

# Technology for Design: Cognitive Mismatches and Their Implications for Good Practice

## Eddie Norman

Senior Lecturer,  
Department of  
Design and  
Technology,  
Loughborough  
University.  
Co-Director of the  
International  
Conference on  
Design and  
Technology  
Educational  
Research and  
Curriculum  
Development  
(IDATER)

### Abstract

This paper begins by noting some background issues concerning the linking of science and design and technological activities. Some theoretical difficulties in expressing ideas about design and technology are noted and the consequential merits of an empirical approach are exposed. Research findings are presented which help to support the development of a theoretical position in relation to technology for design, in particular introducing the notion of 'cognitive mismatches'. The evidence presented suggests that where significant cognitive mismatches exist between the matters which the designer must resolve (e.g. some are qualitative and modelled visually and some are quantitative and modelled mathematically), then focused practical tasks are essential in order to ensure high quality design outcomes. An invitation is included to participate in a broadly-based research programme in order to document good practice in relation to technology for design and explore associated issues.

### Introduction

The author recently published a paper which set out a theoretical position in relation to technology for design (Norman, 1998). In its conclusions the key research priorities and opportunities in this area were identified, namely:

- further case studies concerning the technological knowledge base 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. (ibid., 1998, p. 85)

Research findings concerning the first of these items have been previously reported (e.g. Norman, 1997) and a study related to the second item is the subject of a PhD research programme which has been undertaken by Owain Pedgley (Loughborough University, 1995-1998). Some of his initial work was reported at IDATER (the International Conference on Design and Technology Educational Research and Curriculum Development held annually at Loughborough University) in 1997 (pp. 217-22). This paper concerns initial findings relating to the third item i.e. the identification and critical review of good practice concerning technology for

design. The paper is both a presentation of these initial findings and an invitation to design and technology teachers to join in a research programme aimed at reaching conclusions of more general validity.

The area of concern can be explained more clearly by looking at a quotation from McCormick. 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." (p. 316) McCormick states the difficulties facing teachers 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. p. 309)

He freely admits in the conclusion that "the dilemma posed at the beginning has not been resolved". Design and technology teachers in the UK have developed substantial good practice concerning this aspect of design pedagogy and a substantial step forward can be made by documenting and reviewing what is known.

The inclusion of focused practical tasks has quite rightly become an aspect of good practice, but under what circumstances are they essential to ensure high quality outcomes? When might they be less critical? Or even unnecessary? The analysis in this paper suggests that they are essential in relation to some aspects of technology, but unnecessary for others.

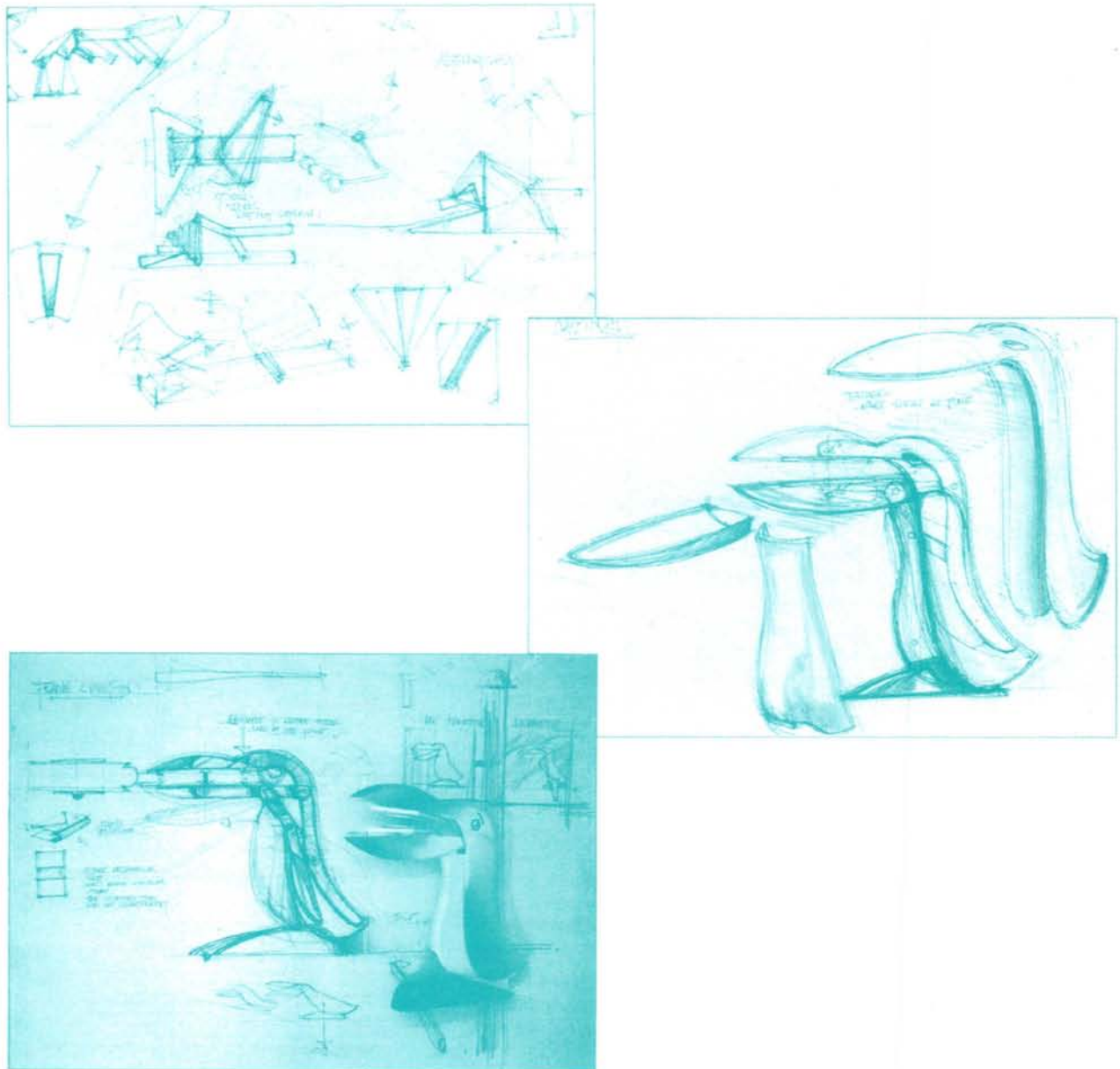
### Establishing a theoretical position in relation to technology for design

My approach to dealing with this issue rests on the theoretical position I have developed in relation to technology for design. This is best explained by looking at my view of the nature of progression and the meaning of synthesis.

Man is distinguished from other animals by his imaginative gifts. He makes plans, inventions, new discoveries, by putting different talents together; and his discoveries become more subtle and penetrating, as he learns to combine his talents in more complex and intimate ways. (Bronowski, 1973)

So begins the first chapter of the textbook to which I contributed (Norman *et al*, 1990). This quotation suggests the nature of the human ability for synthesis better than any other passage of which I am aware. Humans





have the capability to bring together qualitative and quantitative information in decision-making. The development of this capability is in my view one of the fundamental issues which design education addresses (or, at any rate, might be expected to address). Synthesis was illustrated in the textbook in relation to the development of form as shown in Figure 1.

Designing becomes more taxing when the matters to be brought together are expressed in different 'units' or 'languages'. Synthesis in relation to materials processing normally concerns the definition of the product form and is carried out essentially through 2D or 3D visual modelling. Mechanics, for example, might draw on aspects of science and hence the approach to synthesis might not be purely

through visual modelling. Eugene Ferguson has however shown that 'thinking with pictures' is an essential strand in the intellectual history of technological development (1977) and shown how Renaissance engineers recorded key information in diagrammatic form whilst insisting that:

...the mechanic arts had been brought to their current perfection by the power of mathematics, universally applied (p. 833)

Exactly how the synthesis of qualitative and quantitative matters proceeds is a matter for detailed research, but the author is aware that even undergraduate students can have difficulties with such 'cognitive mismatches'. Some evidence of this is presented later.

*Figure 1: The visual synthesis of layout in the determination of form (Norman et al, 1990, p. 87)*

**Table 1: Competencies developed by the year 2 injection moulding project and associated Year 1 foundation studies****Year 2 injection moulding project**

- designing an injection moulded product
- designing using a CAD solid modeller
- designing an injection mould tool
- understanding the issues associated with polymer selection and recycling
- producing the mould tool using CAM or conventional machining
- presenting the concept design professionally

**Year 1 foundation studies**

- conventional 2D and 3D modelling techniques
- 2D AutoCAD
- 3D AutoCAD AME
- engineering drawing
- polymer processing
- materials science
- metal machining
- graphic modelling

Humans carry out the synthesis of quantitative and qualitative information every day without any conscious thought – whenever a purchasing decision is made information about performance, styling, ergonomics, costs, environmental issues etc. are brought together and a judgement reached. This is a clearly comparable process to that carried out by a designer, and gets close to the essence of design intelligence. I would tend to view progression in design and technology as an increasing ability to handle complexity within the synthesis of aspects of multi-dimensional problems. I also believe that good practice in design and technology education facilitates the development of this capability.

***Designing as a teaching and learning strategy***

In concluding their article on kinds of seeing and their functions in designing, Donald Schön and Glenn Wiggins comment as follows:

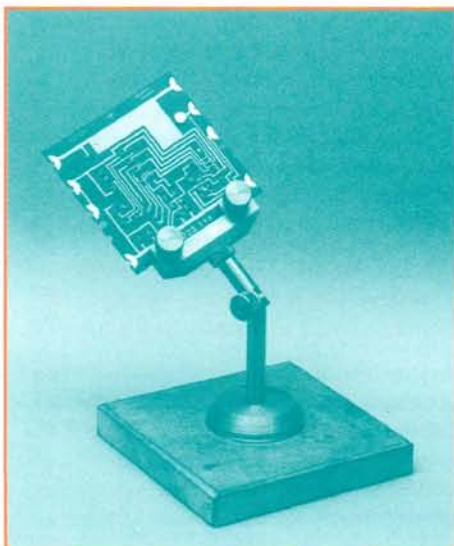
“These propositions have several implications for design education. Chief amongst them, perhaps, is the notion of designing as an educational process in its own right. Not only is designing conducive to discoveries that prepare the student for further designing, but designing may be undertaken in order to build improved understandings of systems or structures” (Note 6). (1992, p. 155)

... (and Note 6) “... Something like this has occurred to several faculty members in the School of Engineering at MIT, where computer environments invented to help students analyse, for example, control systems or building structures, have had their greatest educational use as ‘microworlds’ for design. Students who have used these computer programs as design systems speak of them as sources of better ‘intuitive’ understanding of systems or structures than they had been able to gain by mastering the basic equations.” (1992, p. 156)

I developed, in collaboration with other colleagues, the ‘injection moulding’ project, which is completed by second year industrial design and technology undergraduates at Loughborough University. This is part of Year 2 design practice, but simultaneously seeks to enable students to develop their technological capability in relation to design for injection moulding and CAD/CAM.

The project draws on Year 1 foundation studies. Table 1 shows some of the competencies developed by the Year 2 injection moulding project and the associated Year 1 foundation studies. The correlation between the developed competencies and the foundation work indicated is not exact, but the general picture is indicated.

*Figure 2: The printed circuit board holder completed as an exercise in Year 1 of the industrial design and technology degree at Loughborough University.*





The mould tool is designed in the first four weeks of the project and the critical issues concern the amount that the students need to know about mould tool design in the early stages of the design activity. The students have already completed a printed circuit board holder, as shown in Figure 2, as an exercise in Year 1 – both in the metal machine shop and in the drawing office using AutoCAD. In manufacturing the components they have used horizontal and vertical millers and lathes, so they are aware of the basic operation of these machines. They have also covered the injection moulding process within the Year 1 materials processing lectures and the injection moulding machine is demonstrated with a selection of mould tools from previous years in the early stages of designing.

Further detailed information on mould tool design and designing for machining is not found to be necessary until detailed planning for manufacture begins i.e. the students are not encouraged to think about the mould tool design in any real detail until the conceptual design of the product is complete. It has been found that with the knowledge they acquired in Year 1, students rarely come up with 'impossible' designs – although some can be challenging to make. This is also partly a matter of principle. Design should be driving manufacturing and not manufacturing constraining design, at least to the extent that this can be so.

Once conceptual design is sufficiently resolved, formal inputs are made concerning design for machining covering the positioning of the split line, draft angles, re-entrant features, the use of removable and fixed inserts and controlling shrinkage. In terms of manufacture – mould tools range from simple to complex as shown in Figure 3. No specific allowance is made for complexity in the marking schedule as the assessment of the mould tool design is based solely on its appropriateness. Students are told (or warned!) if they are heading for significant manufacturing problems – given that the tutors spot them in advance – but hopefully are not automatically discouraged. They will in any case be helped and supported through any manufacturing difficulties they encounter.

The crucial point is that the students have been taught the key principles of injection mould tool design 'through designing' and not 'before designing' or at the point of need. It is my view that such approaches remain viable with undergraduates until the students become engaged in design activities for which the modelling involves significant cognitive mismatches. However, it must be

acknowledged that the project rests on the competencies taught in the first year, i.e. some of the technological aspects have been taught before this design task is undertaken. So, it is not simply the technological area, but the balance of 'prior learning' and 'learning at the point of need' which is significant.

#### ***The importance of a technological knowledge base for designing***

The relevant pedagogical question is under what circumstances is the introduction of technological knowledge to students at the point of need either an efficient or possible approach? As suggested in the previous section, one answer I would give is when the designing activity does not involve significant cognitive mismatches. The evidence I have for this statement is outlined below.

Loughborough's industrial design students tend to focus on consumer products such as household goods, garden products, security devices, sports equipment, small power tools, lighting systems and electronic devices. Consider, for example, the four design briefs which were set in 1994/95 for the Year 1 design practice module 'mechanical products' project.

*Figure 3: Simple and complex injection mould tools completed by Year 2 undergraduates on the industrial design and technology degree at Loughborough University*

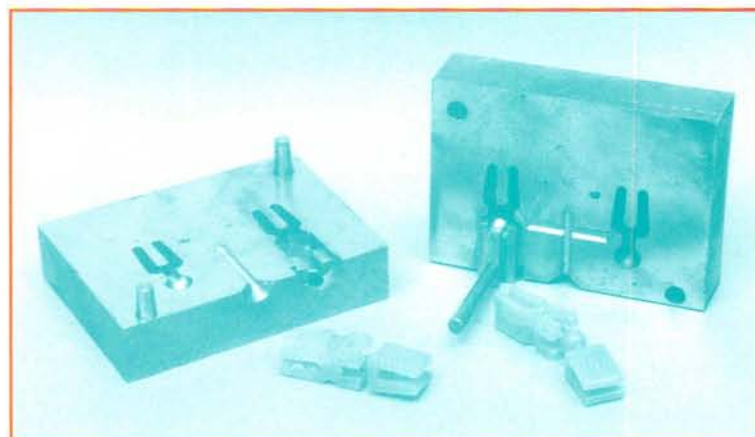
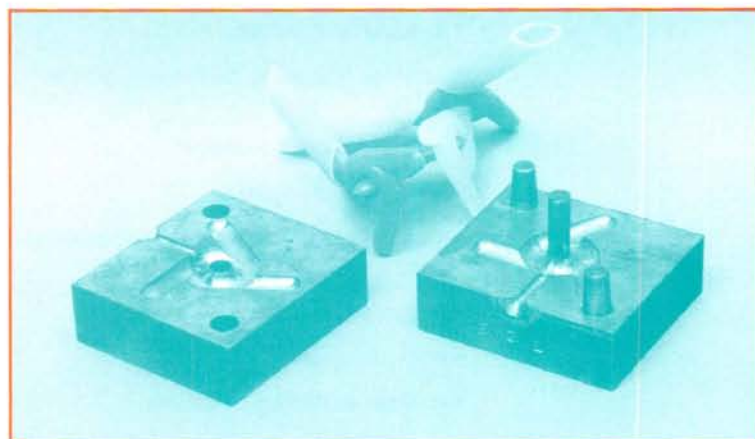


Table 2: Possible mechanics issues related to design briefs

**Wheel nut remover**

- measure required torque
- estimate 5% force
- estimate the required ratio
- decide on an acceptable lever length
- calculate the required gear ratio (if any)
- decide on the number of teeth on the wheels
- estimate the required size of the teeth
- determine gear diameters
- estimate the required beam section
- estimate the weight
- estimate the position of the centre of gravity
- estimate the force on the wrist

**Garden hammock**

- model stability when free-standing (physical/mathematical...)
- consider stabilisers/ballast...
- estimate (measure) cable angle, tensile forces
- estimate bending moment
- estimate section sizes
- consider corner supports, tapered sections materials...
- estimate the weight
- estimate weight
- consider portability, assembly...
- consider joint design/stresses
- consider hammock material
- consider 'entry/exit' stability/forces

**Shopping trolley**

- estimate the loads (shopping, person...)
- consider the centre of gravity
- consider stability, stabilising forces/moments...
- design a mechanism (if necessary)
- estimate member sizes
- estimate weight
- consider carrying/manipulating loads
- consider braking/locking systems (wet & dry conditions)
- consider wind loads (when stationary and moving)
- consider joint design/stresses

**Chopping and grating***If manual*

- estimate forces required (to chop or grate)
- estimate 5%le forces
- estimate the required ratio
- decide on an acceptable lever length,
- number of teeth, ratio of diameters...
- estimate the required sections
- assess stiffness
- estimate the position of the centre of gravity
- estimate the force on the wrist

*If mechanised*

- estimate the work to be done
- estimate the power required
- select power source (motor)
- design gearing (if necessary)
- consider batteries (if portable)
- consider other electrical sources (e.g. car lighter socket...)



**Table 3: Some student responses to the integration of mechanics and design practice**

'I found the integration of mechanics theory in design practice...

...a good idea as at an early stage we began to see the relevance of the two modules we are taught. As before this project I could not see how all the parts are supposed to 'fit' together, as it was not how I was originally taught to design.

...interesting! It was nice to go one step further and combine the two as you would in years to come. It was good for us to see a way in which the two could be interrelated, and even better to have a go.

...interesting (even quite enjoyed it) as I found myself answering some of my own questions in the design process. I felt that my design was more solid/credible with the theory added.

...tricky, made the project much more realistic.

...quite difficult. I think I tended to treat the two as separately as possible. Although the final design integrated the mechanics theory quite well – how, I don't know!?

...perhaps difficult to think of as one process.

...very difficult. I knew the theory and how to use it, but found it difficult to apply to my individual design.

...difficult as I've never tackled anything like this before. It also limited the choice of designs as some could be too complicated to calculate for.'

1 *Wheel nut remover* Often when your car wheels are fitted in commercial situations they are tightened beyond the point where manual removal is possible. Design a hand operated unit which relies on human force to remove the wheel nuts.

2 *Shopping trolley* Design a shopping trolley which converts into a perch seat for the elderly or weary when waiting at the bus stop or shopping queue.

3 *Garden hammock* The hot summer months make it desirable for a particular company to market a 'free' standing hammock. This should be easily erected and require no external support.

4 *Chopping and grating* These are common tasks in the kitchen and can be done by hand or by a food processor. Design some means of achieving a small quantity of chopped or grated foodstuffs which doesn't warrant a food processor, but which can be more efficiently processed than by hand methods. You may utilise manual or energy efficient 'green label' power. Foodstuffs to be considered – cheese, nuts, carrots, cabbage, herbs. You may specify the foodstuffs suitable for your design.

teeth seemed initially obscure to many students, but it is actually this which determines the dimensions of the gear wheels and overall dimensions. Is it the size of a watch or a car gearbox? Similarly, estimating the required beam section can seem unnecessary, but how else can the size and weight of the product be determined? Finding the centre of gravity is the crucial step in assessing how the weight of the product would feel – the force on the wrist, which is vital in judging the quality of the design of such a tool. The students agreed that designers cannot deal adequately with human factors without considering such issues.

#### Analysing the students' performances

Developing an understanding of any difficulties which might result from integrating mechanics into design practice (which might be used as supporting evidence for my notion of cognitive mismatches) depends on understanding the interrelationship of three key variables:

- the students' capability in mechanics
- the students' capability in design practice
- the students' capability to apply mechanics in design practice

Table 2 shows the technological issues related to mechanics that the students might have addressed.

These were discussed with the students in debrief tutorials once their projects had been assessed and feedback had been given by the design practice tutors. Consider the wheel nut remover. Estimating the required size of the

The most difficult issue in analysing such relationships is the avoidance of 'self-fulfilling prophecies'. We took the most direct route to eliminating this possibility by using assessments made by different people. My colleagues assessed the students in design practice and I had no direct involvement. I assessed the students in mechanics with no involvement from my colleagues. The most



difficult variable was the students' capability to apply mechanics in design practice, which in 1993/94 was determined by my examination of the project outcomes – the models and design folders. Forty-six students were involved. In considering the results obtained the most important point to remember is that the integration of mechanics theory in the design practice project did not receive 'marks'. This design practice project was assessed in the same way as all the other projects undertaken during the year – there were no special criteria. The backgrounds of the students in relation to mathematics and physics A/AS-levels and other technical pre-course studies (e.g. engineering foundation studies, transfers from engineering courses etc.) were also noted.

#### General findings

Few students without any strong prior competence in mechanics made any attempt to incorporate it into their project work. The attempts were generally successful except for the brief related to the shopping trolley (to which the students were apparently unable to see the relevance of mechanics). The top (six) performers in the design practice project effectively integrated mechanics theory into their design project work – two of the top six improving their ranking in design practice by about 20 places (presumably as a result of their expertise in mechanics). Many of the top performers in design practice prior to the design practice project lost ground on this project if their knowledge of mechanics was weak, but not inevitably. The top 10 design practice students prior to this project lost an average of about five places in their ranking, but there were significant individual differences. However, even where their marks held-up, these students did not show any effective integration of mechanics theory in their project work unless they were also one of the top mechanics students.

The most revealing analysis concerned the performance of the top 21 mechanics students prior to the beginning of this design practice project.

- All but three of these students showed good evidence of the integration of mechanics theory in design practice. The other three students attempted the shopping trolley brief.
- There were only three students outside the top 21 who showed any evidence of attempting to integrate mechanics theory in their design practice. One was an overseas student, one had obtained a good grade in A' level physics and the other had taken a one-year engineering foundation course.

- The average ranking of these top 21 mechanics students in design practice did not change, but there were significant individual movements both up and down.

The average ranking of the top 10 mechanics students in design practice actually fell by 3.5 places indicating that they did not get the balance of their activities correct.

It was clear that the best performers in the design practice project had integrated mechanics theory in their project activity, but it was equally clear that not all students could manage this activity well enough to achieve a useful outcome. It was also apparent that unless the students knew the mechanics theory before the project started they were not going to attempt to apply it. Table 3 shows some responses from student questionnaire.

At least for this area of technology, prior competence would appear to be essential for its application in designing. The distinctive feature of these briefs is that the mechanics technology plays a significant part in the determination of form and cannot be easily 'packaged'. The form of the hammock is related to the analysis of its structure, similarly, but, perhaps less obviously the shopping trolley. The wheel nut remover and chopping and grating device are closely related to mechanics primarily because they are hand-held. A mechanised chopping and grating device could be a packaged assembly, and hence, without detailed consideration of energy issues, would be the least technically demanding. As the majority of projects at 16+ incorporate packaged technology the briefs represent progression from 16+ and consequently a challenge to first year undergraduates.

#### An invitation and conclusion

If you would like to offer an account of good practice in relation to technology for design, then, either this journal or IDATER would be very pleased to receive it. If you would like to participate in a research programme to record and analyse good practice in relation to technology for design, then please write to me and I shall send you further details (Department of Design and Technology, Loughborough University, Loughborough, Leicestershire, LE11 3TU).

This paper set out to demonstrate that the subject design and technology is characterised and essentially bounded by the kinds of problems addressed and the knowledge, skills and values employed in their resolution. Designing is too complex an activity to be represented by simplistic models of designing and it is not necessary to do so in order to justify its place in school curricula. Design



and technology makes a unique contribution, which is quite distinct from the sciences and the arts through engaging students in decision-making processes employing the simultaneous use of both qualitative and quantitative criteria. This is a fundamental human capability, which is developed through good practice in design and technology education. It lies at the heart of designerly activity and cannot be easily mimicked by either the scientific processes of analysis and optimisation or the development of artificial intelligence software.

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