Design Decision-Making and Materials: Research Agendas and Gathering Evidence

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Abstract
This paper describes the development of the research agendas for three PhD research projects which took place over the last two decades in the Department of Design and Technology at Loughborough University. The emergence of these agendas in relation to their eras is described and the data gathering methods developed to pursue them noted. The paper is intended to support teachers, designers and other researchers in the early stages of the design of their research projects.

Key Words: research, agendas, PhD, methods, materials, designing

Introduction
The last twenty years has seen major developments in Design and Technology. This paper describes the backgrounds, strategies and some of the outcomes, to three research projects which have taken place in the Department of Design and Technology at Loughborough University during this period. The essential aim of the paper is to demonstrate how the research agendas and methods emerged in relation to the contexts provided by their eras and in response to the experience and interests of the researchers. There have been some major research and curriculum development projects in the field of Design and Technology education, but much of the subject's evolution has been, and continues to be, the combined result of many small-scale research projects. The discussion concerning these three projects provides support for those considering similar undertakings. Research can be an isolated pursuit, particularly for teachers in schools, and the key role that such practitioner research can play, both in determining and addressing research agendas, needs to be supported. These case studies should provide some models for reflection, and perhaps help to shape some future projects.

Dr Eddie Norman's PhD research
Dr Eddie Norman (EN) joined the Department of Design and Technology in 1984. He taught technical studies for eight years in secondary schools and completed two years as a research engineer at The Welding Institute after completing an MSc in Welding Technology at Cranfield University in 1978. He was one of the twelve students to complete a Postgraduate Certificate in Education (PGCE) in Engineering Science at the Department of Educational Studies at Oxford University. This course ran for two years (1973-74 and 1974-75). This unusual start to a career was as much a product of the uncertainties of the time as of other factors. (The Oxford course was training teachers for a subject that was very much in its infancy and for which there were few jobs available.) The 1970s had seen a number of major research and curriculum development projects addressing some of the fundamental issues of the subject area. The nature and place of design, craft and technology in the general education curriculum were explored respectively by:

- *Design in General Education* (1979), a project completed at the Royal College of Art
- *The Keele Project* (1971), a project completed at Keele University
- *Project Technology* (1971), a project completed at Loughborough University

There is now an uncritical acceptance of some kind of "design process" which can be transferred between design contexts, but that was certainly not the case in the 1970s and 1980s. Designing was often argued to be discipline (knowledge-base) dependent at that time, (and still is occasionally). Technical Studies departments taught craft-based skills (e.g. metalwork, woodwork, and technical drawing), and were beginning to embrace technological problem-solving as a teaching and learning strategy. It was this pedagogical motivation which resulted in the *Engineering Science Project*, as well as *Project Technology*, at Loughborough University. It had soon been realised that scientific knowledge needed to be learnt in specific contexts in order to promote problem-solving capability. Such recontextualisation is the essence of engineering science and supports the development of particular technologies, although these must also engage with "other knowledge and judgements" (Layton, 1993a: 59). Of course, this realisation was not itself new. Layton in his authoritative discussion of the development of the relationship between science education and praxis describes Rankine's approach to the establishment of engineering science as a discipline as follows:

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> The solution developed by W J M Rankine, Regius Professor of Civil Engineering and Mechanics at Glasgow from 1855 until 1872 was to transcend the traditional categories of 'theory' and 'practice' by focusing on the nature of the interaction between them. To equate this with the application of science was, according to Rankine, to misrepresent it, unless it was understood that the process was an active one, which often entailed the creative reworking of the science.
> (Layton, 1993b: 16)

A similar agenda was pursued by the *Modular Technology Project* (Page et al, 1981) and, more recently, by the ASE (Association of Science Education)/DATA (Design and Technology Association project (Sage and Steeg, 1993).

So, as EN arrived at Loughborough, some fundamental questions were still very much at the forefront of the subject's development, for example:

- What is the nature of designing?
- What is the relationship of designing to particular technologies?
- How can the teaching of designing and technologies be best approached?

Agreement had been reached in the mid-1980s by an Inter-Board Working Party of the CNAA (Council for National Academic Awards) concerning the model for the "common core" Design and Technology syllabuses for A/AS level Design and Technology (Norman, 1993a). This was a significant achievement given the diversity of design areas that the school subject must reflect (engineering design, industrial design, graphic design etc). There were obvious potential advantages to such agreement for schools, teacher trainers, Universities and publishers and one outcome was a sufficiently large market opportunity for Longman to commission *Advanced Design and Technology* to support the range of new syllabuses. Having accepted the challenge of writing the design and materials processing and selection sections for this new textbook (which necessarily had four authors to cover the wide range of topics under the editorship of Professor Syd Urry), part of EN's research agenda was effectively established.

- What is the nature of designing at A/AS level as defined by the common core?
- What is the relationship of such designing to materials technology?

The Design and Technology undergraduate degree programmes at Loughborough University were evolving rapidly in the mid-1980s following a step-change away from craft-based courses in 1982. Thus, the department was engaged in the challenge to C P Snow's "two cultures" model of human knowledge in parallel with the Royal College of Art and Imperial College at postgraduate level and Brunel and Napier Universities for undergraduates. There was, therefore, an essential requirement to understand the pedagogical requirements of teaching technology to industrial design (i.e. arts-based) students. Hence, other aspects of EN's research programme became:

- What are the most effective strategies to use for the teaching and learning of technology for industrial designers?
- For which technologies must there be foundations of learning prior to designing and which can be accessed at the point of need? (always everyone's goal).
- To what extent can flexible learning and emerging information technology alter this position?

It can be seen that the research agenda was a product of both the context provided by developments in the subject area, which were themselves a product of cultural change, and particular personal goals. The outcomes of the research were needed to support the writing of the textbook and the teaching of the students. There was never a sense of teaching and research being separate activities. They had a symbiotic relationship through which both activities developed. This is by no means a unique position, and such practitioner research pursued through case studies and action research has been the bedrock of research and development in design and technology. Consider this commentary concerning the approach taken to a recent review of the research literature in design and technology (Harris and Wilson, 2003: 60).

> As reviewers we were impressed, and somewhat overwhelmed, by the number of references to D&T in the literature mainly

> produced by the community of practice. Within the time constraints within which this review was undertaken we could not hope to do justice to this large volume of work and therefore imposed our own rather more limited criteria for inclusion. The review is based primarily on research which has been peer-reviewed for publication in academic journals or published in research reports. This device excludes much action research and curriculum development undertaken by the 'user' community'.

This quotation from the report, reveals both the extent of the action research which has supported the development of Design and Technology education and its struggle for appropriate recognition, despite the admission by the authors of the report (ibid: 60)

> We acknowledge that action research has a well-established contribution to make to practice. (Stenhouse, 1975)

EN's research programme was carried out through literature reviews, the analysis of curriculum initiatives and the writing of the textbook *Advanced Design and Technology* (Norman, 1999). It was successfully submitted for a PhD through published work in 2002. One of the findings was the greater recognition of the ways in which design areas and particular sets of knowledge, skills and values are associated (e.g. at 16+, "common core designing" and materials and for Industrial Design and Technology undergraduates, industrial design and mechanics). The analysis of curriculum initiatives was typically based on small samples (n=50–100) with all the limitations that this implies. (With such small samples, variations in the results obtained by successive research studies would be inevitable and therein lies the justification for large scale statistical studies.) However within those limitations, greater understanding of the associated pedagogical issues was achieved. For example, it was shown that some technologies can be taught and learnt through designing (e.g. materials processing) and some technologies need to be mastered prior to designing (e.g. mechanics). Flexible learning materials concerning the study of energy and structural analysis were authored and demonstrated to be effective and some evidence found that software can enhance capability.

The relationship between design areas and particular knowledge, skills and values was indicated in the Carter report in 1977, which contained the design spectrum shown in Figure 1. This shows product areas linked to different proportions of industrial and engineering design. This was clearly one of the starting points for the PhD research programme and a position which the outcomes of the research supported.

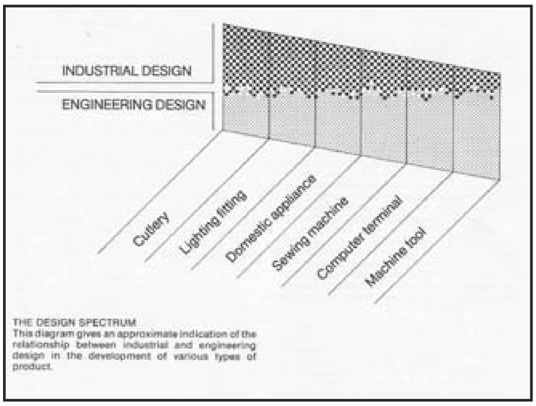

Figure 1 *The Design Spectrum (Carter, 1977:13)*

One of the endpoints for a PhD programme are recommendations for future research and the following quotation shows some of EN's conclusions concerning the future research agenda (Norman, 1998:84-85).

> A paper written in 1993 by Bayazit ended by saying 'We have to make more empirical studies on designs and designers' (Bayazit, 136). In the author's view the highest priority for design researchers in this area remains the documentation and analysis of existing practice and knowledge. For example:
>
> - further case studies concerning the technological knowledge associated with different areas of the design field can be explored and made evident where possible;
> - the way in which technological knowledge, skills and values are used by designers can be carefully documented and analysed;
> - known good practice in design pedagogy can be identified and critically reviewed.
>
> McCormick has made some progress concerning the review of design pedagogy,

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but not in the crucial area. In 1993 he wrote 'What we need, however, is to consider the reality of students using scientific knowledge within a design project. Sadly little research has been undertaken on this topic (McCormick: 316). McCormick poses the dilemma accurately: 'when students perform design activities a teacher is faced with a dilemma about how scientific knowledge should be provided and used. When should the students be provided with the necessary science to enable them to carry out the design task?' (ibid: 309), but freely admits in the conclusion that 'the dilemma posed at the beginning has not been resolved'. There is substantial good practice concerning this aspect of design pedagogy within UK educational establishments (and, no doubt, in other countries, but this is beyond the author's experience). Such good practice needs to be documented and reviewed.

Such was EN's position in the early 1990s and it formed part of the foundations for the two PhD research programmes which followed. However, as in the establishment of EN's research agenda, the evolving cultural influences and the personal requirements of the researchers also exerted their influences. Research is not conducted in a vacuum, insulated from the surrounding culture, or without personal ambitions and goals. It is, perhaps, also apparent why EN has an outstanding interest in the recording and analysis of prior art (literature), particularly the IDATER archive (http://www.lboro.ac.uk/idater/). This archive, at least in part, represents the evolution of good practice.

Dr Owain Pedgley's PhD Research

Dr Owain Pedgley's (OP) research project was established to essentially examine the second of the above bullets:

'• the way in which technological knowledge, skills and values are used by designers can be carefully documented and analysed'.

However, in the late 1990s there was another debate beginning. This debate centred on the nature of design research. Professor Bruce Archer first coined his phrase "research *about* design (and designing), research *through* design (and designing) and research *for the purposes* of design (and designing)" in the late 1970s, during his post at the Royal College of Art. However, despite the completion of numerous design research projects, the debate was still seeking to clarify what this implied. For example, what is the role of designing an artefact within a research project? (This debate has, by now, effectively run its course and there are now numerous models of successful and effective design research on which to build).

There was a requirement within the PhD programme to expose the complexity of the relationship between knowledge and designing and also to explore the possibility of creating knowledge through designing. The relationship is commonly seen as static – perhaps the application of a fixed knowledge base when designing – rather than dynamic. The role of tacit rather than articulated knowledge is also not always fully acknowledged, and, of course, the technological knowledge base is always changing, and not least through the outcomes of designing. The design of a polymer acoustic guitar had already been identified as a suitable case study (Norman, 1993b), and how to pursue it was now the issue.

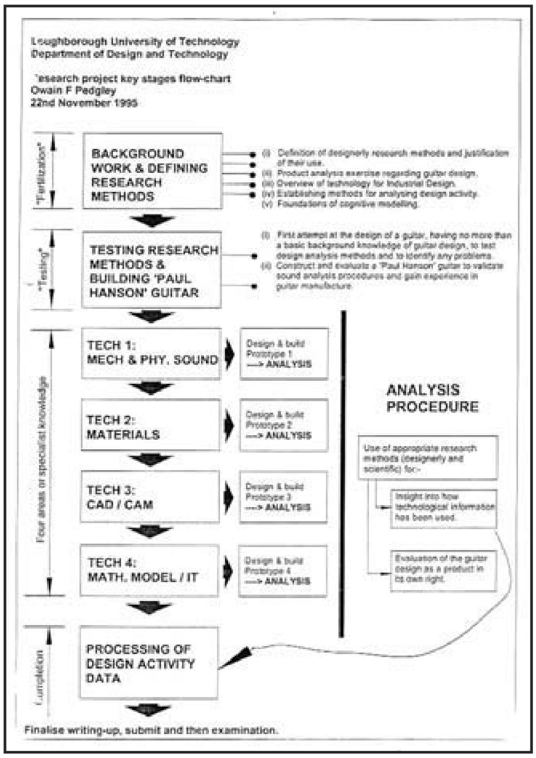

Figure 2 *A rejected model for Owain Pedgley's PhD*

Figure 2 shows the model for the research project, which was progressively rejected by OP and EN during discussions in the early part of the project. The initial attraction of this approach was that particularly technologies could be researched sequentially (in theory at least), but it was rapidly realised that the reality of designing could never be this controlled. The study had to be naturalistic, and expose itself to the complexities of real designing in order to result in useful data (in the same way that educational action research must expose itself to the realities of the classroom). So the immediate research questions for OP became:

- How could data covering all the complexities of the relationship between knowledge and designing be recorded?
- How could this data be recorded over a longitudinal study (of say up to two years)?

The conventional answer to the former question would be protocol analysis (Cross et al, 1996). The filming and sound recording of the activity and the analysis of subsequent transcripts and design drawings. Regrettably a two year project would have taken two years to playback, and this approach was clearly not possible. Consequently, a diary method was developed (Pedgley, 1997). Diary methods have previously been used in the social sciences, but not in design research. Both 'concurrent' and 'end of the day' diaries were explored; the former proving to be impractical and the latter being eventually favoured. However, even so, it was concluded that attempting to record the data for a range of technologies would be ineffective and materials and manufacturing technology was chosen as the focus. Having decided on a diary method, an additional research question became:

- How could the potential bias associated with recording your own practice be guarded against in the data collection and analysis?

It was decided that the diary results would be triangulated against interviews with designers in leading consultancies and prior literature in order to validate the findings. So what was the role of designing the artefact? OP graduated from the Industrial Design and Technology programme at Loughborough University in the summer of 1995 and decided to take on the PhD research before beginning a career in design. It is inappropriate for a design graduate to stop designing when they start researching, so, at least part of the reason for designing an artefact in the research programme, was the maintenance of OP's design skills. However, the artefact was also to be the embodiment of the attempt to develop new knowledge through designing. This new knowledge could have been in relation to either designing guitars or guitar technology, but it was really the latter which was being targeted. A further research question became:

- How could new guitar technology be generated through designing?

A full account of the establishment of this PhD research project can be found in Norman et al (2000) and the results in OP's thesis (1999). The new technology generated was patented (Norman et al, 1999) and the guitars were exhibited at the Frankfurt Musikmesse in 2002. Full details of the subsequent Loughborough University business venture can be found at http://www.coolacoustics.com. These were delightfully successful outcomes, but it must be noted that the real objective of the research project was greater understanding of the relationship between a particular area of the design field (industrial design) and particular technologies (materials and manufacturing processes) and this was achieved as well! The polymer guitar project featured in Professor Geoffrey Harrison's book (2002: 58-59) concerning the relationship of technology and designing for all ages, from young children to professional designers, as an example of a technology emerging from the tacit to the articulate. This is a continuing story, with current collaborative research bids being made with members of the Engineering faculty at Loughborough University in order to determine the underlying engineering science. The 'polymer guitar story' will be no doubt be a book itself one day, but the story is still unfolding.

Rhoda Coles's On-Going PhD Research Programme

Rhoda Coles (RC) also graduated in Industrial Design and Technology at Loughborough University in 2002 and decided to take up the challenge of continuing this avenue of research. As a result of OP's research more was now known about the relationship of knowledge and designing (albeit in relation to one technology and one area of the design field), and it had become increasingly apparent that values played a major role in design decision-making. This was recognised in OP's thesis, but also in recent publications (e.g. Ashby and Johnson, 2002). Consequently, RC's initial research questions were:

- What are the key influences on design decisions?
- What is the role of values in such design decision-making?

As a design graduate, RC also wanted to use her design skills in her research project and there were a number of emerging agendas at this time, notably sustainability and creativity. Sustainable design decisions are driven by knowledge, skills and values, but it is undoubtedly an area which is 'values rich' (in the same way that the polymer acoustic guitar design project was 'knowledge rich'). Consequently, it was likely to be a fertile area to study. It has been argued that the reason we live in such an unsustainable world today is essentially the result of past design decisions (taking design in the broadest sense as the creation of the material culture), and consequently designing sustainably requires "thinking out of the box". Hence, sustainable design and creativity must happen together. There are also on-going discussions concerning the relationship of knowledge and creativity in designing, notably in the context of task-based knowledge. This is, of course, not the first time that these relationship has been reflected on. Particularly noteworthy are the studies by Dasgupta concerning creativity in invention and design (1994) and the relationship between technology and creativity (1995).

Although, it would have been attractive to explore the whole sustainability agenda i.e. the way in which knowledge, skills and values concerning social, economic, and environmental issues impinge on particular design decisions, this was too broad a study to be appropriate for a PhD research project. The focus was to be on "values" and "recycling". So further research questions became:

- How can values be distinguished from knowledge and skills?
- How can data on the influence of values in design decision-making be recorded?

Designing in recycled polymers has been one of EN's long-standing, but embryonic research interests and it was known to be an area where the values of consumers and designers played key roles (Norman, 2001). Established departmental links to Recoup (Recycling of used plastics) Ltd and Smile Plastics Ltd also provided real contexts for designing for RC (a lectern for Recoup) and for design undergraduates (artefacts to be designed using recycled polymers for an imagined garden at the Chelsea Flower Show). This provided RC with immediate opportunities to trial protocol analysis, diary methods and retrospective questionnaires in order to explore their potential for generating data concerning the role of values in design decision-making.

The most significant previous attempt to differentiate and categorise values in relation to designing was made on behalf of the Assessment of Performance Unit (APU). In their publication concerning *Understanding Design and Technology*, they used four categories:

- Technical values (e.g. flexibility, precision and confidence);
- Economic values (e.g. value, price and cost);
- Aesthetic values (e.g. self expression, workmanship and proportion);
- Moral values (e.g. impact on the environment, religion and needs) (1982, 6-7).

In 1993 Professor Phil Roberts noted an additional dimension of values:

- Hedonic values (e.g. the senses, desires and demands) (1993).

This area was no doubt considered in 1982 (private communication from Professor Phil Roberts), but was not included in the final report at the time. Again this could be interpreted as reflecting a change in culture. By the early 1990s the significance of emotional factors in design decision-making was becoming ever more recognised. Nevertheless, the pilot studies (Coles, 2003a) soon demonstrated some of the "grey areas". Through a thorough literature review (Coles 2003b), brainstorming and seminar discussions RC has now developed an appropriate categorisation system for use in this research project. The categories are shown in Table 1 and the proposed recording system in Figure 3 (where NDD stands for novel design decisions). RC is now proceeding towards the main data gathering activities and hopes to have time to investigate both the influence of age (e.g. school and university students and professional designers) and training (e.g. across the industrial and engineering design spectrum) on the role that values play.

External values	**Internal values**
Societal values	Perceived societal values
Identified stakeholder values	Perceived identified stakeholder values
Economic system values	Perceived economic system values
Values embedded in design	Designer's personal values
	Meta-values

***Table 1**: Rhoda Coles' categories for values influencing the design decision-making process*

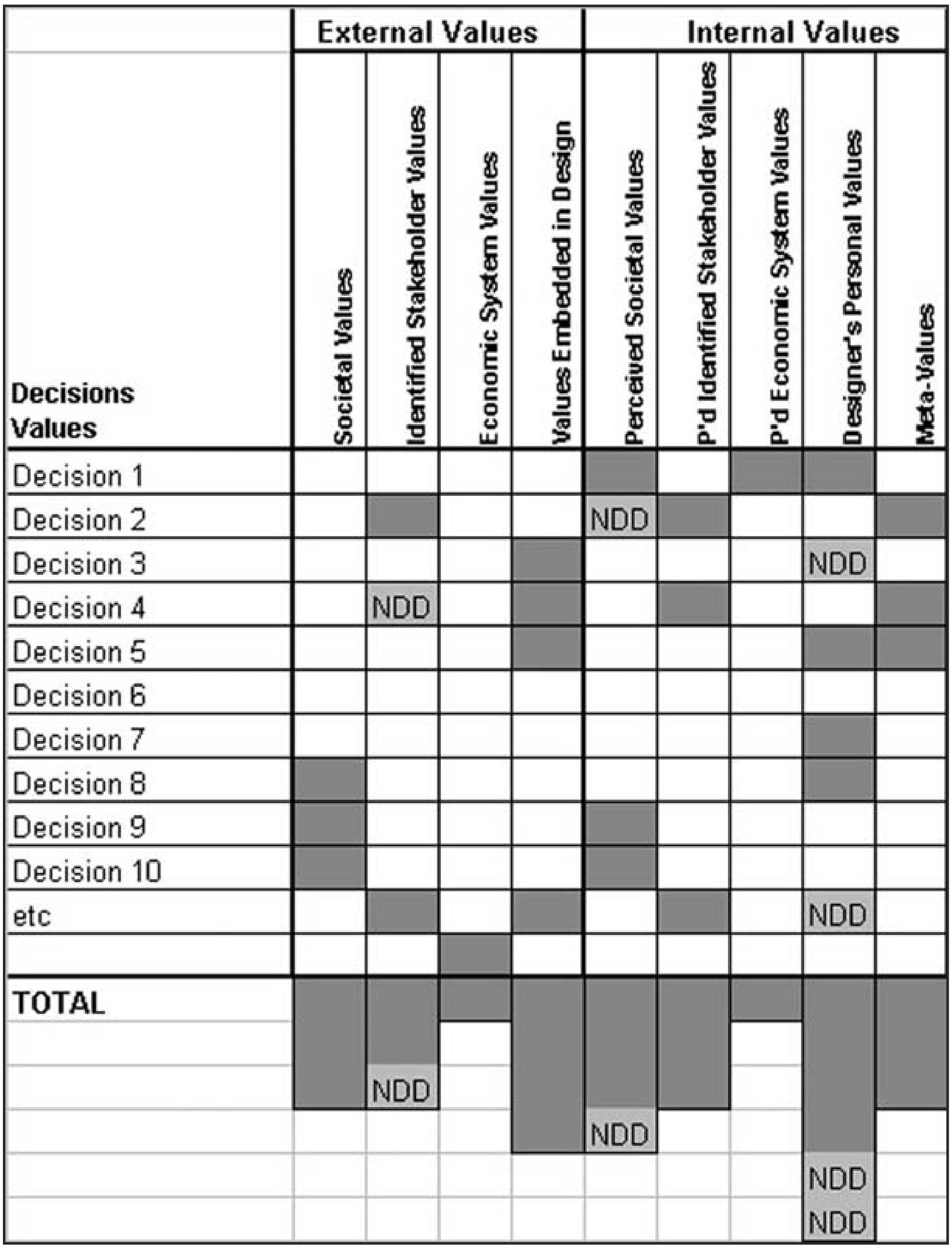

***Figure 3:** Rhoda Coles' categorisation system for recording the impact of values on design decision making*

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Concluding Comment

The ultimate goal of all of these projects is to better understand the nature of design decision-making. If that goal is achieved, then the design of resources, curricula, and support tools all become more securely based. It is hoped that greater understanding of design decision-making can also lead to better designing: improved consideration of sustainability, more creativity in designing products and systems and more numerous technological innovations. However, such research is a slow process and such goals are in the far distance. Nevertheless, it does not stop us dreaming and speculating on what might one day be possible.

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