The Professor John Eggleston memorial lecture 2006. Values, human judgement and sustainability in design and technology education.

The Professor John Eggleston Memorial Lecture 2006 Values, human judgement and sustainability in design and technology education

Dr Eddie Norman, Senior Lecturer, Department of Design and Technology, Loughborough University, UK

RESEARCH

Abstract
This lecture seeks to explore some aspects of the conceptual progress that has been made in design and technology education since the pioneering work of Professor John Eggleston (1971). This exploration draws on research conducted within the Design Education Research Group at Loughborough University over the last ten years, which indicates the crucial part that human judgement plays in design decision-making. The implications are discussed within the context of the sustainability agenda and the role of appropriate eco-design tools is noted. The vital contributions of 'learning by doing' and a 'hands-on approach' are emphasised and the key relationship between innovation, designing and the articulation of knowledge is recognised. The lecture concludes by discussing the importance of this relationship, as well as taking interdisciplinary approaches, for research and curriculum development in design and technology education.

Key words
values, knowledge, articulation, innovation, sustainability, interdisciplinary, design and technology

Introduction
This Keynote Address has four broad aims:

- to review aspects of conceptual progress in design and technology education since Professor John Eggleston's initial work;
- to indicate the particular research focus of the Design Education Research Group (DERG) at Loughborough University;
- to explore the role of human judgement and values in determining sustainable futures;
- to indicate the importance of taking interdisciplinary perspectives.

Current (UK at least) orthodoxies
The current structure of design and technology education was not predetermined. As Layton observed:

> It could all have been different. Other options were available. What we encounter today is the result of decisions which reflect the value judgements of those who shaped a development which was in no sense inevitable.
>
> (Layton 1992:10)

This can be illustrated by briefly exploring some current orthodoxies: theoretical positions which are taken as established, but over which there is considerable room for doubt. For example, there is a commonly held conception that creativity is to do with generating a range of alternative solutions. If you look at a particular area of the design field 'as a whole', then this might be arguable, but at least some of the evidence is against it when you analyse individual acts of designing. In writing about the enthusiasm which emerged for models of 'the design process' in the 1960s, Baynes noted the outcomes of comparing such models with actual designing.

> Studies of how designers actually worked in practice did not appear to conform to any of the theoretical models of the design process then current… Although designers did appear to use divergent and convergent thought processes and there was (almost by definition) a journey from divergent to convergent, it certainly did not proceed in a linear way. Several new theories emerged. It began to look as though many designers actually started with the solution (!) or at least with a strong personal conviction about the direction to follow. They certainly did not use any formal procedures to stimulate divergent thought – on the contrary, they

> appeared to draw on their accumulated store of professional expertise to leap to a design idea that held out the promise of meeting the requirements. They even worked over a relatively long period to 'fill in' the details and realise the design. It was soon clear that different designers worked in different ways and that procedures in distinct fields of design also differed.
>
> (Baynes et al, Ch 3, in preparation)

Other more recent studies concerning the influence of design expertise have essentially confirmed these findings (e.g. Cross et al, 1994; Ball, 2004; Cross, 2004)

Recent work by Dasgupta (2004) has similarly cast doubt on the generation of alternatives as the true vehicle of the creative mind. Dasgupta examined three case studies from the histories of natural science, technology and art[1] and concluded:

> …a fecundity[2] in the generation of variations on which the selection is supposed to work according to the variation-selection model is not evident in any of the examples.
>
> In none of the case studies presented here is there any evidence whatsoever of blind variations being generated. On the contrary, the cognitive process in each instance was goal driven and knowledge driven.
>
> (411-412)

b Generating ideas	i Use a range of design strategies to generate a wide range of imaginative ideas that show evidence of ingenuity and flair ii Use knowledge and understanding gained through research to develop and refine alternative designs and/or design detail iii Evaluate and test the feasibility of ideas against specification criteria

Table 1 AO1 Designing Assessment Objectives for Edexcel AS/A GCE in Design and Technology (Product Design) (2006)

Nevertheless, the concept of creativity as a Darwinian process seems to have now become embedded in our examination specifications (e.g. see Table 1), although there is a healthy ambiguity in the 'or design detail' suggested under 'ii'.

As a further example consider perhaps one of the most crucial current orthodoxies, as indicated by 'iii' in Table 1; namely, an acceptance of 'fragmentation', rather than requiring 'holism'. Evaluating against criteria in a product design specification (PDS) assumes that the whole is equal to the sum of the parts and risks assuming that different aspects of the PDS can be weighted equally, if one of the more rudimentary procedures of this type is followed. In reality the outcome of such procedures is likely to be a reflection of how designers weight one area against another i.e. a designer's personal values. Such procedures also facilitate the avoidance of craft (tacit knowing, skill) as an integral part of designing through negating the role of holistic judgement and promote ideas concerning the separation of mind and body (dualism, or action then reflection).

Current brain research is now indicating the opposite. The separation of mind and body may well be confirmed as a theoretical construct, the 'ghost in the machine' (Ryle, 1949) and thought, emotional responses, senses and kinaesthetic movement might all turn out to be fully linked and interdependent, which would require a return to a holistic view of designing and greater recognition of the importance of judgement. Figure 1 shows a view of designing from the 1970s, which Professor Ken Baynes

[1]The case studies were in natural science, Jagadis Chandra Bose (1858-1937) and his 'Monistic Thesis'; in technology, James Watt (1736-1819) and his 'Separate Condenser'; and in art, Pablo Picasso (1881-1973) and his 'Picture from Afar' (Guernica)).
[2]Within biology or demography fecundity refers to the ability of an organism or population to reproduce.

used in many lectures. With its references to 'interaction through all the senses' and modelling 'in the social world' it would seem that perspectives on the meaning of designing have narrowed over the decades.

As a first example of the need for interdisciplinary perspectives in order to tackle these issues, consider this quotation from a review of two recently published archaeology books by Godson (2006).

> Many disciplines have been inspired by recent developments in neuroscience using various successful approaches to the scanning of a human brain as a jumping-off point, although attempts to correlate brain activities with experience are proving more tricky. Such work is helping to link the brain more intimately to the body by showing that the brain monitors the processes of the body, including its biochemical and emotional states. The old dichotomies between thought and emotion are starting to break down to be replaced by a more holistic view of human experience. Also, emphasis on links between the brain and the rest of the body takes the search for human intelligence out of the body and into the world. Artefacts and landscapes represent a series of activations for the skills of the body, so that links between human muscles and the objects they deploy become crucial. The embodied human being works in partnership with the material world in order to create actions that are socially salient and effective…
>
> It is this body-world combination that may be integral to forms of human intelligence, throwing new emphasis on the link between the human senses, the forms of artefacts that appeal to the senses and the social values attached to people and things. Such an emphasis on the combination of the body and the rest of the material world as the locus for intelligence reformulates notions of mind. The mind has long suffered from an uneasy relationship with the brain – the material brain being seen as the locus of the immaterial mind, which had the effect of subtly dematerialising the brain. But now that the brain is newly enfolded back into the body and the body is reconnected with the artefactual world, where is the mind? (30)

The remainder of the review, and the books it is reviewing (Lewis-Williams and Pearce, 2005 and Mithen, 2005) are equally fascinating from the perspective of those trying to understand the nature of design intelligence. It seems clear that research in archaeology and design and technology education share much potential common ground.

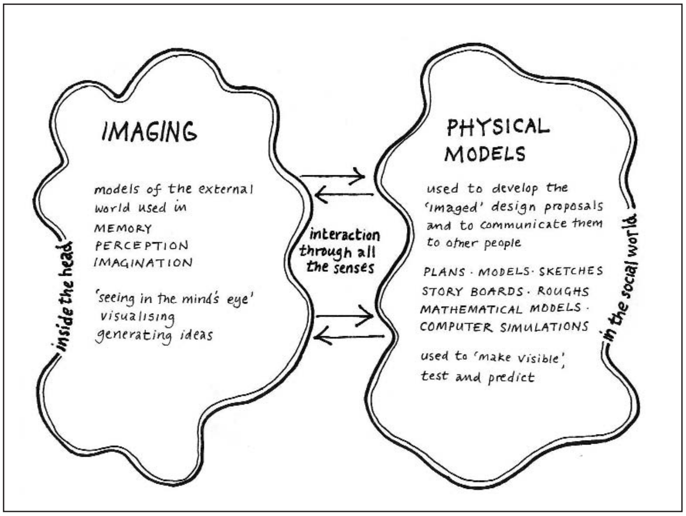


Figure 1 Diagram from the 1970s: Basic elements in the relationship between imaging and modelling represented by Ken Baynes (Baynes et al, in preparation)

It is arguable that such particular views of creativity (selecting from alternatives) and design decision-making (analysing against a product design specification) lead inevitably to correspondingly particular notions of 'a design process'. In fact, they are the conceptual consequences of thinking too much about 'a design process' and how to simplify the complexity of design and designing towards the goal of curriculum design. But let's take a step back

RESEARCH

and consider the position when Professor John Eggleston started his work on the *Design and Craft Education Project* at Keele University in the late 1960s.

It is clear that '(a) design process for secondary schools' looked very different then to the one we are used to seeing today, and, in the context of this presentation, one of the key reasons for this has been the 'downplaying' of the role that human judgement plays in designing. Eggleston clearly recognised that 'judgements and decisions' dominated the later phases of the resolution of a design task, but the model in Figure 2 is equally clear in indicating the role of human judgement in 'identifying the control factors'. Recording data, communicating ideas, applying knowledge, social skills and intellectual and motor skills are not 'value neutral activities'. The outcomes are the result of human judgements. It would almost appear that somewhere along the line more procedural interpretations aligned to 'science' have come to be allowed to have too great an influence on the understanding of designing, and the case which was so strongly made by Eggleston and by Archer and his colleagues at the Design Education Unit at the Royal College of Art (RCA) in the 1960s and 1970s has been slowly eroded (Archer et al, 2005).

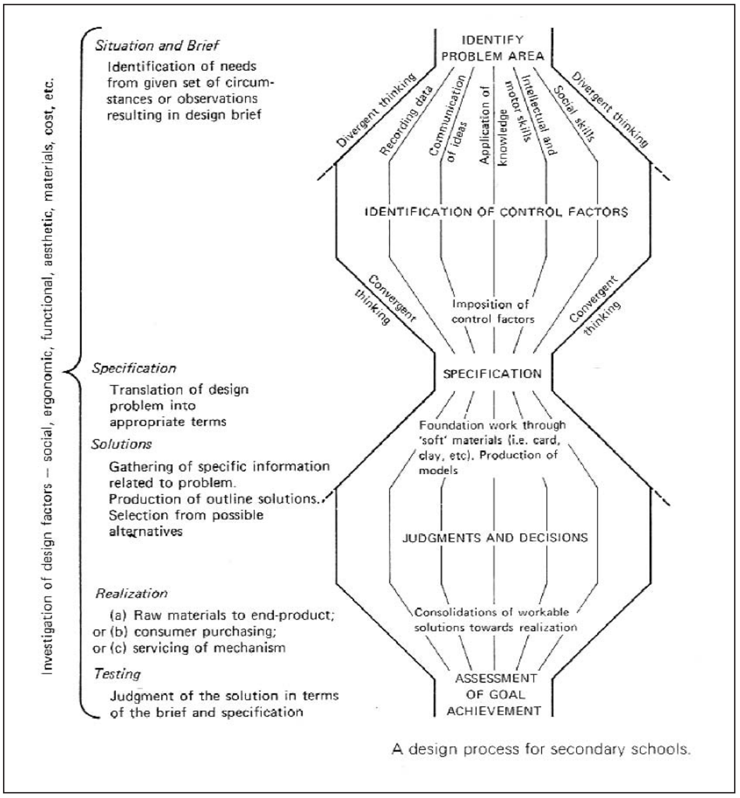


Figure 2 The design process from the Design and Craft Education Project (Eggleston et al,1971:2)

Even the realisation phase in Eggleston's model of the 'investigation of design factors' is more enlightened than recent product-centred interpretations. Consumer purchasing (or Roberts' (2005) transitive model of designing) and the 'servicing of mechanisms' (reuse presumably) were then on the agenda.

The Loughborough approach

Much of the design education research at Loughborough is founded on the theoretical understanding of the nature of design and designing developed at the RCA. Being located in the Bridgeman Centre, one of the best equipped buildings for 'designing and making' in the UK, it is perhaps also unsurprising that much of the Department of Design and Technology Department's research is focussed on the act of designing. Figure 3 shows a view of design and technological activity as presented by Roberts (2005).

In 1982 George Hicks led a Working Party for the UK's Assessment of Performance Unit (APU), which was set the task of exploring the nature of design and technology. Amongst the important ideas which emerged from that group was the categorisation of the key factors influencing design decision-

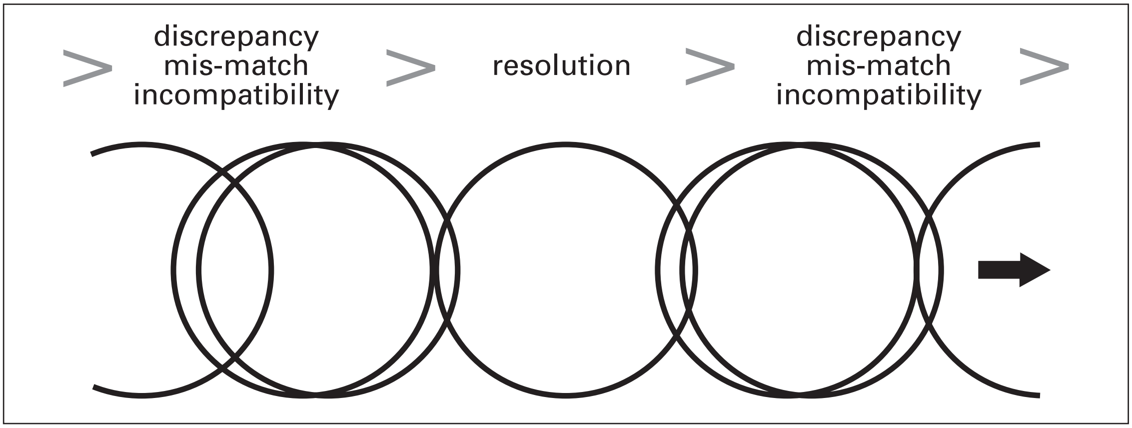


Figure 3 Design and technological activity as learning: problem solving as a continuous process contained in focusing on overlapping states of affairs (Roberts, 2005: 29)

making into knowledge, skills and values. This was extended in a 1998 paper by Norman, which argued that the technology which is used for the purposes of designing could similarly be usefully described in terms of these same three categories (technology for design).

Figure 4 shows a model of designing based on this concept which was presented at DATA's Millennium conference (Norman, 2000). The essential point is that for a particular designer, working on a particular project, the technological boundary is their knowledge, skills and values. Design education or professional development can seek to address any of these categories in order to improve design capability, but it is likely to be some combination of changes in knowledge, skills and values that is needed. So, technology at a micro-level can be seen as a constraining influence on designing and at a macro-level as the means through which society creates its material culture. It might be thought that there was a generally agreed position concerning the nature and meaning of 'technology' or 'technological knowledge' that could have been adopted, but this is not the case.

Carl Mitcham published his seminal work Thinking Through Technology in 1994, in which he identified four different ways of conceptualising technology, as objects, knowledge, activities and volition[3]. De Vries recently commented on this position as follows.

> The Continentally orientated philosophy of technology has mainly focused on technology as volition. As a result the ideas that have emerged in the remaining three conceptualization modes are fairly limited… In the knowledge domain the main result is that we now recognise that there is something like "technological knowledge", which is different from scientific knowledge (Baird, 2004; Laudan, 1984; Vincenti, 1990), although in practice the two can be almost indistinguishable… But what defines the specific nature of technological knowledge is still not well explored.
>
> (2006: 19-20)

[3]De Vries (2006:19) explains these categories as follows. 'By "technology as objects," Mitcham means that we can regard technology as a set of objects that are the result of designing and making. Mostly we speak of "technical artefacts" when the objects are the result of technological activities. "Technology as knowledge" refers to the idea that technology is a discipline with a distinct kind of knowledge. The domain of "technology as processes" deals with designing, making, and using as the main types of processes in technology. "Technology as volition" refers to the notion that technology is part of the human will and is therefore an intrinsic part of our culture, and that technology for that reason has everything to do with values that humans hold.'

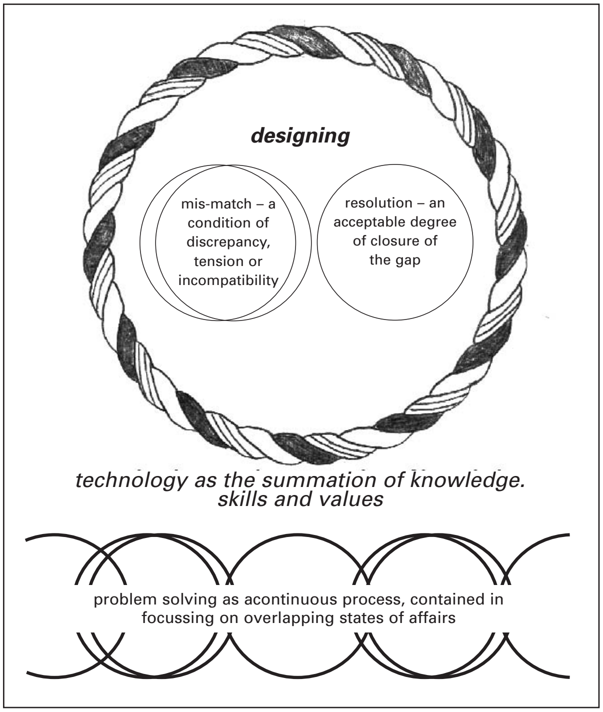


Figure 4 Technology as the summation of knowledge, skills and values (Norman, 2000:129)

My PhD research at Loughborough was that of a reflective practitioner, and some of the research questions I sought to address are shown below.

- What is the relationship of designing to particular technologies ?
- What are the most effective strategies for the teaching and learning of such technologies for industrial designers[4]?
- For which technologies must there be foundations of learning prior to designing and which can be accessed at the point of need?
- To what extent can flexible learning and emerging information technology alter this position?

Fuller accounts of this research can be found in the papers brought together for the award of the PhD (Norman 2002). The important matter here is that the research was exploring the pedagogical implications of recognising that individuals designing by themselves or in groups have a technological boundary comprised of their knowledge, skills and values. They are decision-makers characterised by 'bounded, but expandable, rationality' (Hatchuel, 2002); a topic which will be returned to in the next section.

One further outcome of this research was the desire to examine the notion of representing the boundary for designing as knowledge, skills and values in more depth. This was the fundamental intention of the PhD programme completed by Dr Owain Pedgley, which has since become known as the 'polymer guitar project'. The real goal was to explore the 'knowledge strand' of this boundary in greater depth (Pedgley, 1999). If the overlapping circles in Figure 5 are imagined to be a cross-section of this boundary, then Pedgley was exploring the shaded 'knowledge area'.

The relationship of propositional knowledge (articulated knowledge, knowing that) to designing was more researched (e.g. Vincenti, 1990), than tacit knowledge (Polanyi, 1962) or knowing how (Ryle, 1949). For these latter areas, it was also more problematic to distinguish knowledge from values and skills, so Pedgley's research was purposefully directed towards them. A further discussion of the overlapping of knowledge and values as categories has recently been published by Pavlova (2005:127-147), and as Lawson has noted in discussing technological knowledge:

> This knowledge is predictive but uncertain and laden with values. It is clear that the application of such knowledge is a highly selective process and therefore inevitably results in designers making their own unique interpretation of design problems (Lawson, 2004:14).

[4]Technology is being used here in the sense indicated in Figure 4 i.e. as the summation of all the knowledge, skills and values employed when designing

RESEARCH

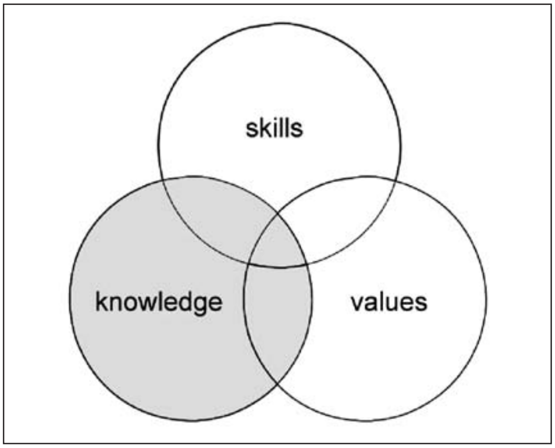


Figure 5 A cross-section of a boundary of designing represented by knowledge, skills and values

From a designing perspective, and particularly in the context of innovation, it was also important to understand the relationship between the articulation of knowledge and its physical manifestation in products. So, after a careful check that all the available materials science of polymers concerned sound absorption rather than generation, the polymer guitar project was conceived (Norman, 1993). Pedgley kept a detailed diary of designing right from the start of the project (as illustrated by the analysis in Figure 6), and so there is a complete case study of design innovation and the creation of associated articulated knowledge to be told, when the story is complete. However, like many a good novel or drama, there are a number of possible endings from this point in time, and events must unfold to shape the final chapters.

Some of the implications of this project in relation to innovation were discussed in a paper concerning Doyle's concept of technicity (2004) by Norman and Pedgley at DATA's 2005 International Research Conference.

> Technicity might best be characterised by a creative capacity to:
> a) deconstruct and reconstruct nature, and
> b) communicate by drawing
>
> (Doyle, 2004: 67)

The technicity hypothesis is that 'innovation is to be expected (and that) technicity is its intellectual driver' (ibid:71). The polymer guitar project provided credible empirical evidence to support this hypothesis and the paper concluded as follows.

> Human decision-making is an expression of the art of making judgements based on incomplete information about existing factors and future consequences. This is the essence of design activity, and hence then of the existence of products and their associated technology (given that the existence of the artefacts or systems preceded the explanation of their performance, empirically or otherwise).
> In the same way that each game of chess is highly likely to be different, so with product design dependent on a multitude of sequential decisions, the designs will inevitably be different. So, in some respect, every resolution of a design problem could be seen as innovative, in the sense that with respect to some factors it is a 'better fit' for the design intentions than its predecessors. It is a matter of judgement as to whether the better fit is of more value than other better fits. So, on the view that technicity can be understood as the capability underlying human decision-making in the face of uncertainties, perhaps innovation can be interpreted as inevitable and product evolution considered the survival of the most valued.
>
> (Norman and Pedgley, 2005: 138)

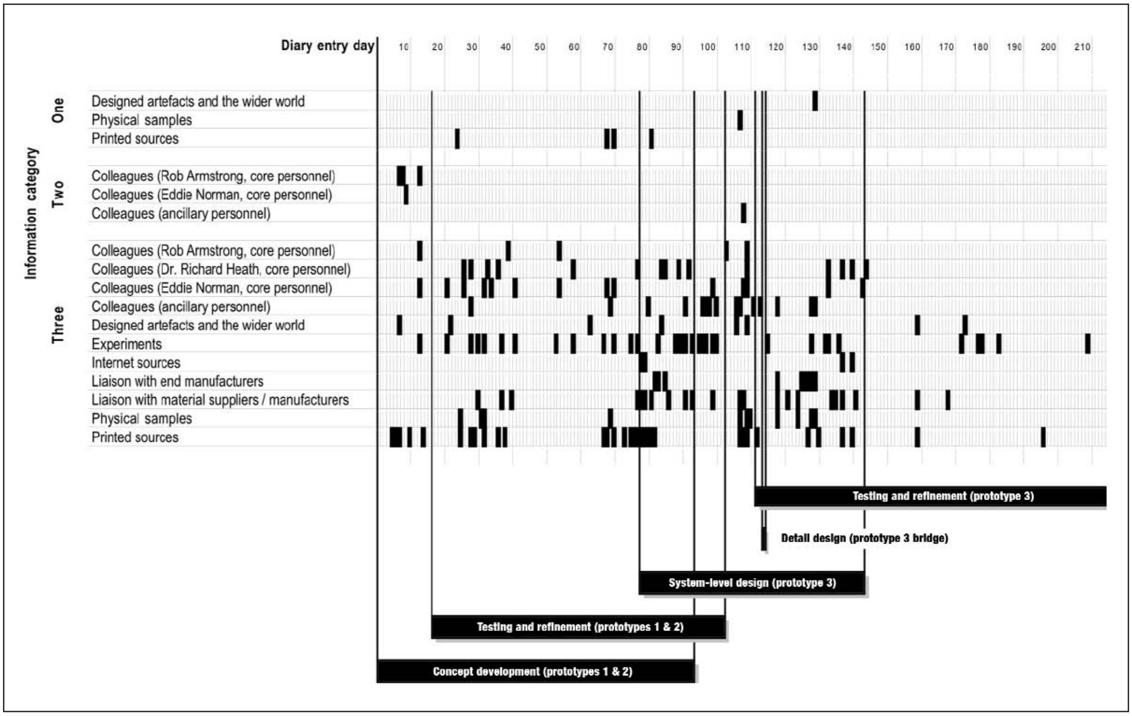


Figure 6 Materials and manufacturing information searches for the polymer acoustic guitar (Pedgley, 1999:231)

This implied relationship between the creation of articulated knowledge, designing and innovation lies at the heart of the issues surrounding the development of knowledge-based economies (e.g. Cox, 2005). Not surprisingly, it is also one of the debates with which the UK's QCA (Qualifications and Curriculum Authority) has chosen to become engaged through undertaking the RECORD&T project following the lead of Professor Geoffrey Harrison. This project[5] stemmed from an analysis of

> …design education for engineering as a consistent, progressive, academic discipline, from primary to higher education; a discipline based on:
> - a recognition of the nature of creativity,
> - both tacit and articulate knowledge and understanding, and
> - how creativity and understanding work together in the processes of designing, making, and innovating
>
> (Harrison, 2002)

The quotation comes from an interesting publication which pursued and illustrated these ideas using examples from UK practice, from 'the very first years' to 'the professional engineer', for which the 'polymer guitar project was used as a case study of the emergence of articulated from tacit knowledge (ibid:58-59). Perhaps these relationships are best illustrated by the diagram (Figure 7) used by Vincenti in the conclusions to his study of What Engineers Know and How They Know It: Analytical Studies from Aeronautical History (1993). His case studies clearly demonstrate that design

[5]RECORD&T stands for RECOgnising Real Design & Technology and details of the project can be found at http://www.qca.org.uk/15423.html. Evidence is presented relating to contexts for designing and making, strategies for designing and making, functions in design and making, sectors in knowledge and understanding for designing and making and concepts in design and technology.

knowledge is both used by engineers and generated by engineers through their activities: and much of the knowledge generated may well be tacit rather than articulated. It becomes a company's or individual's 'know how', and can be as valuable, both commercially in an IP (intellectual property) portfolio and in designing, as articulated knowledge (e.g. patents). Both Vincenti's study and the RECORD&T project were essentially targeting this same agenda, that of understanding the relationship between designing, the articulation of knowledge and innovation.

The data Pedgley gathered through his diary of designing was triangulated against case studies from the literature and in-depth interviews with professional designers. Much as Vincenti's model suggests, Pedgley's research revealed how industrial designers' experiential base for materials and processes decisions extends far beyond propositional knowledge. 'The distinctiveness of industrial designers' attention to materials and processes lies in diversity rather than specialism' (1999:327). And as he goes on to explain:

> … in straightforward terms, it may be considered a synergy between attentions that are the prerogative of the designer-maker, '…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' and those that are the prerogative of the design engineer, '…the use of quantified materials data is entirely appropriate, especially for use in mathematical calculations relating to utilitarian performance.' [ibid: 328] Most critically, '…designers were agreed that there was no substitute for hands-on examination and handling of products to learn about design.' [ibid: 319].

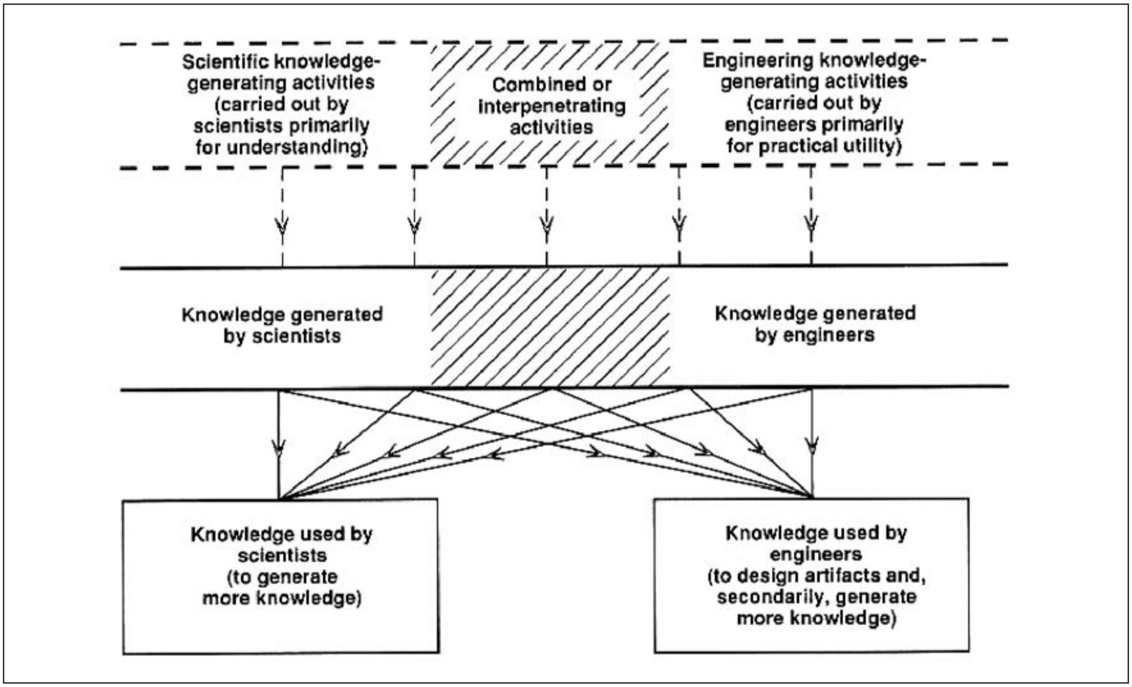


Figure 7 Design knowledge and its generating activities (Vincenti, 1993:226

The Professor John Eggleston Memorial Lecture 2006 Values, human judgement and sustainability in design and technology education

Values and designing
Pedgley's PhD moved Loughborough's agenda forward considerably in reinforcing the essential requirement of direct engagement with materials, and the complexity of exploring the technological boundary of designing. It was clear that it was not always possible to distinguish knowledge from values, and that judgements were often being made made on a spectrum of grounds. It is worth noting how strongly Pedgley's empirical data are reinforcing Eggleston's model of designing (e.g. Figure 2, 'Foundation work through soft materials (i.e. card, clay etc). Production of models').

As a second example of the importance of interdisciplinary perspectives, the role of human judgement in decision-making has been a key focus of substantial research in the management field because of the potential risks to the economic sustainability of companies arising from biases and errors (e.g. Bazerman, 2002). As sustainability has come to be interpreted in terms of social and environmental criteria, as well as economic, there is an emerging need to understand the broader role of human judgement in these areas. Product design, while actually responsible for a relatively small percentage (approximately 5-10%) of the total costs, has a significant impact on the actual costs incurred within the system. Fabrycky (1987) estimated that up to 85 percent of life cycle costs are committed by the end of the preliminary design stages. Similarly, Bhamra et al (1999) found that it is the early design stages which have the greatest influence over the environmental impact of the product. Consequently, it is clear that biases and errors in the judgements of designers have potential consequences more far-reaching than economic success or failure.

Bazerman represented a rational 'management' decision-maker as follows, and the similarity to 'the design process' is disturbing.

> …Let us look at six steps you should take, either implicitly or explicitly, when applying a "rational" decision-making process to each scenario.
>
> 1. Define the problem…
> 2. Identify the criteria…
> 3. Weight the criteria…
> 4. Generate alternatives…
> 5. Rate each alternative on each criterion…
> 6. Compute the optimal decision…
>
> (2002:3-4)

At best, such models describe what might be done. In his Nobel Prize-winning work Simon (1957) described individual judgements as being made within a bounded-rationality framework. Whilst individuals are attempting to make rational decisions, they might lack important information about the definition of the problem and the relevant criteria, time and cost can limit the information available, and their capabilities can limit their analyses. The resulting decisions were seen as being intuitively based, and the resulting judgements as 'satisficing' i.e. resulting in acceptable or sufficient positions. In 1974 Tversky and Kahneman published research building on Simon's work and described some of the systematic biases that affect management decisions. As Bazerman reported:

> Their work, and work that followed, led to our modern understanding of judgement. Specifically, researchers have found that people rely on a number of simplifying strategies, or rules of thumb, in making decisions. These simplifying strategies are called heuristics. As the standard rules that implicitly direct our judgement, heuristics serve as a mechanism for coping with the complex environment surrounding our decisions. (2002:5)

He goes on to describe in detail three general cognitive heuristics that 'affect virtually all individuals' (ibid:5):

- the 'availability' heuristic… a bias towards the familiar;
- the 'representativeness' heuristic… a bias towards known categories;
- 'anchoring and adjustment'… a bias towards an initial starting position.

Since that time on-going research in the management field has pursued the cognitive biases associated with human judgement and their implications for the decisions resulting (e.g. Thaler, 2000), but there have not been comparable research efforts in relation to design decision-making.

Perhaps the reason is that the dire consequences of 'bias' in design decision-making have not been fully appreciated, or perhaps not until recently. It was certainly clear to us at Loughborough in 2002, when Rhoda Coles started her PhD research, that we needed a much greater understanding of the role values play in design decision-making. The position reached might be summarised as follows.

> Designers work within, and are products of their culture. They have acquired knowledge from that culture, and work with technologies, which embody the accumulated knowledge of their society. They develop personal values, but are influenced by the values of all the stakeholders to a design (Norman, Ch 8, in Baynes et al, in preparation).

Coles's PhD can be visualised as a detailed examination of the values strand of the 'knowledge, skills and values' boundary for designing as shown in Figure 8.

Following a full literature review and some pilot studies Coles developed a new taxonomy for analysing the use of values in designing as shown in Figure 9. A discussion of its development has been published as part of a broader account of this strand of Loughborough's research (Norman, Pedgley and Coles, 2004a and 2004b).

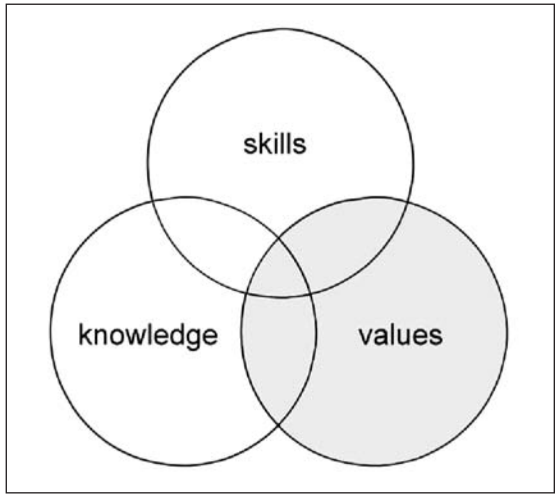


Figure 8 Rhoda Coles PhD programme

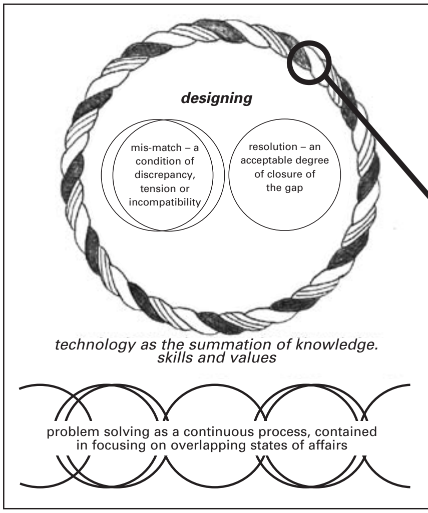
Coles found examples of other researchers beginning work in this area. For example, Kaldate et al (2003) write about decision traps as a result of heuristics and the development of a decision tool for overcoming these traps within the context of sustainable design.

> Designers deal with this new set of complexities through a traditional reductionist approach, breaking the problem into smaller sub-problems and hoping that if they solve each of these sub-problems in isolation, it will lead to the desired final solution (…) it can lead to the products that do not reflect the true preferences of the customers, are not sustainable, or do not achieve the best level of sustainability possible
> (Kaldate et al 2003:1).

The process of anchoring, where designers select a design that is readily available from which they make modifications is another common heuristic reported by Kaldate (2003). As Coles writes:

> Designers also use products as a great source of inspiration and studies have shown that inventors not only use mental images but also 'worked from existing objects to create new ones,' (Middleton, 2003:111). Ashby and Johnson also suggest

RESEARCH



External
- Societal Values
- Identified Stakeholder Values
- Economic System Values
- Values Embedded in Design

Internal
- Percieved Societal Values
- Percieved Identified Stakeholder Values
- Percieved Economic System Values
- Embedding Values in Design
- Designer's Personal Values
- Meta-Values

Figure 9 Values in designing and Coles' taxonomy for the analysis of their use in design decision-making

that it is common for designers to undertake 'selection by similarity, seeking materials with selected attributes that match those of an existing material, without knowing why these have the values they do, merely that they are relevant for the success of the design' (2003:131). These objects must have therefore held some value to the designer in their original form or they had 'some meaningful relationship to the to-be-invented object' (Middleton 2003:111). This concept is important in our understanding of the influence of values on design decision-making as:

> There is a great wealth of knowledge carried in the objects of our material culture…
> A significant branch of designerly ways of knowing, then, is the knowledge that resides in objects. Designers are immersed in this material culture and draw upon it as the primary source of their thinking. Designers have the ability to both 'read' and 'write' in this culture…
>
> (Cross, 1982:225)

Coles's main empirical data was gathered by analysing eight case studies of designers of varying levels of expertise (from first year undergraduates to professional designers). They were each asked to design a lectern using recycled polymer sheet materials for Recoup[6] in a 'one day event'. Retrospective interviews and protocol analysis were used to support the analysis of the designing, and the data was triangulated against a 'normal' project and the findings from the literature. Coles will be reporting her results in due course, but Table 2 gives a flavour of her results, and she described these results as follows.

> Existing artefacts or materials were selected to be combined with the product that is being designed in order to associate their value with the new artefact (for example three participants made the decision to use steel in their designs in order to associate the lectern with the high embedded value of steel, as they all perceived steel to be indicative of quality). New designs are also developed to resemble an existing item in order to take on similar values. These selected products can also be from previous projects, the outcomes of which must hold some value for the participant.
>
> (ibid)

[6]Recoup is a national organisation concerned with the recycling of used polymers. Further details can be found at http://www.recoup.org/business/default.asp

Bar chairs	Steel (3 people)	Surfboard (negative)	Kite	Flower petals
Swan	Glass (4 people)	Bird tables (negave)	Snake	Virgin plastic
Dyson vacuum cleaner	Marble (3 people)	Tree (negative)	Martini glass (negative)	Polyprop integral hinges
Coke bottle (4 people, I negative)	Slate	Sharks fin (2 people)	Other bottles (3 people)	Holly leaf chair (previous project)
Modern art	Leatherette	Clear tubing (previous project	Exhibition stands	Carpet

Table 2. Existing materials and designs used with new designs to transfer embedded value or to reject ideas through not wanting the association (Coles, 2006, in preparation)

Coles's research not only categorises empirical data on the way values are used by designers in their decision-making, but also on how the importance and category of values used alter during the designing. The review of these findings from an educational perspective is just beginning at Loughborough University, and particularly in the context of sustainable design.

The difficulty of making a design decision
In describing the role of scientific knowledge in design decision-making, Layton discussed the model shown in Figure 10. Everyday knowledge was seen as being constructed into scientific knowledge through science education and then de-/re-constructed in combination with 'other knowledge and judgements' in order to provide knowledge for practical action.

The meaning of this can be illustrated by considering the example of selecting between glass and polymer as the most appropriate material for a citrus juicer in the context of sustainability. This is one of the tasks which was given to 60 Year 12 students (aged 16-17), who recently attended a Sustainable Design Awards (SDA)[7] 'Schools Day' at Loughborough University as indicated in Figure 11. The students were learning about sustainable design 'by doing', and were being supported in learning to make necessary judgements. The plan for the day is shown in Table 3.

[7]SDA is the Sustainable Design Awards organised by a partnership led by Practical Action. Further details can be found at http://www.sda-uk.org

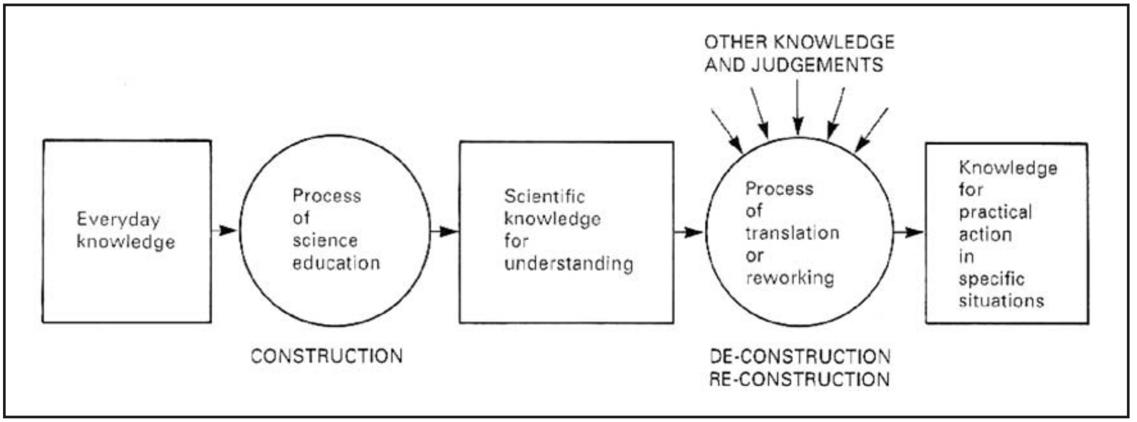


Figure 10 Construction and de-/re-construction of scientific knowledge (Layton, 1993: 59)

Figure 11 Citrus juicers made from a variety of materials

If an attempt had been made to address this question from first principles, then there would have been at least two areas in which very difficult judgements would have needed to be made, specifically:

- the balancing of economic, social and environmental priorities;
- the balancing of issues relating to this generation with future scenarios (inter-/intra-generational equity).

If a life cycle analysis were completed then global impact categories like resource depletion, greenhouse gases and depletion of the ozone layer, and regional impact categories, like ozone formation, acidification, eutrofication and persistent toxicity, would need to be assessed and quantified. Judgements would then need to be made about their relative environmental importance, and then about the significance of these environmental issues in relation to social and economic issues in the context of this generation of global citizens, and future generations. Clearly, if any designing was going to take place that afternoon, then appropriate sustainable design tools were needed. Eco-indicators (eco-points)[8] provide an effective way of reaching a decision on the environmental issues, as shown in Table 4. The environmental impact of issues like material use, processing, transportation, landfill and recycling can be rapidly assessed, and it can be quickly established that the transportation of the oranges from Spain will prove to be the significant longer term issue.

[8]Detailed information concerning the development of can be found by downloading the Eco-indicator Manual for Designers from http://www.pre.nl

Time	Activity	Notes
10.00-10.45am	Introduction to the SDA and sustainable design	
10.45-11.30am	Life-cycle analysis (LCA) of a 'juice shot'	The 'juice shot' has the juice ingredients, a polymer bottle, a metal foil top, cardboard packaging and a paper printed and glued label to consider.
11.30-12.00 pm	Ecopoints and the citrus juicers	The LCA will have demonstrated the complexity of the task. The use of eco-indicators demonstrates one tool which has been developed to help designers deal with this complexity.
12.00-12.30pm	Design abacus for a 'juice drink'	The eco-indicators are useful, but restricted to environmental issues. The design abacus provides a framework for considering relative judgements between environment, social and economic issues. Putting values for the juice shot on the abacus provides a baseline for the afternoon's designing
1.30-4.00pm	Group designing of a more sustainable way of making a juice drink	Juice drinks could be made in a home kitchen, in a supermarket as a service, or in the countries of origin of the fruit and vegetables used. This provides a rich context in which to explore sustainable design and eco-design tools.

Table 3 The plan for Loughborough University's SDA Schools Day

In order to provide eco-indicators values environmental experts have had to perform a life cycle analysis and reach judgements about relative importance. For the calculation of eco-indicators three aggregate values are calculated: damage to human health; damage to eco-systems; and resource depletion. To calculate the eco-indicators value a panel of 365 people from a Swiss LCA interest group decided to use the weightings 1:1:0.5 respectively. In the context of this paper, the key point is that the eco-design tool has been provided by making judgements on behalf of the designer. Just because the eco-point is a single number, it should not be thought of as having any scientific precision. So it is not a matter of whether judgements will be made, but who makes them. In order to support students in making such judgements the 'design abacus' was explored as described in the next section.

If the embodied energy or CO2 footprints for the glass and citrus juicers are calculated instead, as shown in Table 5, then this might appear to avoid making a judgement, but this is not the case. The judgement has to be made as to whether to use carbon emissions or energy consumption as the criterion, or how to weight them if you chose both, and that resource depletion or toxicity are not important issues. These measures are more transparent, but not value neutral.

Material or process	Amount (kg)	Indicator (points per kg)	Result
Glass	0.235	58	13.6
Low Density Polyethylene (LDPE)	0.02	360	7.2
…adding in transport from the Far East by sea (20000km)	(tkm)	(points per tkm)	
Glass	4.7	0.8	+ 3.8
LDPE	0.4	0.8	+ 0.3
…adding in transport from the Far East by air (10000km)			
Glass	2.35	80	+ 188
LDPE	0.2	80	+ 16
…adding in processing for PE (no eco-indicator for glass moulding)	(kg)	(points per kg)	
PE injection moulding	0.02	21	+ 0.4
...adding in landfill			
Glass	0.235	1.4	+ 0.3
Low Density Polyethylene (LDPE)	0.02	3.0	+ 0.1
…savings from recycling			
Glass	0.235	-15	-3.5
Low Density Polyethylene (LDPE)	0.02	-240	-4.8
…adding in the transport of 1kg of oranges from Spain (1500km)	(tkm)	(points per tkm)	
28t truck	1.5	22	33

Table 4 The application of eco-indicators to the selection of the most appropriate material for a citrus juicer

However knowing all of this, there is the reality that despite the better environmental performance and the established safety of the use of polyethylene for food products, many people would still choose glass, because, for example, of the perception that it feels more expensive, up-market, hygienic, solid, durable and of higher quality. So perhaps the stainless steel, or beech wood (from a sustainable source) juicers should also be considered.

There are no easy answers to such apparently simple choices.

Material or process	Amount (kg)	Embodied energy (MJ per kg)	Result (MJ)
Glass	0.235	13	3.1
Low Density Polyethylene (LDPE)	0.02	76.9	1.5
…adding in processing			
Glass	0.235	7.078	+1.7
Low Density Polyethylene (LDPE)	0.02	9.477	+0.2
		CO2 footprint (kg per kg)	Result (kg)
Glass	0.235	0.7	0.16
Low Density Polyethylene (LDPE)	0.02	1.95	0.04

Table 5 Embodied energy and CO2 footprints for the glass and plastic citrus juicers[9]

Values as the essential tool of sustainable design
It is evident that sustainable design decisions depend on judgements which are driven by values. This recognition led to the introduction of sustainable design as optional modules within the Industrial Design and Technology programmes at Loughborough University in 2000 (Bhamra et al, 2002; Badni and Coles, 2003). The experience gained from these modules was an important aspect of the contribution which Loughborough University has been able to make to the SDA (Capewell and Norman, 2003). Students find such judgments easier to make if a framework is provided, for example by the design abacus shown in Figure 12, which was developed by 'Shot in the Dark'[10]. Figures 13a-c show a completed 'design abacuses' from the recent Schools Day.

[9]The values for the embodied energy and CO2 footprint were taken from the Cambridge Engineering Selector (CES) EduPack 2006 Standard Edition

[10]Shot in the Dark is an eco-design consultancy and further details can be found at http://www.shotinthedark.co.uk/html/ecodesign.htm

RESEARCH

The Professor John Eggleston Memorial Lecture 2006 Values, human judgement and sustainability in design and technology education

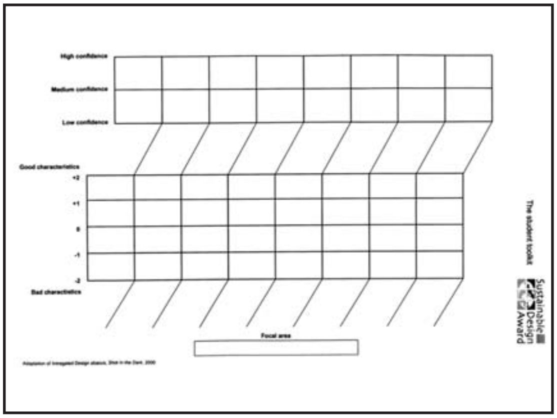


Figure 12 The 'design abacus': a framework for making judgements in sustainable design

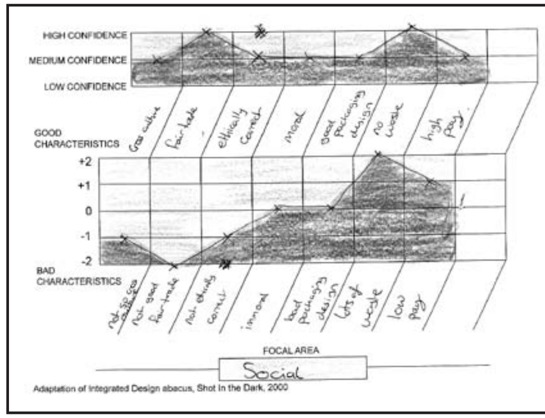


Figure 13a A design abacus completed by a group of students during the SDA Schools Day at Loughborough University: economic criteria

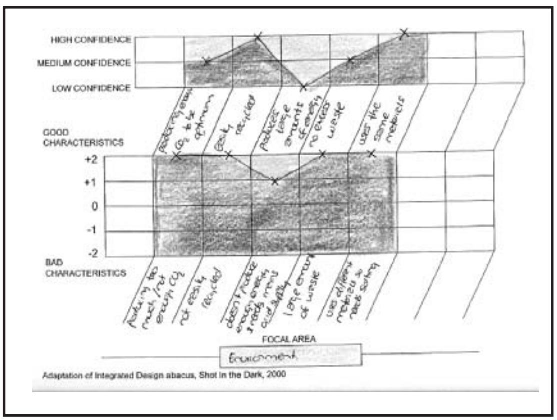


Figure 13b A design abacus completed by a group of students during the SDA Schools Day at Loughborough University: environmental criteria

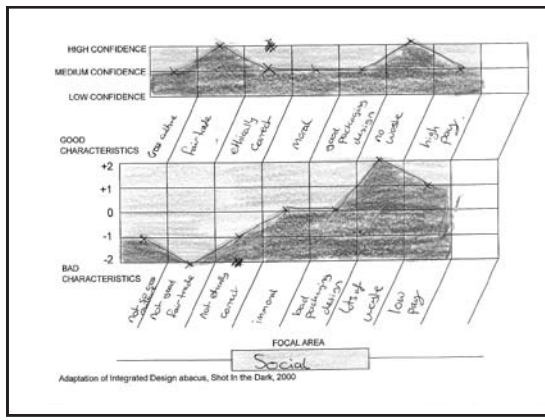


Figure 13c A design abacus completed by a group of students during the SDA Schools Day at Loughborough University: social criteria

Learning through (whilst) designing

The general issues concerning 'learning by doing' and related 'teaching by showing' have been previously discussed in traditional contexts (e.g. Norman, 2000), but it is clear that the complexity of the tasks to which designers and design students must respond is increasing. The design abacus not only provides a framework for structuring design judgements, but also suggests to designers that they should note their confidence in the judgement they have made. The information requirements will increase as the designer's role widens, and it is inevitable that the Internet will play an increasing role in helping to meet designers' information requirements. Simmons has recently completed an analysis of the content of 25 sustainable design websites as a first step in his PhD programme and is reporting the outcome at the 2006 D&T Association International Research Conference. Figure 14 shows one of the 'spider diagrams' he

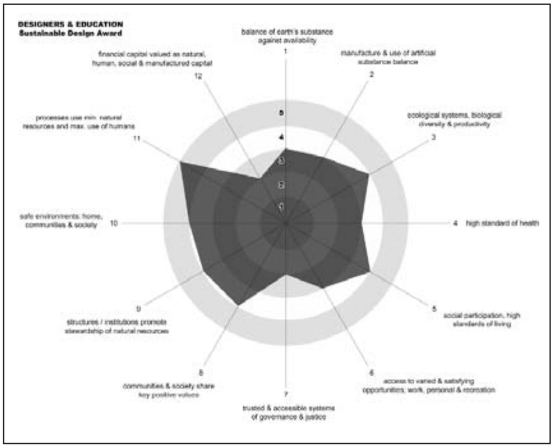


Figure 14 A 'spider diagram' indicating the content of a sustainable design website (Simmons and Badni, 2006:129)

has used to conduct this analysis , in this case for the SDA website, which he helped to design.

There was insufficient time on the Schools Day for the students to use the SDA website, but they were certainly able to justify their designs by using the design abacus. This qualitative tool seemed to present the students with few difficulties, which is both surprising and encouraging, because of the complexity of the agendas being addressed. The key matter is the attention that the students play to the 'confidence indication' and what they subsequently choose to do about it. However, comprehensive the web resources become, their effectiveness will be initially governed by the students' decisions to make use of them (or not). For the designers of the web-based tools the key issue will be the extent to which they facilitate designers' judgements and which judgements are made on the designers' behalf. Figure 15a and 15b show some of the designing taking place.

Conclusions

So, has there been any substantial conceptual progress since Eggleston's initial model of ' a design process for secondary schools' was published? It certainly seems reasonable to suggest that there has not been as much as there should have been, and one conclusion of the discussion in this presentation is that a primary cause of the lack of such progress is the downplaying of the role of human judgement. Innovation should be essentially associated with the articulation of knowledge: from tacit understanding to recorded forms; from knowing how to knowing that. For example, a well recognised endpoint for an innovation is the filing of patent, when the knowledge is articulated and its nature changes.

The empirical evidence from research at Loughborough University points to the need to

Figure 15a Learning by doing on the SDA Schools Day at Loughborough University

Figure 15b Learning by doing on the SDA Schools Day at Loughborough University

[11]The twelve arms of the spider diagram are derived from the 12 features of a sustainable society developed at Keele University, UK in an ESRC project involving 60 academics

RESEARCH

reinforce the key role that human judgements make to both innovation and designing. Tacit knowledge is expressed through know how, and it is crucial to defend the 'hands on' approaches that develop know how and learning by doing, if the goal is innovation within a knowledge-based economy. The key relationships which must be developed are between innovation, designing and the articulation of knowledge. One of the key challenges for future research is to develop understanding of what this means in a virtual world e.g. the research by Thorsteinsson and Denton (2006) reported at this conference.

In broader terms it is equally important to defend action research, which is the 'hands on' approach ideally suited to design and technology education (Norman, Owen-Jackson and Spendlove, 2006). This is the way in which innovation in the curriculum will happen, and the tacit knowledge of design and technology educators will become articulated. Action research programmes to explore design decision-making with younger students could make key contributions to our understanding (e.g. Welch et al, 2006; Mettas and Constantinou, 2006) and to curriculum development.

Similarly the discussion here has demonstrated that as the agenda which design and technology education must address widens it will be necessary to engage with other disciplines, e.g. archaeology, cognitive science, management and philosophy, in order to fully come to terms with sustainability agendas. It is interesting to reflect on the survey conducted by the then Trent Polytechnic (now Nottingham Trent University) for the APU in 1983, which is shown in Figure 16 (Eggleston, 1996). It was a cross-curricular survey of the contributions of different subjects to technological understanding, and was conducted in terms of the knowledge, skills and values categories identified by the APU in 1982. If design and technology is to make its unique contribution to children's curriculum experience, then it must focus on its core agenda, which at Loughborough we would see as the act of designing, and draw on children's cross-curricular experiences.

However, returning to music and guitars to illustrate just how complex this could all turn out to be, as Pedgley wrote:

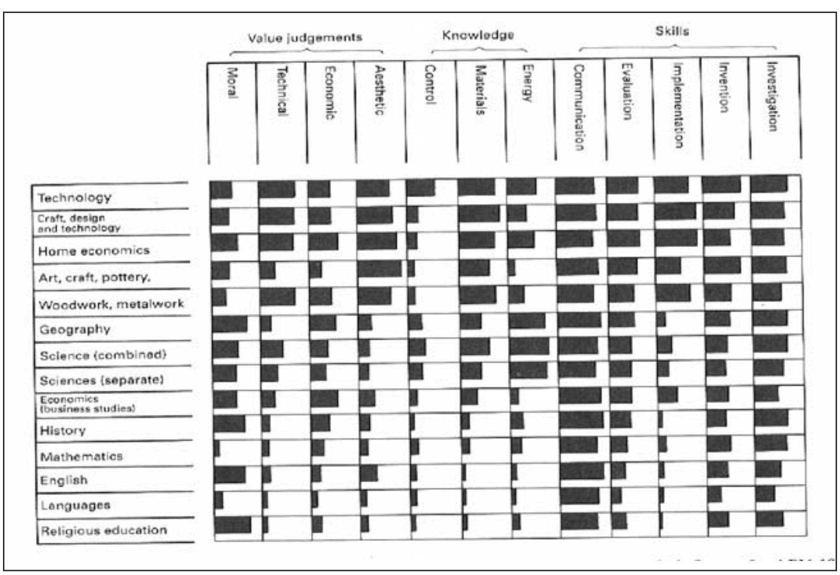


Figure 16 The contributions of UK school subjects to technological understanding: a survey conducted for the APU in 1983

Figure 17 Rob Armstrong demonstrating know how in deciding on a bracing pattern

> Decker (1999) reports that the general public, when subjected to blind audio tests between high-end and entry-level instruments, showed an ability to discern high quality from not so high quality. However, blind tests by acoustic physicists given audio spectra and vibration mode data for high-end and entry-level instruments could not discern high quality from not so high quality. So as technology currently stands, the luthier's tacit knowing must still be regarded as the most valuable of sources of expertise for polymer guitar design. This begs the questions: what is the luthier hearing/feeling to discriminate between good and bad materials? What is in the luthier's mind when devising a bracing pattern, and what sensory cues are being employed?

If only we could scientifically predict what would happen if we moved a strut slightly to the left... an easy enough task for Rob Armstrong (Figure 17), but still highly problematic (Figures 18 and 19).

Acknowledgements
My particular thanks are due to Dr Tracy Bhamra, Rhoda Coles, Dr Owain Pedgley and Peter Simmons of the Department of Design and Technology at Loughborough University, who willingly contributed to the development of this paper.

E.W.Norman@lboro.ac.uk

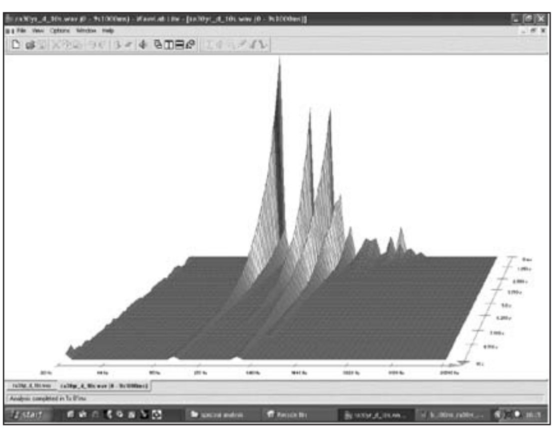


Figure 18 Knowledge still in need of articulation: an audio spectrogram from a 'top of the range' Rob Armstrong acoustic (No. 673)

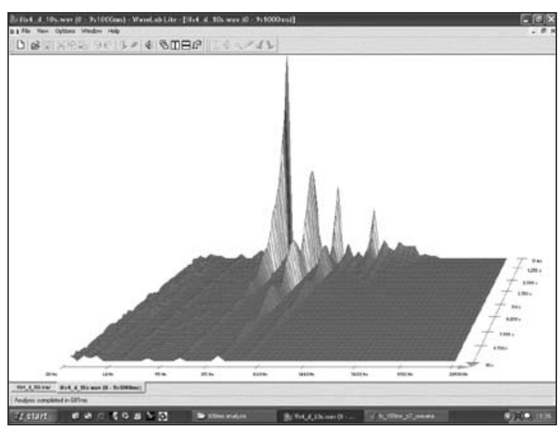


Figure 19 Knowledge still in need of articulation: an audio spectrogram for an all-polymer acoustic guitar

RESEARCH

References

Archer L B, Baynes K and Roberts P H (2005) *A Framework for Design and Design Education: A reader containing key papers from the 1970s and 80s*, DATA, Wellesbourne, UK

Ashby M and Johnson K (2003) *Materials and design: the art and science of material selection in product design*, Butterworth Heinemann, Oxford

Badni K and Coles R (2003) 'A Review of the Recent Eco-design Education Initiative for Industrial Design and Technology undergraduates at Loughborough University', *The Journal of Design and Technology Education*, 8(2), 65-79

Baird D (2004) *Thing Knowledge*, Chicago University Press, Chicago

Ball L J, Ormerod T C and Morley N J (2004) 'Spontaneous analogising in engineering design: a comparative analysis of experts and novices', *Design Studies*, 25 (5), 495-508

Baynes K et al (in preparation) *Modelling the Future*, Chapter 3

Bazerman M H (2002) *Judgement in Managerial Decision Making* (fifth edition), John Wiley and Sons, New York

Bhamra T, Lofthouse V and Norman E (2002) 'Ecodesign Education Strategies: A recent initiative for Industrial Design and Technology undergraduates at Loughborough University', *The Journal of Design and Technology Education,* 7(2), 133-141

Bhamra, T A, S Evans, T C McAloone, M Simon, S Poole, and A Sweatman (1999) 'Integrating Environmental Decisions into the Product Development Process: Part 1 The Early Stages'. *Proceedings of the First International Symposium on Environmentally Conscious Design and Inverse Manufacturing,* Tokyo, Japan, February 1999. Los Amitos, CA: IEEE (Institute of Electrical and Electronic Engineers), 329-333.

Capewell I and Norman E (2003) 'The Sustainable Design Award: Supporting 16 plus students in addressing sustainable design issues', *The Journal of Design and Technology Education*, 8(2), 82-90

Coles R L (2006) *An exploration of the role values play in design decision-making,* PhD thesis in preparation, Loughborough University, UK

Cox P (2005) *Cox Review of Creativity in Business: building on the UK's strengths, HM Treasury*, http://hm-treasury.gov.uk/cox

Cross N (1982) 'Designerly Ways of Knowing', *Design Studies*, 3(4), 221-27

Cross N (2004) 'Expertise in Design: an overview', *Design Studies,* 25 (5), 427-41

Cross N, Christiaans H and Dorst K (1994) 'Design Expertise amongst Student Designers', *Journal of Art and Design Education*, 13, 39-56

Dasgupta S (2004) 'Is Creativity a Darwinian Process?', *Creativity Research Journal*, 16(4), 403-413

Decker J (1999) 'What makes a Rainsong have its unique sound?', available at: http://www.rainsong.com/acc101.htm (accessed 08.03.05)

De Vries M J (2006) 'Technological Knowledge and Artifacts: an analytical view'. In J R Dakers (Ed) *Defining Technological Literacy: Towards an epistemological framework*, Palgrave Macmillan, New York

Doyle, M (2004) 'The evolution of technicity: whence creativity and innovation? In Norman E W L, Spendlove, D, Grover, P and Mitchell, A (Eds), *Creativity and Innovation: DATA International Research Conference 2004,* The Design and Technology Association, Wellesbourne, 67-72

Edexcel (2006) Specification for AS/A CGE in Design and Technology (Product Design), Issue 4, October 2003, http://www.edexcel.org.uk/quals/gce/dt/adv/9094/ (last accessed 26 June, 2006)

Eggleston J et al (1971) *Design for Today: Schools' Council design and craft education project*, Arnold, London

Eggleston J (1996) *Teaching Design and Technology (Second Edition)*, Open University Press, Buckingham - Philadelphia

Fabrycky, W J(1987) 'Designing for the Life Cycle', *Mechanical Engineering,* January, 72-74.

Gosden C (2006) 'Stone Age Man was a Touchy Feely Type', *The Times Higher*, 3 March, 30

Harrison G B (2002) *The Continuum of Design Education for Engineering*, The Engineering Council, London

Hatchuel, A (2002) 'Towards Design Theory and Expandable Rationality: The unfinished program of Herbert Simon', *Journal of Management and Governance*, 5, 3-4

Hicks G et al (1982) *Understanding Design and Technology*, Assessment of Performance Unit: London

Kaldate et al (2003) 'Overcoming Decision Traps in Sustainable Design', *Proceedings of the 14th International Conference on Engineering Design*, Stockholm, Sweden

Laudan R (1984) 'Introduction'. In R Laudan (Ed) *The Nature of Technological Knowledge.: Are models of scientific change relevant?* D Reidel Publishing Company, Dordrecht, 1-26

Lawson B (2004) 'Schemata, Gambits and Precedent: some factors in design expertise', *Design Studies*, 25 (5), 443-457

Layton D (1992) *Values and Design & Technology – Design Curriculum Matters: 2,* Department of Design and Technology, Loughborough University of Technology, UK

Layton D (1993) *Technology's Challenge to Science Education: Cathedral, quarry or company store?*, Open University Press, Buckingham

Lewis-Williams D and Pearce D (2005) *Inside the Neolithic Mind*, Thames & Hudson, London

Mettas A C and Constantinou C P (2006) 'The Development of Optimisation Decision-making Skills within the Area of Technology Education through a Technology Fair'. In E W L Norman, G Owen-Jackson and D Spendlove (Eds) *Designing the Future : DATA International Research Conference 2006*, The Design and Technology Association, Wellesbourne, UK, 79-88

Middleton H (2003) 'Some New Ideas on New Ideas: Creative, inventive thinking, values and design and technology education'. In J Dakers and M J de Vries (Eds) Patt-13: *International Conference on Design and Technology Education Research 2003*, University of Glasgow, 165-169

Mitcham, C (1994) *Thinking Through Technology: The path between engineering and philosophy*, University of Chigago Press, Chicago

Mithen S (2005) *The Singing Neanderthals*, Phoenix, London

Norman E W L (1993) 'Science for design', *Physics Education*, 28(5), 301-306

Norman E (1998) 'The Nature of Technology for Design', *International Journal of Technology and Design Education*, 8(1), 67-87

Norman E (2000) 'The Teaching and Learning of Technology for Design'. In Kimbell R (Ed) *Design and Technology International Millennium Conference 2000*, The Design and Technology Association, Wellesbourne, UK, 128-134

Norman E W L (2002) *The Technological Knowledge Base of Design and Associated Pedagogical Issues*, PhD published papers, Loughborough University, UK

Norman E (2003) 'Innovation in Design and Technology: the polymer acoustic guitar and the case for the relegation of the design process'. In E W L Norman and D Spendlove (Eds) *Design Matters: DATA International Research Conference 2003*, The Design and Technology Association, Wellesbourne, UK, 131-139

Norman E, Pedgley O, Coles R (2004a) 'Design Decision-making and Materials: Research agendas and gathering evidence', *The Journal of Design and Technology Education*, 9(2), 107-115

RESEARCH

Norman E, Pedgley O, Coles R (2004b) 'Design Decision-making and Materials: Investigations in the context of recycled polymers'. *In Design and Manufacture for Sustainable Development 2004*, T Bhamra and B Hon (Eds), Professional Engineering Publishing Limited, Bury St Edmunds, UK, 209-219

Norman E and Pedgley O (2005) 'Technicity as the Conceptual Basis for Explaining Innovation in Design and Technology'. In E W L Norman, D Spendlove and P Grover (Eds), *Inspire and Educate: DATA International Research Conference 2005*, The Design and Technology Association, Wellesbourne, UK, 91-97

Norman, E, Owen-Jackson, G and Spendlove D (2006) 'Editorial', *Designing the Future : D&T Association International Research Conference 2006*, The Design and Technology Association, Wellesbourne, UK, 1-8

Pavlova M (2005) 'Knowledge and Values in Technology Education', *International Journal of Technology and Design Education*, 15, 127-147

Pedgley O F (1999) *Industrial Designers' Attention to Materials and Manufacturing Processes: Analyses at macroscopic and microscopic levels*, PhD thesis, Loughborough University

Polanyi M (1962) 'Tacit Knowing: Its Bearing on Some Problems of Philosophy', *Reviews of Modern Physics*, 34(4), 601-616

Roberts P H (2005) 'Of Models, Modelling and Design: an applied philosophical enquiry', *A Framework for Design and Design Education: A reader containing key papers from the 1970s and 80s*, The Design and Technology Association, Wellesbourne, UK, 22-33

Ryle G (1949) *The Concept of Mind*, Hutchinson, London

Simmons P C and Badni K (2006) 'Developing a Framework for Analysing the Effectiveness of Sustainable Design websites in Influencing Design Decisions', In E W L Norman et al (Ed) *Designing the Future : D&T Association International Research Conference 2006*, The Design and Technology Association, Wellesbourne, UK, 121-134

Simon H A (1957) *Models of Man*, John Wiley and Sons, New York

Thaler R (2000) *From Homo Economicus to Homo Sapiens*, University of Chicago working paper

Thorsteinsson G and Denton H G (2006) 'Ideation in a Virtual Reality Environment: A pilot project from Iceland in innovation education'. In E W L Norman, G Owen-Jackson and D Spendlove (Eds) *Designing the Future : D&T Association International Research Conference 2006*, The Design and Technology Association, Wellesbourne, UK, 155-164

Tversky and Kahneman (1974) 'Judgement under Uncertainty: heuristics and biases', *Science*, 185, 1124-1131

Welch M, Barlex D and O'Donnell E (2006) 'Elementary Students' Beliefs about Designers and Designing'. In E W L Norman, G Owen-Jackson and D Spendlove (Eds) *Designing the Future : D&T Association International Research Conference 2006*, The Design and Technology Association, Wellesbourne, UK, 165-176

Vincenti W G (1990) *What Engineers Know and How They Know It: Analytical studies from aeronautical history*, The Johns Hopkins University Press, Baltimore