoughts on the design of the upper head casing. An image of the following member came into my mind whilst walking back from home this lunchtime... it clicked in my mind that the machine heads would need to be supported by this component, and so (accordingly) the detail on the head casing need not be as intricate as I had up until now envisaged. Supporting columns would not need to be moulded-in."
7.5.98     | 298      |         | "It strikes me now, on reflection, that many of the guitar's components are at the 'roughly correct shape' stage but far from dimensionally committed. This is on purpose: I have decided not to detail parts which are (a) not going to be made by me in the prototype and (b) are in need of further development work to see what configurations will work well in practice. For the most part, this boils down to the neck and head parts. I feel I will have done my part in the project when: (a) the correct shape has been specified by me for all prototype components (and roughly correct shape for all mass-manufactured counterparts); (b) details of manufacture, material, finishing and assembly have been provided, and a casting; (c) a report on the merits of (a) and (b) have been completed. This is what I am working towards now as my final design report."
20.5.98    | 299      |         | "I've also chewed over in my mind the importance of different tools and therefore he expense. I am going to base my rough ideas on rough ideas that Dick had. I don't have experience in the cast of tools, so rough estimates of the right order will have to suffice. I found also that it was useful to me to write down why I've opted for particular materials/processes— kind of making explicit the reasons for my final decisions which will all be necessary for the final report."
1.6.98     | 300      |         | "Fork a trip to K&C Mouldings, Caanville, and collected materials for GRP lay-up. Only had 200gsm woven roving, so this is what will be used for the lay-up, along with medium-weight chopped strand mat." |    |    |    |    |    |    |    |    |    |
| 1.6.98     | 301      |         | "Obtained 5mm Lexan sheet from Polyken, Sheppord. This will be used for the strutting (which will be less 'overdone' then on prototype 2."

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<th>Ts</th>
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<td>1.6.98</td>
<td>301</td>
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<td>&quot;Faxed Polyfibre Ltd, Birmingham, for a price on additional GFRP supplies that I didn't get (or weren't available) from K&amp;C Mouldings. Avoiding this, I've asked them for a quote on carbon fibre fabric (which will probably be used on the 2nd of the two final prototypes, or certainly given a go, in order to find out if it sounds different/better/worse than standard glass reinforced plastic). Also, I have my eye on Aluminium metal powder which is listed in their Aug '97 catalogue. I'm thinking that this could be added to any colourant to create a speckly [sic], interesting surface (rather than using it, as described, to mimick [sic] a completely metallic surface). I've got visions of speckly [sic] silver coatings on portable CD players in my head, creating something along those lines would be worth investigating.&quot;</td>
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<td>1.6.98</td>
<td>302</td>
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<td>&quot;Telephoned Plastic &amp; Rubber Engineering - the contact that Les had - no, contrary to their leaflet, they don't stock any blue polycarbonate, or any 10mm blue acrylic (5mm max). Seems that it's confirmed that 10mm blue PC/PVMA sheet has to be specifically manufactured.&quot;</td>
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<td>1.6.98</td>
<td>303</td>
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<td>&quot;Telephoned technical advice at Ciba-Geigy epoxy GFRP section, Cambridge. The woman specialist was most helpful. I described my requirements of the prospective resin (181.74) and she was able to offer me three possibilities (and will send full details through the post). She noted that impact resistance and rigidity was a trade-off. Ciba's impact-resistant resins have address to aid flexibility, which in turn reduces the rigidity and therefore 'looseness' of the final laminate. For this reason, the 'standard' resin would probably be best, rather than the 'maris' range which has been specially developed for sports (high impact) applications. Any colourant would have to be powder or epoxy-based too - and a max. of 5% of the final mix should be colourant, to avoid interfering with mechanical properties. She was able to confirm that a mid blue colour at this concentration would still produce a strong, vivid colour.&quot;</td>
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<td>22.6.98</td>
<td>304</td>
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<td>&quot;Working out how much epoxy resin I'll need - sent off a fax to John Burns (Birmingham), Ciba suppliers, for a quote.&quot;</td>
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<td>14.7.98</td>
<td>305</td>
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<td>&quot;This first-stab [at a back shell] using a combination of woven roving (for neatness) and chopped strand mat (for stiffness) has been produced in order to see how stiff 3-layer (VR/CG/VR) system is; see how thick and heavy this system is, get to grips with epoxy lay-up (the resin is a lot thicker); generally see how the product turns out (at first glance it looks like the mould will be opaque, something which was not envisaged... I can then make an evaluation based on the product on what modifications/further procedures might be needed. A bit unknown at the moment, with what it all being new... just a matter of seeing how it turns out.&quot;</td>
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<td>15.7.98</td>
<td>306</td>
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<td>&quot;When I plowed the shaft against my table (reasonably dark wood) it confirmed in my mind [and what I'd drawn on D551] that I'd like the neck and head to be manufactured from very light coloured wood. It looked too dingy and furniture-like with the darker wood.&quot;</td>
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<td>21.7.98</td>
<td>307</td>
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<td>&quot;When I checked out the spray-painted shell this morning, only the area that I had sanded-down allowed the point to shine (and even then my sanding marks were quite noticeable). Without abrasiion [sic], the point doesn't stick at all. If the 2nd shell comes out well, hopefully they'll be no need to point it - but one thing I like about the point is its consistency of colour, and I'm not sure the moulding can match that.&quot;</td>
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<td>22.7.98</td>
<td>308</td>
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<td>&quot;Removed the 2nd guitar shell today. I love the finish you get with the glass fibre texture hidden [just below the surface of the transparent coloured resin]. When polished up, this would look great (in contrast to the satin sheen soundboard). However, the 'A' logo still hasn't come out well and I've opted to F35P [fill the deficient areas in] and then sand-back to shape. I doubt I'll be able to get back the brilliant gloss finish, but either way the F35 sticks out a different colour. My plan therefore is wet-and-dry back the whole guitar and spray paint it with textured paint.&quot;</td>
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<td>4.8.98</td>
<td>309</td>
<td>PHOTO</td>
<td>&quot;When sanding back the 4th shell I left the 'A' logo to the end. I loved the surface texture change that I happened across when I did this - matte surround and high gloss logo. I thought that it might be quite a good design detail change in a more 'upmarket' version.&quot;</td>
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<td>20.10.98</td>
<td>310</td>
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<td>&quot;Flicking through (The Ultimate Guitar Book and The Guitar Handbook) I've marked maple down as the kind of coloured neck I would like to see on this prototype (light wood was determined some time ago).&quot;</td>
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<td>3.2.99</td>
<td>311</td>
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<td>&quot;A brief note - sanding the PC bridge with grits 1200 wet &amp; dry (but before polish) the surface finish was really quite interesting - clouded and transparent in the way that a lot of plastics products are at the moment. I thought that this would be a possibility to include on a final production version by creating the surface texture in the mould. But for now, I prefer the plastic as it is (shined-up and so) I will continue to construct the prototype like that.&quot;</td>
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<td>15.2.99</td>
<td>312</td>
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<td>&quot;Took a trip to Kettering today (TW Plastics) to glue the bracing onto the soundboard-success. (...) Having had more experience today with the full future time MA9140L1, I am sure that it will do the job. I had realised how easy it was to spread by hand. It won't be a problem achieving a thin consistent layer around the rim. Great adhesive!&quot;</td>
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