SCHOOL OF SOCIAL SCIENCES AND HUMANITIES

DEPARTMENT OF DESIGN AND TECHNOLOGY

THE TECHNOLOGICAL KNOWLEDGE BASE OF DESIGN AND ASSOCIATED PEDAGOGICAL ISSUES

by

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Published Papers

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LOUGHBOROUGH UNIVERSITY

ABSTRACT

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Ph.D

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Eddie Norman

What might count as the technological knowledge bases (or underpinning) of design practice (and, more particularly, Industrial Design, and Design and Technology in general education) has always been an unresolved matter. This series of papers, developed through an action research approach over a number of years, sought to develop understanding of the technological knowledge base of design, (taking account, also, of the apparent needs of Industrial Design practitioners and of those engaged in Design and Technology in schools). Hence, a theoretical position and research agenda developed concerning the nature of technology for (the purposes of those engaged in) designing. Three areas have been explored through a case study format:

- designing and materials and processes at advanced (A) and advanced supplementary (AS) level in UK Design and Technology syllabuses;
- the teaching and learning of mechanics and materials technology by Industrial Design and Technology undergraduates;
- the use of flexible learning and information technology (IT) to support the analysis of structures by Industrial Design and Technology undergraduates.

A complementary review of A/AS-level syllabuses was conducted and a major contribution made to a textbook concerning A/AS-level Design and Technology based on the understanding developed. The long-standing issues surrounding the teaching and learning of technology, as a foundation for designing and through designing, were also explored in relation to the evolved structure of the Industrial Design and Technology degree programmes at Loughborough University. This study provided strong support for understanding to be developed in relation to some technologies before engaging in designing activities. It also demonstrated the effectiveness of flexible learning strategies. A resource pack concerning the designing of kites has been developed to facilitate on-going research concerning the relationship between technology and designing at Key Stage 3 (pupils aged 11-14 in UK schools).

Recommendations for future work are included. One of these recommendations is shown as having been pursued: a PhD programme, which built on the foundation provided by the outcomes of this work and which was supervised by the author, was carried out between 1995 and 1999. The relevance of its outcomes to the teaching and learning of technology for design are made clear in the concluding paper.

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1. Introductory chapter

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The key issues

Being of the real-world, design problems are, in principle, unbounded. Since the 1970s, 'design and technology' has been emerging as an important area in both secondary and higher education, and the act of designing has been a key element of these curriculum developments. The inclusion of design activities, however, has required, inevitably, that artificial boundaries be imposed on the problems being addressed, but the existence of such limits on design activities is rarely acknowledged; indeed, it is often denied. Taken together with the ambiguities resulting from different conceptions of technology - for example as a process and as a particular area of practice, and the commonly held but simplistic assumption that technological knowledge must in some way map onto scientific knowledge, as 'applied science' - it is perhaps unsurprising that this evolution has been a challenging process. Design and technology educators impose constraints on their students through the design briefs they offer, the resources they provide, the time they make available, the pedagogy they use, the assessment methods they employ, and, no doubt, through their own knowledge, skills and values. 'Design and technology' curricula do not represent open-ended problem solving, or even problem resolving opportunities: in reality 'best practice' is usually represented in carefully constructed learning opportunities and environments.

The papers contained in this submission report the author's efforts to tackle this complex agenda in relation to writing a textbook for A/AS-level Design and Technology and developing appropriate pedagogy in relation to Industrial Design and Technology undergraduates. The papers report the outcomes of these efforts, and also analyse key aspects of the processes involved. They make contributions both to defining the technological knowledge base in these distinguishable areas, and, hence, towards making the boundaries imposed visible, and to providing some fundamental insights into the theories and assumptions which underlie such decisions.

The papers included describe research undertaken concerning 'design and technology' curricula developed for A/AS-level and undergraduates. One way of exploring any general significance of the emerging theories is to explore their validity at different levels. The resource pack for Key Stage 3 (pupils aged 11-14 in UK schools) makes a beginning in this process and facilitates future work. The PhD study conducted by Owain Pedgley (1999) began the exploration of the relationship of one technology - materials and manufacturing processes - and one area of the professional design field, industrial design. These are referred to in the recommendations for future work.

Context

Numerous attempts have been made since the 1970s to explore and define the relationships between 'technology' and 'designing' within the curricula of general education in the UK. The topics addressed by publications relating to three of the major initiatives are shown in Table 1. The Engineering Science project began in 1970 at Loughborough University of Technology. On the first introductory page to the Teachers Resource Book, Kelly writes as follows:

> The project's primary aim has been to produce stimulating and enjoyable text books by adopting an engineering approach to the treatment of the physical

> science included in a wide range of A Level courses. Our educational objectives include the development of abilities in communication, synthesis, design, evaluation and decision-making in addition to the more traditional abilities of analysis and comprehension.
> An attempt has been made in each of the texts to treat the science in the context of the ways in which it is applied to the solution of practical problems. Of necessity, therefore, the familiar concepts of physics are considered alongside ideas of optimisation, of engineering judgment and decision, and of economic and social resources and restraints. Science itself is seen as both a powerful tool and an inflexible limiting agent. (1976, np)

This project was a response to the perceived needs to facilitate 'discovery learning' and promote 'relevance' (ibid, p1), which had arisen from the dissatisfaction with science syllabuses and examinations that became evident in the late 1950s.

Engineering Science Project	**Modular Courses in Technology**	**Science with Technology**
Schools Council/Loughborough University of Technology 1976	*Schools Council/National Centre for School Technology, Trent Polytechnic, 1981*	*Association of Science Education (ASE)/Design and Technology Association (DATA), 1996*
Dynamics Electrical fields and devices Electricity Electronics, systems and analogues Heat transfer and fluid flow Structures Thermodynamics Tribology The use of materials Waves and vibrations	Electronics Energy resources Structures Mechanisms Materials technology Technological problem solving Control electronics Aeronautics Pneumatics Instrumentation Acoustics Optical instrumentation Electrical applications Technology and society Microprocessor control	Understanding the science of food Developing food products Developing textile products Understanding control Investigating and designing control systems Understanding sensors Control in action: designing a fermenter Cars and the environment Green buildings Human factors in design Evaluating environmental impact Energy transfer from source to load Making use of renewable energy Energy in Kalyanpura (Investigating energy and developmental issues)

Table 1 The technological topic areas identified by three major curriculum initiatives.

Table 1 shows lists of technological topics that were selected for students to study. The essential weakness of such approaches whether at 14-16, 16+ or in higher education is the difficulty of guaranteeing any connection between the technologies learnt and subsequent projects (assuming that the projects do not address pre-defined problems).

Figure 1 shows the model of Technology adopted by the Modular Courses in Technology Project (Page *et al*, p.1). The working definition adopted by the development group was:

> Technology is the process by which people cope with their environment. It is therefore a problem-solving process (emphasis added), which draws on the knowledge and resources available to us, while working within the constraints that the knowledge and resources place on us. (ibid, p.1)

With such an all-embracing definition and associated model, the subtlety of the relationship of 'technology' and 'design' is easily lost. In the UK, curriculum development for design and technology has been characterised by an absence of general agreement over the appropriate relationship between design, technology and science.

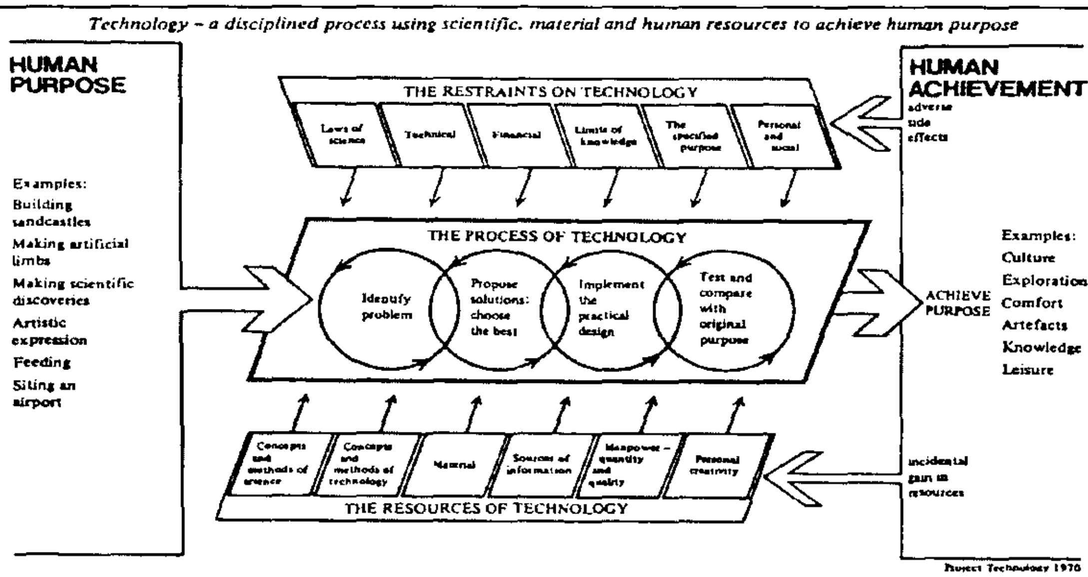

Figure 1 A model of Technology adopted by the Modular Courses in Technology Project (ibid, p.1)

In returning to this area in 1996 the ASE/DATA (Association of Science Education/ Design and Technology association) project again put technology first.

> The materials we have been writing have been technology led, that is, the overt motivation for the work has been provided within a technological context (Sage and Steeg, 1993, p.62)

All the publications listed in Table 1 have excellent features, but have not been widely adopted. All three projects essentially started from 'technologies'. Technologies were chosen and boundaries drawn around them. Publications were then prepared in the expectation that appropriate links to 'designing' would evolve naturally. This approach has not proved to be sustainable.

In order to pursue a designerly mode of research in this area, three topics – leading to a case study approach - have been explored:

- designing and materials and processes at advanced (A) and advanced supplementary (AS) level in UK Design and Technology syllabuses;
- the teaching and learning of mechanics and materials technology by Industrial Design and Technology undergraduates at Loughborough University;
- the use of flexible learning and information technology (IT) to support the analysis of structures by Industrial Design and Technology undergraduates at Loughborough University.

These topics were chosen to research into selected issues as they emerged. They partly reflected my career needs, but also a movement from what are sometimes seen as 'soft' technologies towards 'hard' technologies. It became evident during my research that such a distinction might have its basis in more significant matters than, for example, the perceived difficulty of learning them.

One of the outcomes of this research is the textbook on *Advanced Design and Technology* (Norman *et al*, 1990) - aimed primarily at A/AS-level students, but it is also used with undergraduates. This was a contribution to addressing one of Archer's observations (1978, p.7) in helping to provide a resource for students and teachers that might be used at secondary level. Its writing was a building block in this study. The importance of this work can be seen in the extract from the review in *The Times Educational Supplement*, which was published in October 1991 (shown in Appendix 1). This review shows the ready acceptance of the positions adopted and hence their accuracy in reflecting the common understanding of design and technological activity at A/AS-level in schools and colleges at that time. However, the general acceptance of the textbook is witness not only to the quality of its presentation and content, but also to the weakness of developed theory in this area of the design field. The book was the product of many discussions, drafts and difficult decisions. It is not likely to have been right first time, however much the authors strived to make this the case.

Later publications have sought to improve the potential for debate over some of the positions which were adopted in preparing the textbook for A/AS-level, and also in the further case studies concerning the technological knowledge base for students of industrial design. This area of the design field is similarly neglected. Design courses in higher education have traditionally been studio based - almost an 'apprenticeship' style of teaching and learning - so finding any written statements indicating what undergraduates should know is unusual. This is an evolving situation and a review of changing practices on industrial and product design courses in UK higher education was reported by Myerson in 1991. Myerson's survey contains a number of interesting outcomes and in relation to the technological knowledge base of design the views expressed by course leaders and employers are particularly noteworthy.

> A majority of course leaders now considers the traditional practice of introducing individual students to bodies of technical knowledge on demand rather than as a planned part of the curriculum to be inefficient and not sustainable. (p.40)

And that was before the rapid expansion in student numbers in higher education. The claims by course leaders require analysis based on evidence, but they also expressed severe doubts concerning the possibility of establishing a technological knowledge base for design.

> Many course leaders at both degree and HND level admitted they had problems in defining a technological core of content. The following views were repeatedly expressed:
>
> - technology is fluid and ever-changing so there is no constant empirical body of technical knowledge that can be defined and communicated;
> - technology will continue to change long after students have graduated so the key strategy in the technological underpinning of courses should be to imbue students with a spirit of technical enquiry and give them the skills to go on researching fresh technical information throughout their careers;
> - no industrial designer can acquire a breadth and depth of technological knowledge that will equip them for every eventuality in every industrial sector, so the development of problem-solving and information-synthesis skills should take precedence over learning scientific principles by rote;
> - the role of the industrial designer is to challenge existing engineering precepts so that original and unorthodox solutions can be achieved, not to passively accept and assimilate long-established techniques and methods
>
> (ibid, p.28)

These statements accurately reflect the challenge that this aspect of the research presents. The following extracts concerned the comments of employers;

> There is also a general acceptance among employers that it is unrealistic to expect new ID (industrial design) graduates combining expertise in design and engineering to acquire technical know-how comparable to a pure engineering graduate. Many regard three-year degree courses as far too short to accomplish all course aims. As one explained:
>
> *'Product design is closest to architecture in that its knowledge base is gigantic and its learning curve almost vertical. Three years is not enough and BTEC courses suffer even more'*
>
> ....
>
> Employers generally agree with the definition of a technological core of study embracing materials, processes (especially when they provide an insight into manufacturing), human factors, computing and workshop practice, and regard its effective delivery as essential to produce well-rounded graduates. But there is concern that the curriculum should not become overloaded with technical studies at the expense of time devoted to design methodology and problem-solving:
>
> *'A lot of academic science and engineering is just not relevant to industrial design. Courses teach the wrong stuff. Students don't need to know how many molecules there are in a polymer chain. They need to know if something is possible or not, and the parameters that govern that design choice.'*
>
> (ibid, pp.58-59)

These extracts represent the difficulties very well. Not all academic science and engineering is relevant to designers of a particular product group. It is a matter of selecting potentially relevant technology for particular design areas. Establishing whether something is possible or not sounds as though it might be easy, and is clearly what is required, but is actually rather difficult.

Published papers

Research agenda

- Norman, Eddie: 1993, 'Science for Design', *Physics Education*, Vol.2, No.5, pp.301-306.

This paper was an invited contribution to a special edition of *Physics Education* (concerning the relationship between physics and engineering). Its primary objectives were to clarify issues and define terms. It considers the problem of distinguishing different areas of the design field - in particular engineering and industrial design - through the products of the design activity and through the initial training of their practitioners. This is a key step towards identifying potentially relevant technology for design. It goes on to highlight pedagogical issues through a case study endeavouring to establish that the practice of teaching science for design by supporting design and technological activity deriving from needs identified by students would be unsustainable on a significant scale. (This kind of position was being adopted in relation to early versions of UK National Curriculum Technology, although there has now largely been a retreat.)

- Norman, E.: 1998, 'The Nature of Technology for Design', *International Journal of Technology and Design Education*, Vol.8, No.1, pp.67-87.

This paper sets out to review ideas concerning conceptions of technology from a design and technology education perspective. It examines ideas about technology for design, in particular the nature of associated knowledge, skills and values. A distinction is made between knowledge and information in this context. Most significantly, it seeks to establish a research agenda concerning technology for design and associated pedagogical issues, which appears in its concluding discussion.

Research methods

- Roberts, Phil and Norman, Eddie, 'Models of Design and Technology and their Significance for Research and Curriculum Development', *The Journal of Design and Technology Education (Research Section)*, 4(2), 1999, pp.124-131

This paper identifies the nature of design problems and discusses theoretical difficulties in expressing ideas and developing models of design and technology. The viewpoint of the researcher has a major impact on research outcomes and consequently must be made clear. The paper was largely drafted by Eddie Norman, but draws heavily on earlier work by Phil Roberts. Equal contributions to this paper would seem to be an appropriate judgement.

- Norman, Eddie, 'Action Research Concerning Technology for Design and Associated Pedagogy', *Educational Action Research - an International Journal*, 7(2), 1999, pp.297-308.

This paper indentifies and discusses action research as a designerly mode of enquiry. The principal outcomes of such research - a textbook for A/AS-level Design and Technology and teaching and learning strategies for industrial design and technology undergraduates - might not be regarded as conventional research outputs, but the arguments presented show that such a viewpoint would be mistaken. Some characteristics of action research as a beneficial mode of enquiry for academics in higher education are noted.

Designing and materials and processes at advanced (A) and advanced supplementary (AS) level

- Norman, Eddie: 1993, 'Review of Current A/AS Syllabuses in Design and Technology', *International Journal of Technology and Design Education*, Vol.3., No.2, pp.41-57.

This paper was the outcome of a preliminary study intended to identify a particular area of technology for design: in this case, the knowledge, skills and values associated with UK Design and Technology at 16+ from 1990 (the so-called common core syllabuses). It was necessary to get a clear understanding of the nature of the design and technological activity embodied in these syllabuses. It was the movement towards a common core that produced both the requirement for the textbook and a commercially viable opportunity. The paper presented is a review of common core A/AS-level syllabuses, which had different areas of emphasis and, consequently, did not result in an easily interpreted common definition of the 'required' technological knowledge base.

- Norman, Eddie: 1997, 'Materials and Processes within A/AS-level Design and Technology: a Study of Implementation', *The Journal of Design and Technology Education*, Vol.2, No.3, pp.264-273.

This paper details the implementation of the 1990 common core syllabuses by Examination Boards and the interpretation that was necessary to write the materials processing and selection chapters for *Advanced Design and Technology*. This interpretation built on the theoretical positions already published, but also embodied a viewpoint concerning the nature of designing at 16+. The paper makes these adopted positions clearer. It was written at a time when the nature of Design and Technology at 16+ in the UK was being reviewed.

Pedagogical issues concerning technology for design in relation to industrial design and technology undergraduates

The Department of Design and Technology at Loughborough University was invited to produce a special edition of *Studies in Design Education, Craft and Technology* for Summer, 1988. This edition was an opportunity to describe the work of the Department, which had been evolving rapidly since 1982 under the leadership of Prof

K.W.Brittan. Two papers from this special edition have been included here in order to establish key aspects of the course content and philosophy. The 1986 common core A/AS-level syllabuses in Design and Technology were an attempt to replace the proliferation of syllabuses ranging through craft and design to engineering drawing and science that had previously existed. As such they were an 'experiment' at evolving a balanced approach to product design, merging elements from all these traditions. The Design and Technology degree programmes at Loughborough University were a parallel innovation in higher education to which the author was a contributor. (The word 'Industrial' was added to the degree title in 1990 in order to avoid confusion with National Curriculum Design and Technology, but only evolutionary changes were made to the degree programmes at that time.) The author was 'in the thick' of these developments having been involved in the early '80s in teaching one of the A-level syllabuses (Cambridge Board's *Elements of Engineering Design*) which was replaced by the 1990 common core model and appointed to Loughborough University in 1984 - two years after the 'step function' in the move away from craft-based design occurred.

This was a time when the 'two cultures' model was being challenged and it was no longer automatically accepted that the 'arts' and the 'sciences' were irrevocably divided. The report published by Ewing (1987) on the postgraduate course in Industrial Design Engineering at the Royal College of Art (jointly run with Imperial College) had highlighted the difficulties of teaching industrial design graduates engineering (as opposed to teaching engineering graduates industrial design). Ewing's report found 12 UK courses, 4 US courses, 1 course in Holland and 1 course in Japan which were involved in teaching design as a subject that linked industrial design with engineering and technology. The numbers might have changed since 1987, but this, in any case, represents a very small fraction of the higher education courses teaching either engineering or industrial design separately. There definitely appeared to be some issues to identify and, where possible, resolve.

- Norman, Eddie, Bullock, Brian and Hall, Mike: 1988, 'Materials for Product Design', *Studies in Design Education, Craft, and Technology*, Vol. 20, No.3, pp.163-168.

This paper reviews existing practice concerning materials and processes on the design and technology degree programmes in 1988. Workshop practice was being taught (by the author and others) through both exercises and design activities. Materials science was being taught through lectures and laboratory investigations. Materials technology was never regarded as a problem area of the curriculum by staff or students. The links with product analysis and design practice - and particularly to the work of the finalists in the Degree Show - were straightforward to develop. It was mechanics and electronics that presented the more difficult issues and, consequently, these technologies provided the focus for later action research initiatives. This paper was largely drafted by Eddie Norman, but drew heavily on the work of Brian Bullock and Mike Hall. Equal contributions would be an appropriate judgement.

- Norman, Eddie and Riley, Joyce: 1988, 'Technological Capability in Design', *Studies in Design Education, Craft, and Technology,* Vol. 20, No.3, pp.154-161.

A first attempt at producing a detailed draft of the required knowledge of mechanics by Industrial Design and Technology undergraduates was completed in the summer of

1985. A copy of this draft *Mechanics for students of product design*, samples of student work, and course and student records are available. This draft was the focus of internal debate with colleagues and teachers on in-service education and training (INSET) courses during 1986 and was a key step towards the identification of the required technological knowledge base.

This paper focuses on mechanics, but extends the discussion to include elements of electronics and electromechanical system design. It illustrates the hoped-for progression from the analysis of existing products, through feasibility studies and onto the analysis at the design stage of original concepts. Eddie Norman largely drafted the paper, but the work described represented the results of collaborative teaching with Joyce Riley (now Joyce Cubitt). Again equal contributions would be an appropriate judgement.

- Norman, Eddie, 'Technology for Design: Cognitive Mismatches and their Implications for Good Practice', *The Journal of Design and Technology Education (Research Section)*, 4(1), 1999, pp.32-39.

This paper presents an analysis of where pedagogical issues relating to technology for design are likely to emerge by introducing the notion '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 may best be modelled visually and some are quantitative and may best be modelled mathematically), then difficulties can be anticipated. Prior learning in the 'quantitative' technological area resolves issues of confidence, but issues remain concerning the balance of activites when designing. Appendix 2 is a Departmental Research Seminar Paper which presented a detailed analysis of the 'mechanics' design practice projects undertaken by first year undergraduates in 1993/94 and 1994/95. The evidence of the need for prior learning of mechanics, if it was to be applied in the design practice module, was overwhelming, but there was also evidence of the difficulties students could have in managing priorities when designing.

Information and design activity: flexible learning and the use of information technology (IT) to support the analysis of structures by industrial design and technology undergraduates

- Norman, Eddie: 1988, 'Information and the Design Process', *Studies in Design Education, Craft, and Technology*, Vol. 20, No.3, pp.137-141.

This paper reviewed prior work concerning information and designing. It was necessary to consider both the professional and school contexts and to establish an appropriate position for that time concerning the role of textual resources in relation to other media.

- Norman, E.: 1987, 'Expert Systems in the Design Process', *Studies in Design Education, Craft, and Technology*, Vol. 20, No.1, pp.10-15.

In the l980s, expert systems were the focus of much research relating to artificial intelligence. A possibility existed that expert systems might be able to go further than flexible learning resources and encapsulate aspects of design intelligence. The designer might be enabled to go beyond the acquisition of low level information and gain access to aspects of higher level skills. This paper established the (then) current state of the art in relation to such systems. Exploratory studies concerning TIMM and INSIGHT - two PC-based expert system shells were also reported. This study had been undertaken in a spirit of optimism, but it was concluded that there was insufficient to gain through the use of expert system shells at that time.

- Cubitt, Joyce, Hodgson, Tony and Norman, Eddie: 1994, 'A Flexible Learning Strategy for Design and Technology Students', chapter in *Flexible Learning in Higher Education*, Winnie Wade, Keith Hodgkinson, Alison Smith and John Arfield (eds.), Kogan Page, pp.89-98.

Flexible learning strategies seek to give learners control over their learning, so they offer the potential to allow learners to access their information requirements at the point of need. Flexible learning materials have been developed by teachers in schools and colleges for use in secondary education and by Open University course teams for use in higher education. The central focus of this study was not to investigate whether flexible learning could work, but to investigate best practice in flexible learning within the context of Industrial Design and Technology. The topic chosen was energy. The Supported Self Study Unit in Northumberland had a national reputation for the development of learning materials for A/AS-level and had developed materials for every area of the curriculum except Design and Technology. Learning materials developed for physics A/AS-level were also examined, but not found to match adequately with the Foundation Technology module. It was decided, therefore, that learning materials suitable for this research would need to be written. The materials clearly had to be of the highest quality in order for the trials to be meaningful. The development of these materials and their trialling was conducted in collaboration with Joyce Cubitt and Tony Hodgson (Visiting Lecturer and Lecturer respectively in the Department of Design and Technology, Loughborough University). However, the author was solely responsible for the research initiative and direction and jointly responsible with Joyce Cubitt for the content. The flexible learning materials on energy were largely written and desk-top published by Joyce Cubitt. Tony Hodgson's contribution was vital, but primarily as an IT expert. A copy of the learning materials developed is available from the author.

The trialling of the materials also had to be conducted in accordance with best practice. The model of learning adopted was that developed by the Northumberland Supported Self Study Unit and shown in Fig.2 (Cubitt *et al*, 1993). It is important to note that this research was undertaken in parallel with the Higher Education Funding Council for England (HEFCE) funded programme 'Flexibility in course provision' which helped to initiate the Flexible Learning Initiative (FLI) at Loughborough University. However, funding had already been obtained from British Gas for the development of the learning materials on energy in the Department of Design and Technology before this wider initiative began. Nevertheless, this research programme became absorbed into the FLI and some additional funds to aid the implementation programme were provided from this initiative.

This project was selected by an external researcher, Marion Wilks, as a case study of good practice for the 'Course Design for Resource Based Learning' project funded by the HEFCE through the Effective Teaching and Assessment Programme (ETAP). (Hodgson and Norman, 1994). This report is shown as Appendix 3.

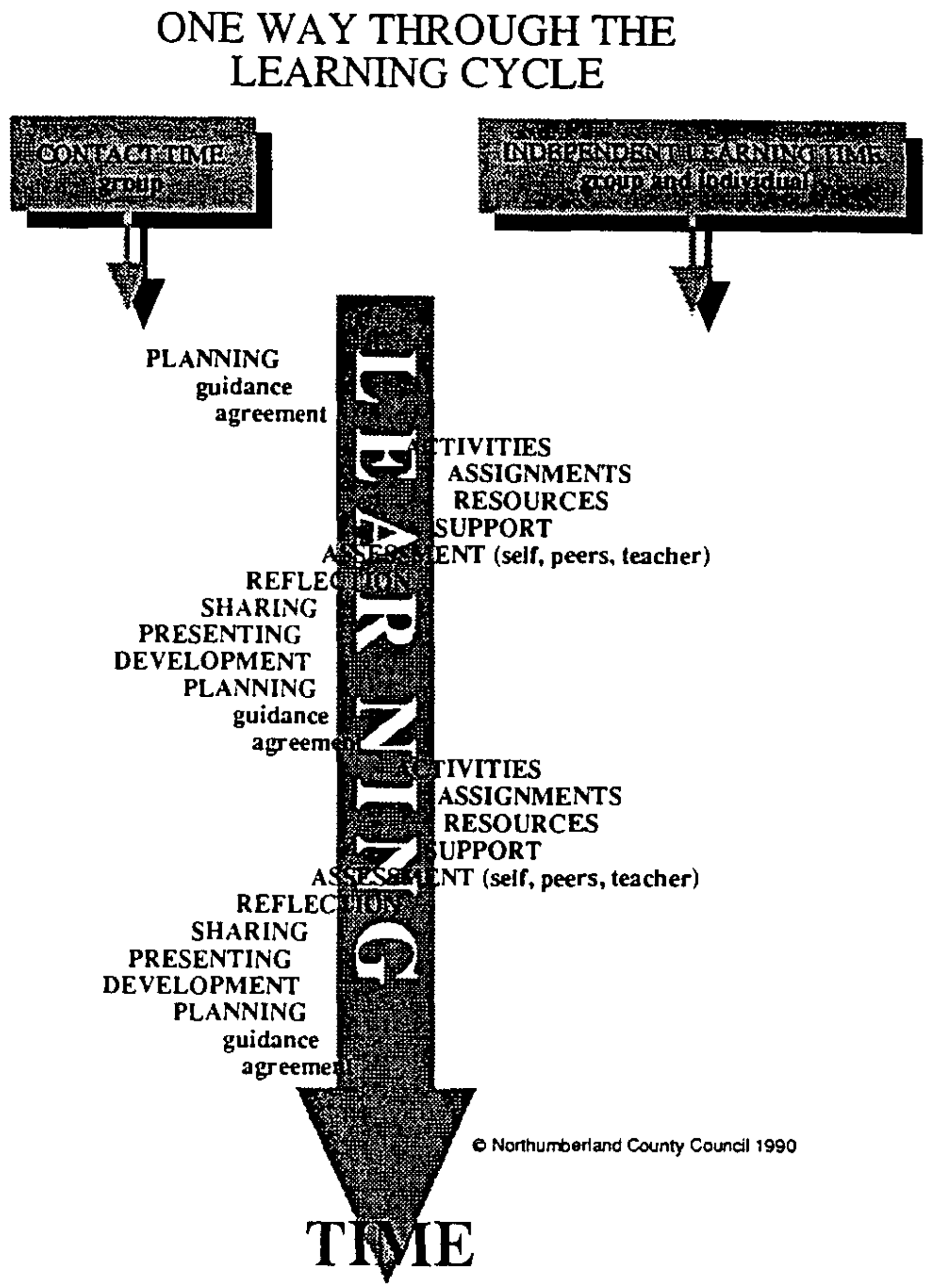

Fig.1 The model of learning developed by the Northumberland Supported Self Study Unit (Cubitt, Hodgson and Norman, 1993)

• Norman, Eddie: 1997, 'Towards the capture of design intelligence - independent learning materials and calculation software for the analysis of structures', *Proceedings of 10th International Conference on Design and Technology Educational Research and Curriculum Development*, J.S.Smith (ed), pp.196-204.

This study was undertaken to investigate the extent to which flexible learning materials in combination with software calculation packages could influence the technological capability of industrial design students. The first requirement was the development of high quality learning materials. These were developed using the best practice established when developing the flexible learning materials on energy. The software was written by Prof. S.A.Urry. Again, the author was solely responsible for the research initiative and direction and jointly responsible with Joyce Cubitt for the content. The flexible learning materials on structural analysis were largely written and desk-top published by Joyce Cubitt and are available from the author.

The decision had been made that conventionally published flexible learning materials offered the most appropriate route at the time for developing independent learning skills with industrial design and technology students. A key factor in this decision was the avoidance of a 'black box' approach amongst the students. All the software and procedures were fully transparent to those students with the appropriate background to understand them. Consequently, this particular project has stopped at the point of demonstrating the potential of software based systems to extend the technological capability of Industrial Design and Technology students through conventional calculation packages. These calculation packages form part of an 'expert system' through which the students can make ball-park estimates of the required sizes of structural members.

Concluding paper

- Norman, Eddie, 'The Teaching and Learning of Technology for Design', *Proceedings of the Design and Technology International Millennium Conference*, 2000

This paper was written to provide a summary of the progress made concerning my research. It includes evidence derived from Owain Pedgley's PhD thesis (1999) which was based on the case study I proposed in 1993. The basis for the kites resource pack for Design and Technology at Key Stage 3 is also described (Norman and Cubitt, 1999). This is available from the author and is intended to be a basis for future work, relating particularly to the visual representation of technology. A review of this resource pack is shown in Appendix 1.

Concluding discussion

In discussing the humanities tradition of research, Bruce Archer made the following comments:

> It is in the nature of the Humanities disciplines that its judgements are made within a subjective framework of values. There is no such thing as 'objective' Humanities research. That is why it is important for the investigator to declare

> his of her 'theoretical position'. Nevertheless, some Humanities research strives to present generalisable findings within a given context. In such a case, one has to determine whether or not the arguments and the findings would remain valid in a different context. A series of concordant subjective judgements by different scholars can nevertheless take on the weight of generalisable theory. (1995, p.4)

In relation to this study the comparable issue is the extent to which the conclusions reached for these particular areas of technology, in relation to these particular areas of the design field, can be considered to be more generally applicable. The research project started because of the requirement to construct curricula, teaching and learning stategies and resources for particular areas of the design field. Such areas might be defined by many factors, such as the age of the students concerned, the categories of products with which they are concerned and the knowledge, skills and values being employed. Design and Technology curricula emerge in particular times, places and cultures as a result of the conceptions and ideologies held by their originators and the external pressures upon them. Each Design and Technology curriculum is therefore a 'special case'. Hence, any attempt to develop an understanding of good pedagogical practice in relation to technology for design must begin by developing an understanding of 'design' and 'technology' as they are being interpreted in a particular area of 'design and technology'. Papers are included here which address these matters in relation to the case studies selected: namely 'common core' Design and Technology for 16+ students in the UK and Industrial Design and Technology undergraduates at Loughborough University, also in the UK. Clearly any attempt to strive for more general theories must engage the work of other scholars in different times and cultures.

Defining the meaning of technology is not a trivial matter as Mitcham's book (1994) has ably demonstrated. The position taken concerning the meaning of technology in this study has been carefully explained, primarily to meet Archer's point that there is no such thing as an objective researcher in the Humanities area. The paper presented here concerning 'The Nature of Technology for Design' is essentially a personal viewpoint, although it also makes some more theoretical contributions. It is quite likely that a researcher with a different perspective on technology would have reached different conclusions. However, it is not possible to know until such scholars have made their contribution. These papers can only be seen as a contribution within a particular tradition (in that they build on prior work by researchers like Archer and Roberts).

Establishing a research agenda in relation to technology for design might well have been regarded as the primary objective of these studies, but establishing a designerly research approach to pursuing such an agenda was only a little less important. In his paper 'Designerly ways of knowing' (*Design Studies,* 1982), Nigel Cross concluded as follows:

> We need a 'research programme', in the sense in which Lakatos has described the research programmes of science. At its core is a 'touch-stone theory' or idea - in our case the view that 'there are designerly ways of knowing'. Around this core is built a 'defensive' network of related theories, ideas and knowledge .... (p.226)

The concept of a designerly way of knowing appears to be central to the debate about designing as a distinctive activity. Similarly, a designerly way of researching must be developed. Scholars work within the humanities research tradition; scientific research is pursued within the science tradition; design researchers must establish their tradition and not seek to survive on the fringes of the sciences and the arts.

This research has been carried out through a designerly mode of action research as advocated by Archer (1992). Collaboration is a key aspect of action research and vital in assuring that the researcher's judgements are constantly under review; by colleagues during the process of developing teaching and learning strategies and resources; through student feedback; by publishers and reviewers and, particularly, by referees when related academic papers are submited. There are inevitable ethical issues associated with any curriculum development and the collaboration, which is inherent in the designerly mode of action research which has been pursued, ensures that the researcher's positions are constantly challenged. This process of constant critical review is a strong argument for the desirability of teachers engaging in action research, and, where the award of a research degree is being pursued, for the appropriateness of the 'published papers' route in its pursuit. This submission is part of the process of being held to account for the work conducted in the last sixteen years. Once taught, curricula cannot be 'taken back'; books, teaching resources and published papers cannot be 'unprinted'. They will have had their effects, which can be judged against appropriate criteria. There would be an expectation of personal progress during such a study, and this may be evident in comparing the earlier and later papers included here. However, to rewrite them would destroy the essential validity of both the process and the historical record. They are what they were: key building blocks in the development of my understanding of technology for design and the associated pedagogical issues.

Recommendations for future work

- There is a need to research the manner in which the defined and ill-defined aspects of design problems are controlled within existing Design and Technology pedagogical practice. This would facilitate the identification of aspects of progression in relation to technology for design.

- There is a need to document and analyse good pedagogical practice in relation to technology for design.

- There is a need to investigate the dynamics of the use of technological knowledge and information by designers. It is by no means clear how quantitative and qualitative knowledge, skills and values are brought together in design decision making. 'Synthesis' is an easy shorthand for an extremely complex cognitive modelling process. There have been suggestions that technological awareness and/or capability can inhibit creativity and this could only be explored through the detailed investigation of this cognitive modelling activity. Owain Pedgley's PhD study (1999) has made a start in this area.

- It can be speculated that different forms of knowledge are represented in the mind in a form which facilitates their synthesis. For example, representing the principles of mechanics in visual form and using an organised schemata for manufacturing processes. The significance of the form in which technology for design is presented to designers needs research.

- There is a need to research the significance of tacit knowledge of technology for designers. Some authors have argued that tacit knowledge is less inhibiting (than procedural knowledge) in the performance of a skill, but this is by no means self-evident. Simple arguments for this idea rest on the notion that if the performer of a skill focuses on a particular aspect then the overall performance is undermined (e.g. they fall off the bicycle, lose control of the ball or lack fluency in their designing). However it is also suggested that focusing on detailed aspects of technique can result in improved performance (e.g. a determined effort to control a racquet angle, body position or voice modulation) particularly when all other aspects of the performance are under unconscious control. Research in this area probably most properly belongs to the field of experimental psychology.

- There is a major research agenda to be developed and pursued concerning technological information and knowledge based (expert) systems for designers, given that a deeper understanding of the cognitive modelling processes associated with design synthesis and the role of tacit knowledge in designing have been established.

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2. Published papers

2.1 Research agenda

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2.4 Pedagogical issues concerning technology for design in relation to industrial design and technology undergraduates

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2.5 Information and designing: flexible learning and the use of information technology (IT) by industrial design and technology undergraduates

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Norman, Eddie, 'The Teaching and Learning of Technology for Design', *Proceedings of the Design and Technology International Millennium Conference*, 2000, pp.128-134, ISBN 1 898788 48 0

3. Appendices

Appendix 1

Reviews of published resources (*Advanced Design and Technology* (1990 and 1995 and the resource pack for KS3 Design and Technology, *Kites: Flexible Structures*).

Appendix 2

Norman, Eddie and Wormald, Paul, 'The Technological Knowledge Base for Industrial Design - Mechanics within Foundation Technology', *Department of Design and Technology Research Seminar Paper*, December 1996

Appendix 3

Hodgson, A R and Norman, E W L, 'The use of diagnostic testing and a flexible learning pack to replace lectures and practicals in the use of energy', in Course design for resource based learning: Art&Design, Wilks M and Gibbs G (eds), The Oxford Centre for Staff Development, Oxford, 1994, pp.45-50.

Appendix 2

The following paper was essentially written by Eddie Norman, but with valuable contributions throughout its preparation and the later part of the research from Paul Wormald (Y1 Design Practice Module Leader for the Industrial Design and Technology programmes.)

- Norman, Eddie and Wormald, Paul, 'The technological knowledge base for industrial design - mechanics within foundation technology', *Department of Design and Technology Research Seminar Paper*, December 1996

(It was completed and edited slightly when adding the figures subsequent to the seminar.)

The technological knowledge base for industrial design - mechanics within foundation technology

Department of Design and Technology Research Seminar Paper, December 1996
Eddie Norman and Paul Wormald

This paper discusses a case study relating to one area of the technological knowledge base of design - engineering mechanics. (This is referred to simply as mechanics throughout this paper.) This area is particularly revealing in that it lies at the 'frontier' of those technological areas which are commonly accepted as essential to the education of industrial designers. The study of more central areas, like materials and processes, human factors, computing and manufacturing, do not demonstrate the nature of the boundary in the same way, because it is more difficult to identify knowledge and information which goes beyond the industrial designer's requirements. The paper begins by exploring the general technological content of industrial design degrees by reference to the Myerson report (1991) and moves towards a discussion of a specific module - Foundation Technology (Mechanics) - which is part of the Industrial Design and Technology degree at Loughborough University. The structure of the paper is shown below;

- the technological content of industrial design degrees;
- the nature of the issues;
- mechanics within the Industrial Design and Technology degree;
- the content of the Foundation Technology (Mechanics) module;
- analysing the students' performance;
- discussion of current practice.

Loughborough's Industrial Design and Technology is not a conventional industrial design degree and the distinctions between it and others are made clear. However, it is because this degree has been established for over a decade that the staff are able to make a useful contribution to the discussion of the boundaries of technological knowledge required in the industrial design area.

The technological content of industrial design degrees

Myerson conducted a survey of higher education, employers and relevant literature concerning technological change and industrial design education in 1991. The core areas of technology to be studied by industrial design students were recommended as materials, processes, human factors, computing, workshop practice and manufacturing. In the survey four other areas were identified as then being taught (somewhere, but presumably only necessarily at 1 of the 25 institutions visited). These were information management, engineering science, mechanical engineering and electrical/electronic engineering. Table 1 shows the topics identified in these 10 different areas. Course leaders seemed to be uncertain about these later four areas. They were being taught (presumably) because someone felt that industrial design

Table 1 Range of technological content found on product and industrial design courses in the UK (Myerson, 1991, p27)

1. **MATERIALS**
Classes
Properties
Structure
Strength, testing and failure
Selection

2. **PROCESSES**
Metals processing
- methods, applications and design constraints
Polymer processing
- methods, applications and design constraints
Other processes
Finishing processes
Joining, fastening and fabrication

3. **HUMAN FACTORS**
Aesthetics
Anthropometry
Anatomy, physiology and psychology
Ergonomics
Man/machine systems

4. **COMPUTING**
Organisation and presentation tool
2D draughting
3D modelling and design
Engineering analysis of software model
Computer-aided design and manufacture (CAD/CAM)

5. **WORKSHOP PRACTICE**
Safety
Hand and power tool operation
Joining and forming
Model-making
NC machining
Engineering drawing

6. **MANUFACTURING**
Systems aspects of design for manufacturing
Techniques used in design for manufacturing
Planning
Costing

7. **INFORMATION MANAGEMENT**
Libraries and sources
Product data: location and usage
Standards
Databases

8. **ENGINEERING SCIENCE**
Forces
Stress and strain
Energy and power
Control
Thermodynamics and fluid dynamics

9. **MECHANICAL ENGINEERING**
Structures, sections and loading
Friction, fatigue, creep
Mechanisms
Pneumatics and hydraulics

10. **ELECTRICAL/ELECTRONIC ENGINEERING**
Components and identification
Terminology and definitions
AC, DC and simple circuits
Electromagnetic induction and electric motors
Digital electronics and microprocessors
Transducers, signals and signal processing

students needed to know something about them - typically through service teaching from an engineering department - but the course leaders were not reported as being convinced of the relevance of this teaching. No significant statements were included concerning these areas in the recommendations, but those that were made are reproduced later in this paper. It would appear that there is a belief that industrial design students should know something about these topics, but there is no clear understanding of exactly what this should be.

In classifying the industrial design courses surveyed as 'Low Tech', 'Mini Tech', 'Midi Tech' and 'High Tech' attention was paid to the level of competence required in these 10 areas. This was defined in terms of mastery, proficiency, familiarity and awareness. Even for the 'High Tech' courses it was only familiarity which was required in mechanical engineering, engineering science and electrical/electronic engineering. Familiarity was defined as:

> '- a knowledge of a subject, its capabilities and limitations, the ability to understand the language and communicate with specialists in the field;'
> (Myerson, 1991, p.34)

It is also important to note the findings of the report in relation to service teaching. These will be referred to later in the paper, but are quoted here in establishing the context for this study.

> 'There is strong evidence to suggest that the best results in the teaching of technological subjects by engineering and science staff are achieved when:
> - engineering specialists reorganise their material and rethink their delivery in response to a course team ' brief' to suit the particular needs of ID (industrial design) students;
> - harmonious long-term relationships are established with course teams over several years, so getting away from the damaging effects of anonymous, ad hoc, ill-defined service teaching;
> - industrial design courses are of sufficient size that engineering specialists can become full-time staff members of the course team, subscribing to its aims and sharing in its organisation and delivery. This has occurred in some cases through historical accident but is now a policy being consciously pursued by course teams: 'It is important for course tutors to instruct in technology - not make it the province of outsiders.' (ibid., p44)

The course at Loughborough was not part of the survey, but because of the many years of accumulated experience we can usefully contribute to this debate. One of the authors of this paper (Eddie Norman) was appointed in 1984 and - as an 'engineering specialist' - has had a particular interest in the technological aspects of the course. He has run the year 1 'Foundation Technology - Mechanics' module since 1985. The other author (Paul Wormald) was appointed more recently. He has a first degree in Mechanical Engineering, which was followed by an MDes at The Royal College of Art and has been in charge of year 1 Design Practice for the last few years. This article summarises current practice at Loughborough, but seeks to go beyond lists of content to discuss the thinking behind existing activities and indicate typical outcomes. It is hoped that this will be useful to colleagues engaged in industrial design education, particularly those who are engaged in debate concerning these 'fringe' areas of the technological knowledge base of design. Loughborough clearly indicates its intention to tackle these fringe areas through its degree title - Industrial Design and Technology - but there are a growing number of courses of this kind, and, no doubt, many institutions not currently involved are reflecting on their virtues. Feedback from colleagues would be very welcome.

The nature of the issues

The nature of the technological knowledge required by industrial designers is the central concern of this paper, but one way to gain insight into the unique nature of the issues is to look at comparable studies in related fields. One such study was conducted by Sparkes in 1993 concerning the nature of engineering and the physics it needs. Sparkes begins by distinguishing science and engineering and showed the essential differences in a table (Table 2). As Sparkes states when introducing this table:

> 'The principal difference between science and engineering is that, whereas science is concerned with discovering and theorising about 'what is', engineering is concerned with creating and theorising about 'what might be'....' (p.293)

Of course industrial design is also concerned with 'what might be' and the activities of industrial designers and engineers can overlap. Figure 1 shows the convergent nature of the design process (Cross, 1983).

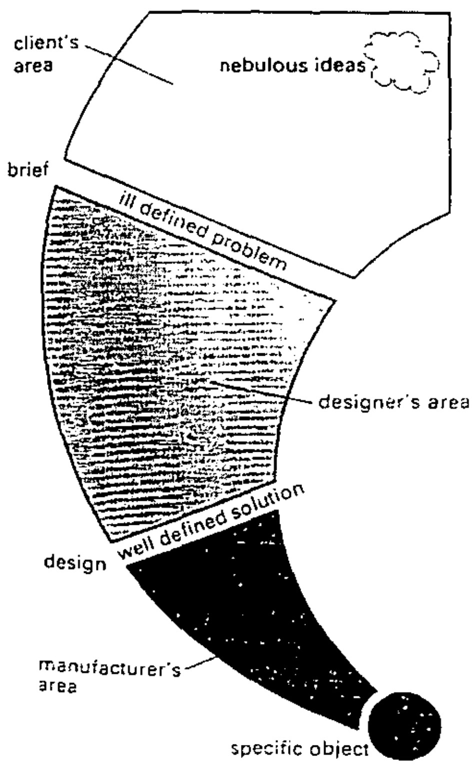

Fig.1 the convergent nature of the design process

Design activity begins in the area of 'ill-defined problems' and the convergence occurs through the process of synthesis. These early stages of the design activity are the recognised province of the industrial designer. If mechanics is going to be useful in these early stages it must provide the means to model ill-defined concepts in such a way as to yield useful outcomes. Scientific ideas are more easily applied to the analysis of 'well-defined' rather than 'ill-defined' concepts, but in the early phases of design activity that is not what is required. As the design becomes more defined, more exact forms of analysis become appropriate and, eventually, this becomes the recognised province of the engineer.

At some stage in this progression industrial designers could be seen as moving into the traditional province of engineers. It is becoming ever easier to slip over this boundary as more powerful, user-friendly software becomes available for engineering analysis - often integrated with the CAD systems the industrial designers are using. Whether or not it is a good idea to do so is another matter and this needs to be kept under constant review. It may not be appropriate to go as far as existing software could allow within industrial design education courses . Not only might industrial designers be entering areas of analysis which are open to misinterpretation, but the very act of undertaking such analysis might influence the design activity.

Nevertheless, whilst acknowledging that engineering and industrial design can be distinguished the conclusions of Sparkes' study make an interesting comparison. They are presented here and used as a basis for later discussion.

Sparkes describes the different kinds of engineers as follows.

> 'Three kinds of engineers, with different kinds of capabilities, are now formally recognised by the engineering institutions, namely 'chartered engineers', 'incorporated engineers' and 'engineering technicians'. Broadly speaking, as regards the technical side of their activities, the chartered engineer can be expected to be innovative and competent *beyond* present procedures, incorporated engineers can be expected to be innovative within standard procedures, and engineering technicians can be expected to operate standard procedures. These capabilities translate, for chartered engineers, into acquiring 'transferable skills' and 'understanding' (i.e. grasping basic concepts and the capacity to apply them in new situations); for incorporated engineers they translate into learning 'know-how' (i.e. an integration of knowledge and skills through experience of engineering problem-solving in specialist areas); and for engineering technicians into acquiring specialist knowledge and skills.'
>
> (ibid., pp296-297)

It is perhaps evident already that the kind of technological knowledge required by industrial design students is not just 'know-how' as is commonly believed. They are operating within a specialist area, but the knowledge they have must be transferable to new situations if it is to be effectively applied in designing. Sparkes goes on to comment on the different teaching methods required:

Table 2 Some differences between science and engineering (Sparkes, 1993, p.294)

SCIENCE (Goal: the pursuit of knowledge and understanding for its own sake)	**ENGINEERING** (Goal: the creation of successful artefacts and systems to meet people's wants and needs.)
Key scientific processes	**Corresponding engineering processes**
Discovery (mainly by controlled experimentation)	Design, invention, production
Analysis, generalisation and the creation of hypotheses and theories	Analysis, modelling and the synthesis of designs
Reductionism, involving the isolation and definition of distinct concepts	Holism, involving the integration of many competing demands, theories, data and ideas
Making virtually value-free statements	Activities always value-laden
The search for, and theorising about, causes (e.g. electromagnetism, gravity, etc.)	The search for, and theorising about, processes (e.g. feedback, information, circuit theories)
Pursuit of accuracy in modelling	Pursuit of sufficient accuracy in modelling to achieve success
Drawing correct *conclusions* based on good theories and accurate data	Taking good *decisions* based on incomplete data and approximate models
Experimental, logical and communication skills	Design, construction, test, planning, quality assurance, problem-solving, decision-making, interpersonal and communication skills
Using predictions that turn out to be incorrect to falsify or improve the theories or data on which they were based	Trying to ensure, by subsequent action, that even poor decisions turn out to be successful

> ' ... chartered engineers need physics that emphasises the conceptual level - the basic concepts of mechanics, electricity and magnetism, thermodynamics, etc., and how to apply them, so that engineers can devise or choose appropriate models, especially for back-of-envelope calculations in the design process. Incorporated engineers need to be able to use physics to analyse and explain existing developments, whilst engineering technicians need physics only at the descriptive level. In other words the physics taught needs to be matched to the intended kinds of engineering capabilities expected of successful students.'
> (ibid., p297)

It would not be difficult to infer that industrial designers really need a knowledge of science comparable to that of chartered engineers, but it would also miss the subtlety of the issues. Industrial design students actually need a highly selective course combining aspects of know-how and fundamental concepts. An advanced knowledge of appropriate areas of science would undoubtedly include what was necessary, but also substantial knowledge that was unnecessary. This paper is about the identification of such a highly selective course for industrial design students.

The penultimate section of the paper by Sparkes goes on to begin to detail the kind of physics that (chartered) engineers need. He identifies the 'common-denominator' physics as:

> ' Essentially it is the physics that enables them to create, as far as possible, dependable and understandable physical models during the design process, or the fault diagnosis and cure process, of new artefacts. In design, the purpose of such models is to enable reliable simulations or calculations of final performance to be made before too much time has been invested in construction and production. ...' (ibid., p.297)

One of the functions of comparable models for industrial designers is to enable simulations or calculations of final performance to be made before too much time has been invested in designing. 'Blind alleys' are to be avoided whenever possible, particularly with the increasing commercial pressure to reduce the lead times on product design. Sparkes notes that engineers do not need to know all that is known by physicists:

> '... Only the basic physical principles and concepts that underpin the hardware aspects of engineering need to be taught. ... More modern physics need only be taught at the descriptive level...' (ibid., p297)

He also observes that the physics taught should be presented through a series of progressive models and that 'the range of validity of simple models must be clearly stated' (ibid, p297). Most importantly he states:

> ' In order to maintain motivation, it is best to relate physics concepts to engineering creations that depend on them, rather than to physics experiments and bench-top demonstrations... In general, developing understanding, modelling skills and the application of fundamental concepts through design projects is much more important for engineers than learning 'experimental methods' or simulating the 'discovery' process.' (ibid, p298)

This is certainly no less true for industrial designers. And, finally, echoing the comments included earlier from industrial design course leaders and service teaching:

> 'Where possible physics must be matched to course aims... *Describing* physical phenomena may be all that is needed for environmental engineering.
> This is quite different from *analysing* phenomena in physical terms. *Modelling* phenomena and artefacts and systems so that students can design more effectively is different again... These different learning outcomes require different teaching methods ...' (ibid., p298)

Mechanics within the Industrial Design and Technology degree

The objectives of the 'Foundation Technology - Mechanics' module go beyond the idea of 'familiarity' as defined by Myerson and are closer to his concept of 'proficiency'. This he defines as

> '- more detailed knowledge of principles and practices; the ability to liaise effectively with relevant specialists and complete tasks under supervision'
> (ibid., p34)

The degree in Industrial Design and Technology at Loughborough University is therefore more technologically demanding than most industrial design degrees - seeking to give its graduates capability as well as awareness. Nevertheless, the knowledge and skills taught have been identified from the kind of products the students design (Norman, 1987 and 1988) and hence are inherently supportive of design practice. It has also been refined through continuous feedback from students. An initial draft of the lecture notes concerning 'Mechanics for Design and Technology' was produced in the summer of 1985 and the performance of the students during the following year was carefully monitored. This draft was Eddie Norman's first conception of the mechanics which industrial design students needed to know. Just as in any other initial model it had its strengths and weaknesses, but essentially it did not concentrate strongly enough on fundamental principles and was not adequately product-centred. (Even in its first year only about 80% of this initial draft was actually taught.) Teaching and learning are most effective when their context is, at least, derived from, if not embedded in, a design scenario or product design exercise. Fundamental scientific principles are actually amongst the most relevant concepts that a designer can exploit (to answer questions like 'Could this concept ever work?' or ' Is this approach feasible?'), but students are unlikely to learn them unless they are motivated. This requires direct and immediate relevance to their design activities. Making this possible whilst accommodating all the other constraints (e.g. course deadlines, workshop availability etc.) on a degree course is by no means straightforward.

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 and it is from within these product categories that the relevant aspects of mechanics have been identified. Consider, for example, the design briefs which were set in 1995 for the year 1 Design Practice module - 'mechanical products' project. Four briefs were set;

- *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.

- *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.

- *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.

- *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.

Figures 2-5 show photographs of student designs produced in relation to these briefs.

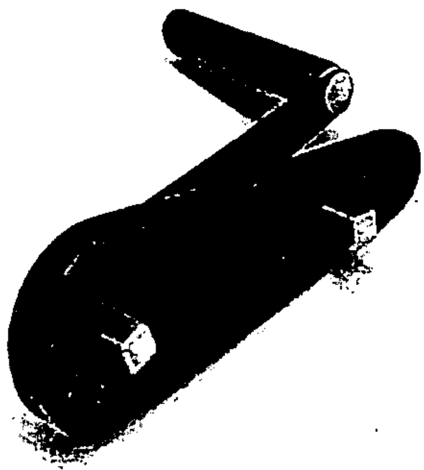

Fig.2 Wheel nut remover

Fig.3 Shopping trolley

Fig.4 Garden hammock

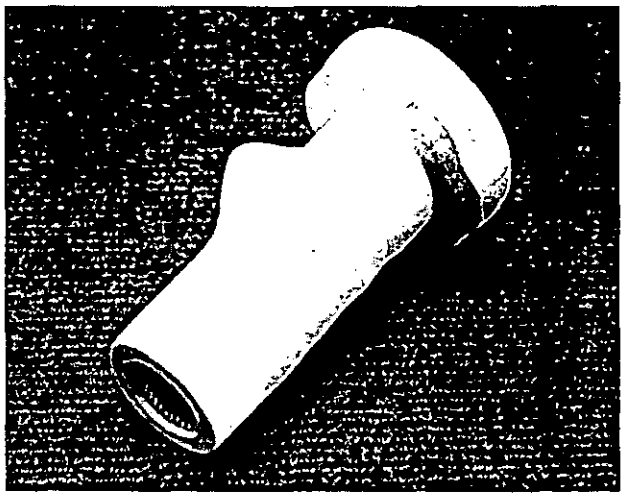

Fig.5 Chopping and grating

Many other briefs have been set over the years e.g. a can-crusher, juice extractor, baby food processor, high chair/low chair, folding stairgate, emergency escape system, plastic granulator, coffee grinder, slab shifter, cork extractor .... , but the four set in 1995 illustrate the key issues. Debrief tutorials were held with the students once their projects had been assessed and feedback had been given by the Design Practice tutors. The tutorials were held in groups of four and began with a discussion of the issues related to mechanics that the students might have addressed. Lists of possible issues were provided as indicated in Table 3.

Of course the tutorials began by consider whether or not these are reasonable questions for industrial design and technology students to be trying to answer. The following discussion is not an attempt at a full transcript, but a presentation of the sharper areas of debate. Consider first the wheel nut remover. Estimating the required size of the teeth seems 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? How can industrial designers deal adequately with human factors without considering these issues? (and industrial designers are expected to deal with human factors at an expert level). Finding the centre of gravity is the crucial step in assessing how the weight of the product would feel - the force on the wrist. Again this is vital in judging the quality of the design of such a tool. Are any of these issues really beyond the province of the industrial designer?

It is undoubtedly the way in which these technical issues are intertwined within the domain of the industrial designer that has led to the course leaders' belief (as reported by Myerson) that industrial design students need some knowledge of mechanics, but they are quite properly reluctant to suggest venturing too far into these difficult areas. The recommendations in the report by Myerson include the following statements relating to mechanics;

> 'Additionally, course teams should pay attention to the following aspects of course content:
>
> - courses should endeavour to develop in students an ability to calculate order-of-magnitude estimates about, for example, load-bearing capacity of structures or strength of materials;
>
> ...
>
> - students should gain experience in the testing and evaluation of the technical performance of designs, including test rigs and working prototypes where appropriate; ....' (op cit., p.65)

The Foundation Technology module relates closely to the first of these statements. The second of the statements relates to a number of modules which build on the year 1 mechanics module in the second and third years. Students may choose between a BSc route - which requires them to take options in mechanics and electronics - and a BA route - which requires them to take product analysis options. (They can also opt for a combination, but this group is in the minority.) The BSc students look more closely at technological issues, but all the students become engaged in the analysis of

Table 3 Possible mechanics issues related to design briefs

Wheel nut remover

- measure required torque;
- estimate 5%le 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.

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.

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 weight;
- consider portability, assembly ....;
- consider joint design/stresses;
- consider hammock material;
- consider 'entry/exit' stability/forces.

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 weight;
- 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 ......)

the technical performance of designs. This is represented by the work of a number of colleagues and is beyond the scope of this article. Foundation Technology concerns the teaching and learning of the fundamental principles and techniques, which is followed by a first attempt at applying some of these in a design practice project. As the first year is a progress year (the marks do not directly count for the degree assessment), the whole of this experience is comparatively 'risk free'. This is particularly important for students who enter the degree course from an arts background.

The other briefs expose these same issues, but they also demonstrate other difficulties associated with the grey area at the boundary between industrial design and technology. Consider, for example, the shopping trolley with an integral seat. Stability - as represented by the angle at which a product topples - is normally quite comfortably accepted as an issue for industrial designers, but even this requires the estimation of the position of the centre of gravity. However, if someone is resting on the shopping trolley they can play an active role in sustaining stability. The mechanics associated with this situation is much more difficult. Again, the consideration of manipulating the trolley requires an estimation of the weight and therefore (initially) the member sizes. But what about wind loads? Surely these are irrelevant? Well, the drag factor for a 'square form' could be around 1.0-1.2, and for a streamlined object around 0.3-0.4. So a streamlined form could be three-four times easier to push against air resistance than a squared one. Industrial designers have designed streamlined objects for less obvious reasons! Even though wind speeds (and therefore wind loads) on a shopping trolley are likely to be low it is technically a much better case than for a stapler (although, of course, the reasons for streamlining such objects are not actually technical at all). Not all the students were convinced by these arguments, but it was generally (and interestingly) considered to be more important than the stresses at the joints, which might be considered a traditional target for mechanics teaching in this design area. This was, presumably, because the wind loads influence the whole form, whereas the joint design is a matter of detail - admittedly very important detail.

The garden hammock is probably the most technically demanding of them all. Modelling stability with a moving load, and hence a moving centre of gravity is very difficult mathematically. The students were advised to use physical 3-D scale models, and at least one student took this advice as can be seen in Fig.6. It was suggested that the cable angle was estimated from these models using string once a suitable configuration had been decided on. However, establishing a suitable configuration was extremely problematic for the students, because any free-standing hammock is going to be prone to overturning. With current trends relating to product liability such issues are becoming of ever greater concern to designers. Even when the decision about the overall dimensions had been made the problems for the students were by no means over. Estimating the bending moment made the students quickly realise

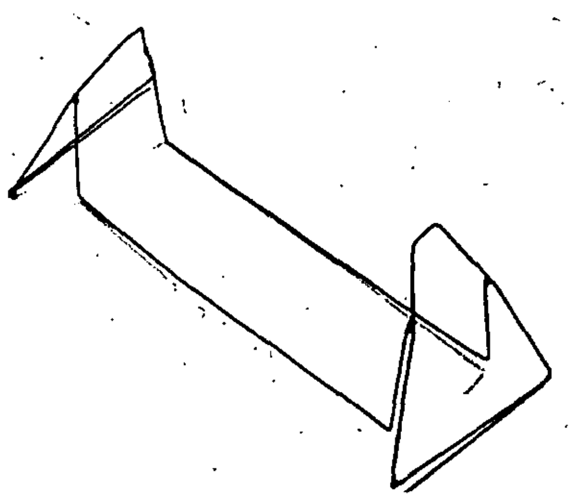

Fig 6 A scale model of a garden hammock design

that they were either going to have to use heavy sections or they needed to consider technology similar to that used in the manufacture of modern bicycles - highly alloyed steels, double-butted tubes, composites etc. Portability and easy assembly would otherwise be compromised (although stability might be much improved!) The next two questions - joint design and the hammock material were again dismissed as details and working out what happens as a person gets into or out of the hammock as much too complex.

The performance of the students in relation to these design briefs is discussed in detail later in this article, but Figs 7-12 show design sheets taken from the folders of students. Some students were only able to identify issues, whereas others were able to follow-up this stage with effective modelling. Many similar examples could have been given. The analysis, which follows the description of the detailed content of the Foundation Technology (Mechanics) module, focuses on the extent to which such differences in 'mechanics' performance are reflected in design practice outcomes.

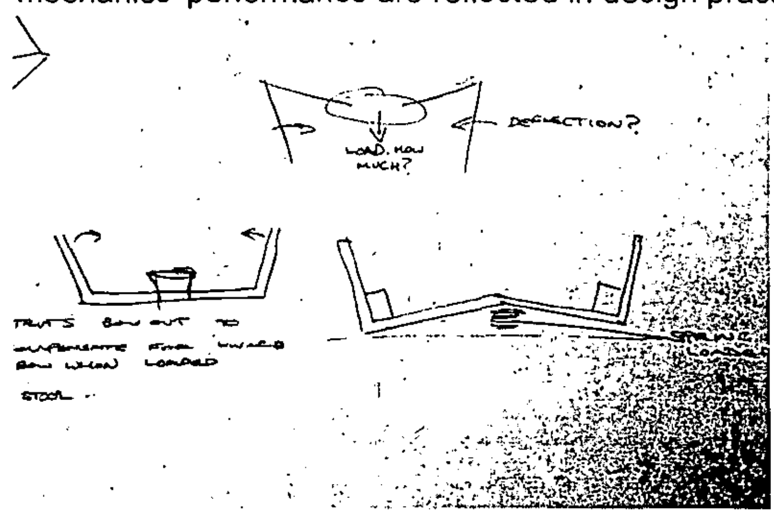

Fig. 7 Evidence of a weaker approach to modelling – only identifying the issues

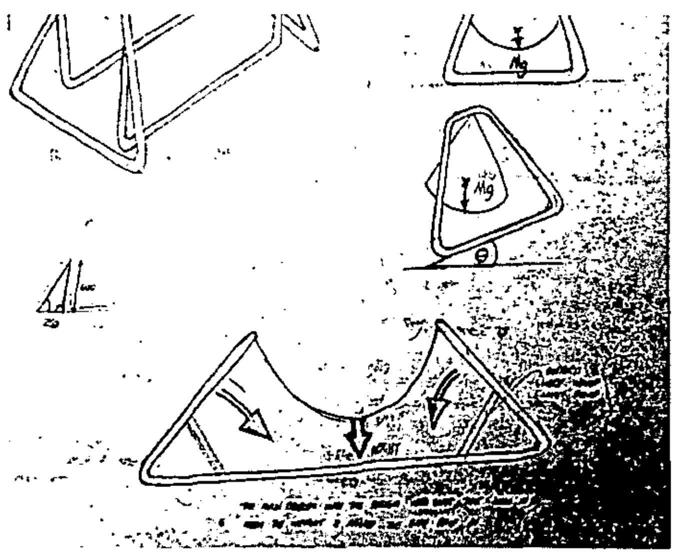

Fig.8 Identification of the issues, followed up by ...

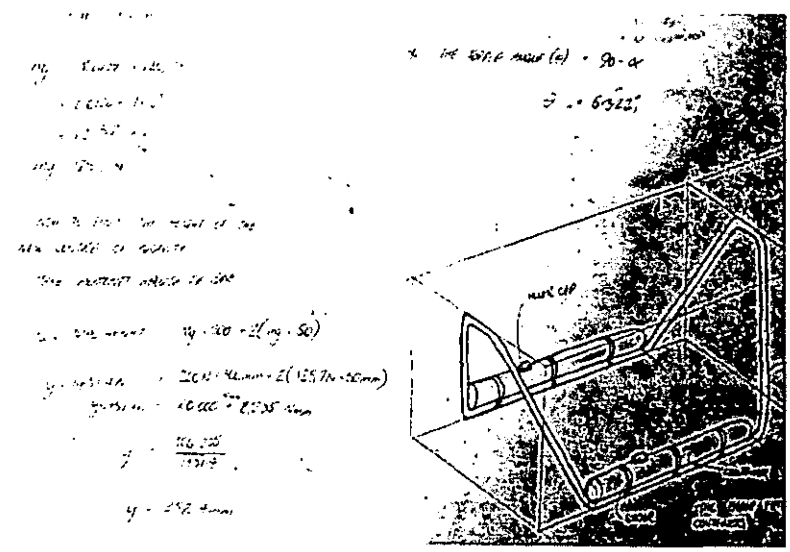

Fig.9 Effective mathematical modelling

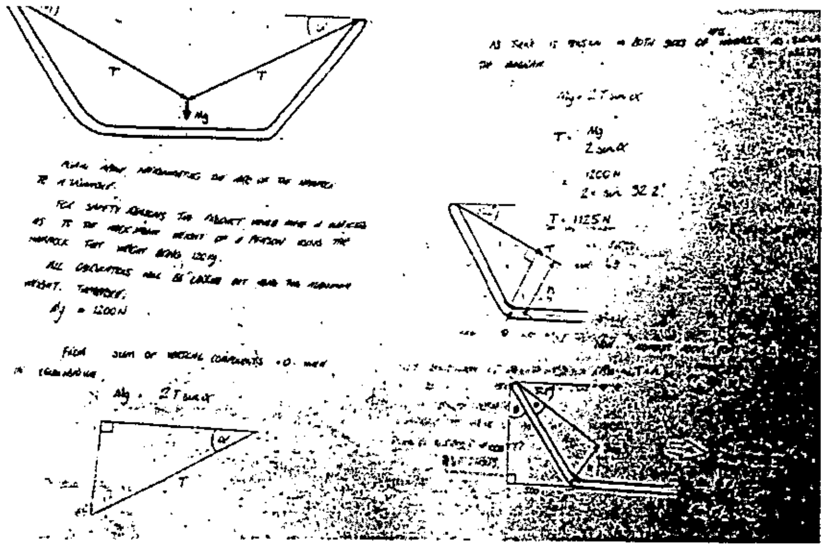

Fig.10 Effective mathematical modelling

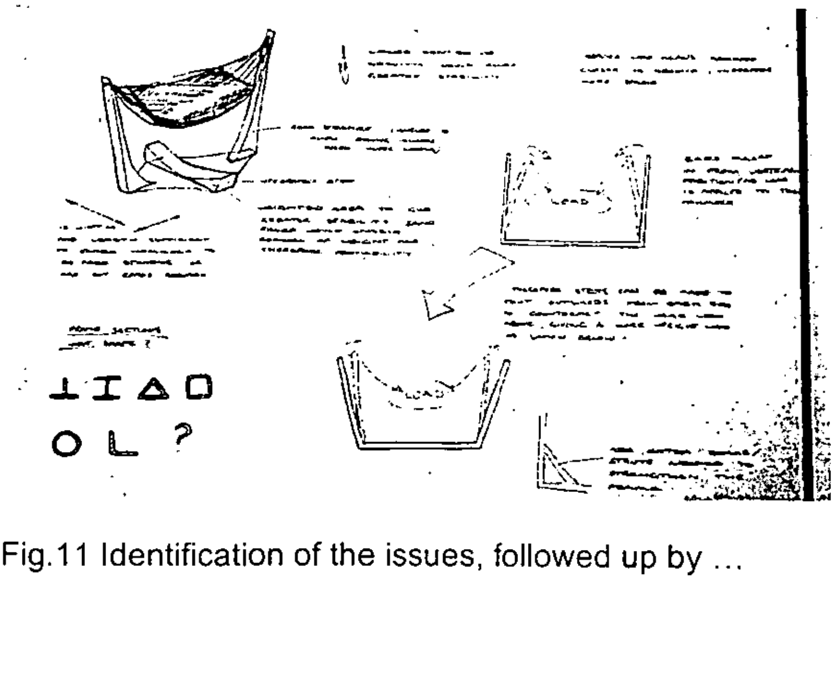

Fig.11 Identification of the issues, followed up by ...

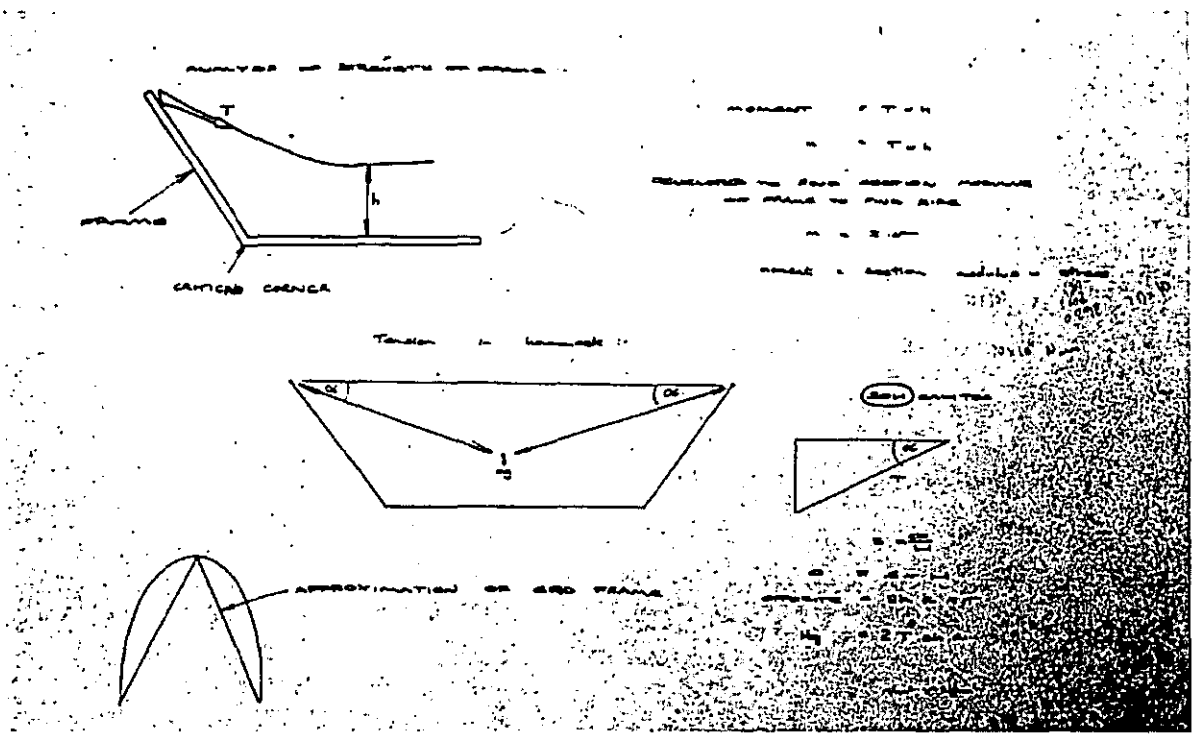

Fig.12 Effective mathematical modelling

The content of the Foundation Technology (Mechanics) module

Table 4 describes the content of the Foundation Technology (Mechanics) module. A logical progression from statics to dynamics can be observed, but it is also important to emphasise that this knowledge and information is presented within design contexts. It is only possible here to give a flavour of what this means, but consider the first practical exercise concerning the modelling of the forces acting on a barrow and finding centres of gravity. The students are shown a graphical method for finding the force which a person must exert as the barrow rotates (based on the principle of concurrency and the triangle of forces.) This is compared with a simple mathematical model (based on taking moments), which only gives sensible results in the initial positions. The students are asked to consider what level of accuracy would be required in an imagined barrow design scenario, and, hence, whether it is worthwhile increasing the sophistication of the mathematical model to cope with greater angles of rotation (this requires some awkward trigonometry.) A similar approach is taken to finding centres of gravity. Two different methods are considered - card and mathematical modelling - and their applicability to different products considered. How accurately can the centre of gravity of a loaded barrow be known anyway when the type and size of the load are not uniquely defined? The virtues of computer modelling (through CAD systems) is discussed here, but not pursued. The students are thus immediately exposed to the concept of sufficient accuracy for a particular modelling purpose, which is a significant culture shock for some 'science-trained' students. Much of their earlier education seems to have concerned the highest level of accuracy which is achievable, whatever the purpose or requirement.

Some other points about this programme are worth noting. Weeks 5 and 8 in the

Autumn and Spring terms were Design Practice 'priority weeks'. This helped to reinforce the supporting nature of modules concerning knowledge, skills and values, which were suspended where possible during these weeks. The priority given to enabling students to make order-of-magnitude estimates prior to the Design Practice 'mechanical product' project at the end of the Spring term is also evident. This required considerable effort in teaching and learning, because it requires the development of both theoretical understanding, in order to establish acceptable models, and analytical capability. This capability is developed through practical investigations, the teaching of graphical methods and instruction in the use of software. Significantly less time was spent on the understanding of mechanisms and machines - not least because students find these easier to grasp.

It is also worth noting how the time for tutorials was found in the Summer term. Whilst the tutorials were happening the other students were working on flexible learning materials (developed with the support of British Gas). The development of these materials has been reported elsewhere (Cubitt, 1994). Apart from gaining staff time for tutorials the flexible learning approach makes it easier to cope with the diverse student background concerning the knowledge of energy. Students may have come across this topic in a variety of syllabuses e.g. GCSE, AS- and A-level sciences, geography, design and technology etc. Consequently, students' prior knowledge varies from having covered none to all of the energy topics included in Foundation Technology (Mechanics). Formal lectures are particularly ineffective in these circumstances.

The project debrief tutorials provided an opportunity to both review student progress in mechanics and in applying mechanics in their Design Practice projects. The students were asked to bring a completed self-assessment form to the group tutorial. The content of this form is shown in Table 5. The responses to these questions are discussed in the next section. Following the discussion of what the students might have done they were asked to undertake another form of self-assessment as shown in Table 6. This is again discussed in the next section.

Table 4 *Detailed content of the Foundation Technology (Mechanics) module 1994/95*

Autumn term

Week	*Lecture*	*Practical class*
1	Introduction to mechanics in product design	-
2	Course overview. Addition of forces and the principle concurrency. Graphical and mathematical modelling of the barrow	Class 1 Modelling of the forces acting on a barrow - finding centres of gravity
3	Centre of gravity, stability and toppling	"
(Assignment 1	*Modelling the forces acting on a barrow – the concept of sufficient accuracy)*	
4	Equilibrium and the modelling of the toggle mechanism.	Class 2 Modelling frameworks - graphical and computer modelling
5	-	-
6	Forces in plane frames. Designing ties and shear pins.	"
(Assignment 2	*Stability of a lounge storage system)*	
7	Shearing forces and bending moments	Class 3 Beams - computer analysis and practical deflection investigation
8	-	-
9	Section properties. Determination of appropriate sections for beams and struts using deflection formulae.	"
10	Progress test	Assignment 2 feedback

Spring term

1	Spring term overview. Progress test feedback	Calculations tutorial and the use of the SECTIONS program.
2	Beam design for stiffness and strength. Joint design.	Class 1 Modelling mechanisms using GENUS - practical and computer analysis of sections
3	Modelling motion. Velocity and acceleration diagrams	"
4	Equations of linear motion	Class 2 Friction - the analysis of the mastic gun. Velocity and acceleration diagrams
(Assignment 3	*Structural analysis of a lounge storage unit)*	
5	-	-
6	Newton's second law - the concepts of force, energy and work.	"
7	Theory of simple machines	Class 3 Design practice project consultancy
(Assignment 4	*Design of a wear testing machine)*	
8	-	-
9	Rotating systems - the concept of torque	"
10	Simple, compound and epicyclic gears	Progress test

Summer term

1	Mechanics design practice project debrief	Class 1 Introduction to flexible learning unit on energy - energy and its conversion - and group mechanics project tutorials
2	Rotary equations of motion	"
3	Moments of inertia - energy storage	Class 2 Group progress tutorials - energy sources
4	Examination briefing based on 1993 and 1994 papers	

Table 5 Self-assessment form used for the mechanics project debrief tutorials

H775 Mechanics

Summer term - tutorial 1 *Name:*

Please bring to the tutorial *For the discussion of the mechanics design practice project;*
- this sheet completed
- your mechanics project from design practice.

For discussion of the flexible learning package;
- glossary sheet 1 complete
- your study planning sheets for the energy unit completed (after having done the diagnostic test)

Mechanics design practice project

I chose the brief concerning the shopping trolley/wheel nut remover/ hammock/kitchen device because ....

I found the integration of mechanics theory into design practice ......

I feel I could have done better at integrating the mechanics theory into design practice if ....

This project was a valuable/unhelpful learning experience because ....

Table 6 Student self-assessment of their performance in the Design Practice 'mechanical product' project

Conceptual design

No apparent integration of mechanics theory in the practice project	. . . .	Apparently full integration of mechanics theory in design the conceptual design

Modelling

Nothing has been done to demonstrate that the product will function	. . . .	Appropriate and sufficient modelling has been carried out

Analysing the students' performance

It is the interrelationship of three key variables that we would like to understand:

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

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. Paul Wormald and his colleagues assessed the students in Design Practice, in which Eddie Norman had no direct involvement. Eddie Norman assessed the students in Foundation Technology - Mechanics, and Paul Wormald had no direct involvement. The most difficult variable was the students' capability to apply mechanics in design practice. Two different methods were used in successive years:

- in 1993/94, Eddie Norman examined the project outcomes - the models and design folders;
- in 1994/95, the primary method used was the students' self-assessment as shown in the previous section, but this was cross-checked by a staff examination of 10 randomly chosen folders before their return (by Eddie Norman and Paul Wormald).

Forty-six students were involved in the Design Practice 'mechanical product' project in 1993/94 and fifty-seven in 1994/95.

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. Of course the students knew that the staff hoped they would apply their newly acquired knowledge, skills and values but there was no insistence. It was left to the students to do what they perceived to be most advantageous.

1993/94

The measures used were:

- the students' total mechanics marks prior to the beginning of the Design Practice project (coursework and tests) and at the end of year;
- the students' total design practice marks prior to the beginning of the Design Practice project, their mark on the 'mechanical products' project and their total mark at the end of the year;
- ratings of the use made of mechanics theory as shown in Table 6, but by Eddie Norman.

The background of the students in relation to mathematics and physics A- and AS-levels and other technical pre-course studies (e.g. BTEC, engineering foundation studies, transfers from engineering courses etc.) were also noted.

General findings

Few students without any strong prior knowledge of mechanics made any attempt to incorporate it into their project work. In the attempts made, they were generally successful where the briefs related to machine or mechanism design, but unsuccessful for the brief related to a free-standing structure. 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 twenty 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 ten Design Practice students prior to this project lost an average of about 5 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 twenty-one 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 free-standing structure brief - the shopping trollley .

- There were only three students outside the top twenty-one who showed any evidence of attempting to integrate mechanics theory in their design practice. One was an overseas student, one had obtained a 'B' in A-level physics and the other had taken a one-year engineering foundation course.

- The average ranking of these top twenty-one mechanics students in Design Practice did not change, but there were significant individual movements both up and down.

- The average ranking of the top ten 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 clear that unless the students knew the mechanics theory before the project started they were not going to attempt to apply it. The end of year mechanics rankings did vary a little, but not enough to infer a motivating effect from the project (as we might have hoped).

Student reactions

Clearly the most obvious measure of the students' reactions was the information in the student questionnaires. This was used to shed light on the issues raised by these measures of student performance. However, there were also other measures, including the choice of brief. Two of the briefs used in 1993/94 were the same as those used in 1994/95 - the wheel nut remover and the shopping trolley. These two were discussed earlier, and the other two - the orange squeezer and plastics granulator - are given below.

- *Battery-powered orange squeezer* Breakfast orange juice from cartons has been criticised for being too processed, losing its natural goodness. The brief asks for the design of a device for extracting the juice from oranges, which is to be used at the breakfast table. The device should be powered, but cannot use a mains supply.

- *Hand-powered plastics granulator* Rigid plastics are used extensively in food packaging (e.g., the PET bottle). The brief is to design a device which can help in the recycling of such plastics. The device should accept most plastic waste products and reduce them to smaller pieces which can be transported and recycled more effectively. The device is to be totally hand powered. It should be capable of being used safely in most homes.

Choice of brief

Eight students chose the shopping trolley brief, three chose the plastic granulator, seven chose the orange squeezer and twenty-six chose the wheel nut remover (two were not-recorded). There were eight women students and five of these chose the shopping trolley. A variety of reasons were given, but perhaps the most revealing was that of the top mechanics student tackling this brief (a woman) .... 'It seemed to involve just simple beam and stress calculations.' It was initially perceived as easier. The plastic granulator brief was chosen only by students who were good at mechanics. As one of the students put it, 'The brief was appealing - it was an idea which to my knowledge had not been produced - and yet was also a realistic and possible future household item. The mechanics were unlikely to be too complex, once finding experimentally the required/possible forces'. The other comments were similar - these students could see right through the mechanics required and realised it was straightforward. Five of the seven students choosing the orange squeezer were also good mechanics students and again displayed obvious confidence: ' I felt there was more potential for aesthetic consideration (for domestic situation); it was more interesting than the others as it contained more in terms of mechanical problems (as it incorporated motors and batteries etc.)'. Everyone else was doing the wheel nut remover.' But why? There seemed to be two schools of thought. Firstly, 'I had a car, therefore it related to my everyday life.' Many students clearly found getting involved with this brief straightforward, whilst others saw it as being easier - but not necessarily in a 'mechanics' sense. 'I thought it would be the most interesting choice to apply the work that we had done on epicyclic gears. The model could also be made quickly giving a good overall impression of the size, shape and colour.'

Integration of mechanics theory in design practice

This question was included to provide a comparison of Eddie Norman's external perception of the students' efforts with their own. The following is a range of responses from the enlightened to the worrying.

'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.'

There can be little doubt that although the vast majority of the students coming to Loughborough will have studied design and technology A-level - many of these including specific modules like mechanisms, energy and structures - the concept of integrating these areas is still regarded by them as radical and new. They still seem to have an 'over-the-wall' model of design activity embedded in their consciousness despite the moves towards concurrent engineering in the professional world, and integrated design and make activities in the world of education.

Doing better

Again the students' responses are best revealed by a selection of their comments. The responses ranged from those seeking improvement in their learning to those making suggestions about improved strategies for the project support.

'I feel I could have done better at integrating the mechanics theory in design practice if

... I had a wider knowledge and was able to put theory to practice with ease.

... I knew more of the mechanics theory we have already been taught and could understand how to apply it.

... I was more confident with the mechanics theory. I thought integrating them would be far more complicated than treating them separately. In retrospect I think it would have been easier.

... I had not been scared of even starting it. I spent too much time designing instead of calculating, after all the mechanics dictates the design.

... a better indication of what we should be calculating had been given.

... there had been one mechanics tutorial when we had been required to show the calculations we were planning to make and we were then told of further ones which would be useful. Also some initial tips on, not which areas to use, but on how to eliminate if they were not useful, would have been useful as a refresher.'

Of course the ultimate question is, How do industrial design and technology students learn to transfer a knowledge of fundamental scientific principles to the analysis of original designs? The latter comments are tending towards the 'ask an engineer' viewpoint, which is, of course, not wholly in keeping the aims and objectives of the Loughborough course.

<u>The value of the learning experience</u>

Two students expressed the view that it was an unhelpful learning experience. As one put it - 'It did not teach me how to set about working out how to apply theory to an original design'. All the other views expressed were positive. The following four capture their spirit ...

'The project was a valuable learning experience because ...

... it shows how much you really know, and if you can put theory into practice.

... it combined four areas of the work we cover - Design Practice, Mechanics, Graphics and Engineering Drawing, so it was nice to be given the opportunity to apply these skills.

... it improved my confidence in general. It provoked thought into the viability of designs - designs were practical as well as aesthetic.

... I learnt a new skill, although I would be interested in learning the role of the industrial designer in a design team consisting of engineers, and the responsibilities that I must fulfil in that situation.'

Of course, the final comment gets to the very heart of this debate. What is the emerging role of the industrial designer, and what knowledge, skills and values must they possess in order to be able to fulfil it?

1994/95

Whatever conclusions you draw concerning the evidence obtained in 1993/94 they are largely dependént on the judgements made by Eddie Norman concerning the students' performances in integrating mechanics theory and design practice. Consequently, the emphasis was shifted in 1994/95 to student self-assessment. Also, as a result of the students' poor performances in relation to the free-standing structure brief, group tutorials with Eddie Norman were offered at which the students could discuss the issues. Both these changes in strategy had very significant outcomes.

Student self-assessment

Figure 11 shows the results of the students' self assessments. Two potentially contradictory outcomes are evident.

- Firstly, the ten random staff assessments (done jointly by Eddie Norman and Paul Wormald) indicate that the level of prior mechanics knowledge strongly influences the ability to integrate mechanics theory in design practice (as in 1994/95).

- Secondly, the vast majority of the students all believed that they had made 'an above average' effort at integrating mechanics theory in design practice.

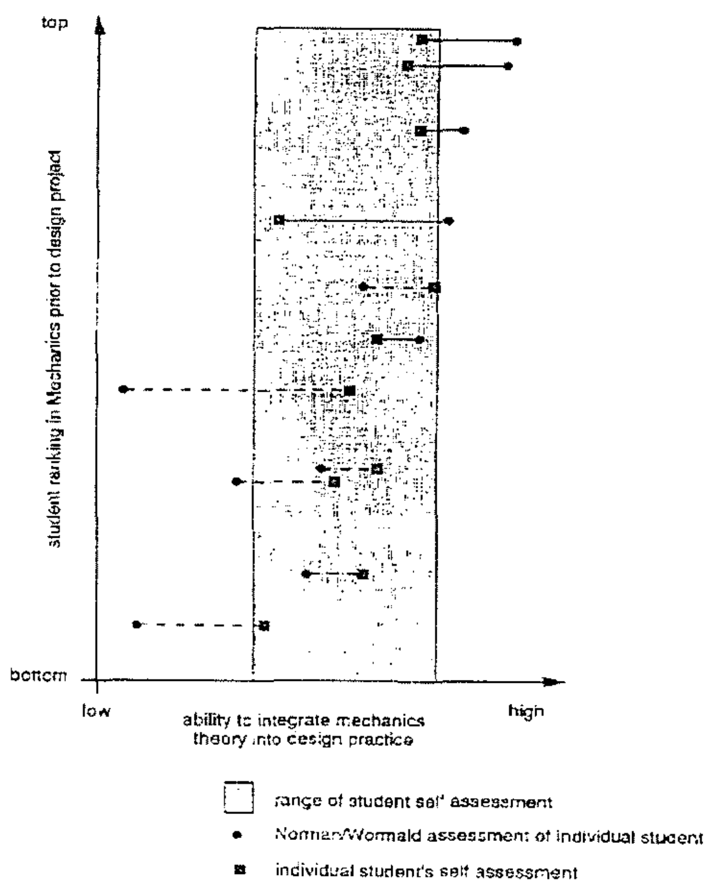

Fig.11 Diagram of Mechanics capability against integration in design practice

So, according to staff assessments, above average students under-rate their performances and below average students over-rate their performances, leading to them all being 'above average'. It is important to emphasise that the issues they might have addressed had been discussed with them at the tutorial before they made their self-assessment. Whatever else they were, they were not unaware of the issues. It is probably merely an outcome of asking students to assess themselves, but this is clearly not a very effective form of feedback.

Mechanics briefing tutorials

These initial tutorials were held as a result of feedback from the previous year group. They clearly had significant outcomes; in particular, the performances on the 'free-standing' structures briefs, which had been found to be weak in 1993/94, were indistinguishable from those on others. It was also clear that the students generally felt that they knew what they were doing. (Whether or not this is true is another matter.) One of the few students to assess their ability to integrate mechanics theory into design practice attributed this to not being able to attend this tutorial. This might also be a major boost to Eddie Norman's ego (who ran the tutorials), if it was not for the reality that the students' self-assessments were not completely reliable. These tutorials clearly produced more satisfied customers, but it is by no means evident that they resulted in increased sharpness of the learning experience and improvement in the quality of feedback.

Student performance

Table 7 shows how the 'top ten' Mechanics students performed on the Design Practice - Mechanical Products project. These outcomes are shown in terms of ranking (out of 57). It is evident that all those students with low prior Design Practice rankings improved their position, whereas those who also ranked highly in Design Practice faired worse on this project. This is the same problem of becoming obsessed or lacking proper control of the balance of their activities which was seen in 1993/94.

Table 7 The performance of the 'top ten' Mechanics students

Mechanics ranking (before the Design Practice - Mechanical Product Project)	**Design Practice ranking** (before the Design Practice - Mechanical Product Project)	**Design Practice project ranking** (on the Design Practice - Mechanical Product Project)
1	1	12
2	37	11
3	16	27
4	55	21
5	25	13
6	3	5
7	6	48
8	47	16
9	29	14
10	44	3

Table 8 shows how the 'top ten' Design Practice students performed on the Design Practice - Mechanical Product project. These outcomes are also shown in terms of ranking (out of 57).

Table 8 The performance of the 'top ten' Design Practice students

Design Practice ranking (before the Design Practice - Mechanical Product Project)	**Mechanics ranking** (before the Design Practice - Mechanical Product Project)	**Design Practice project ranking** (on the Design Practice - Mechanical Product Project)
1	1	12
2	48	6
3	6	5
4	22	8
5	41	2
6	7	48
7	36	28
8	42	26
9	21	25
10	38	33

Again these results match those expected from 1993/94. The position of the top designers is threatened, but not inevitably weakened, by a lack of prior technological knowledge.

Student responses

Only one of the fifty-seven students felt that the project had been an unhelpful learning experience, (because 'it wound me up!'). There was a much more even balance in the brief selection - twelve students chose the hammock, fourteen chose the kitchen device, nineteen chose the wheel nut remover and eleven chose the shopping trolley (This included only one woman in 1994/95, so the previous bias associated with sex was not repeated.)

The following extracts from the questionnaires have been selected to try and convey the essence of the 1994/95 student feedback. The feedback was generally constructive and there were clear indications of mature reflection on their practice in many of the student responses.

<u>Integration of mechanics theory into design practice</u>

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

... very interesting and more of a challenge than regular design practice or mechanics assignments.

... reasonably straightforward. The mechanics knowledge provided a useful foundation for the design work. It was useful to use the mechanics in a design situation.

... reasonably straightforward, a natural progression and I feel it worked well.

... quite straightforward but the calculations were quite difficult and complex.

... moderately difficult as there are no hard and fast rules to follow to judge what is required.

... not so easy (some aspects) as examples we had studied did not relate directly if I tried to make more original shapes/designs.

... difficult after I had exhausted what I thought was the relevant theory. I felt that the data obtained from the theory made me alter parts of my design, mainly the size and looks, which perhaps spoilt the original concept.

... interesting. It made me consider more of the detail which I might otherwise have neglected. It meant that the design did not only revolve around form , but function as well.

... interesting as it changed the approach I have taken to design briefs in the past.

... challenging as it is difficult to design freely once the mechanical constraints of a project are known.'

These comments show a greater maturity than the numerical assessments at the tutorials appeared to do. The students are obviously learning, but asking them to mark or rank their performance does not seem to be particularly helpful.

<u>Doing better</u>

'I feel I could have done better at integrating the mechanics theory into design practice if ...

... I had done A-level Maths and Physics, as I would have been able to get a more thorough grasp of the aspects involved.

... I had a more natural understanding of mechanics rather than having to struggle at it.

... I had spent more time outside lectures and labs doing mechanics.

... I had done further background reading and research to make sure I understood the techniques involved.

... we had more practice with using mechanics in the real world.

... I had more experience at combining knowledge in both areas.

.... tutors had kept a check on our calculations through the project.

... I had been told in more detail how to apply the relevant mechanics theory to the project. Perhaps had more contact with the mechanics teacher as the project progressed.

... I had known the amount of mechanics which was required for the project.

... if I gave more time to explore the mechanics part of the project. Mechanics theory can be daunting.

... I had concentrated more on the mechanics and kept equal balances of form, function and theory.

... I had been a bit more adventurous about the initial frame design before I started to think about the mechanics

The early comments recorded here indicate the students' own understanding that they need a thorough understanding of mechanics if they are going to apply it in project work. The idea that knowledge needs to be internalised if it is not to adversely affect design activity is well documented (e.g Cross, 1982). The requests for continued support during the project shows the lack of confidence of these students, but it is necessary to let them tackle these matters themselves if they are ever going to gain any. Such tutorial 'support' could merely inhibit the onset of independence. The later comments clearly indicate reflection on their own practice - how should they exploit a knowledge of mechanics in their design practice activities?

The value of the learning experience

The project was a valuable learning experience because .....

... it brought reality into design practice.

... it taught me that mechanics lectures were not just about unexciting calculations, and more about solving practical problems.

... it helped me realise how important mechanical principles are in getting a developing prototype to work to its best ability.

... it helped me to realise the necessity of a mechanical background and helped me incorporate mechanics into future projects.

... it made me realise that I need to learn mechanics more thoroughly.

... it forced us to consider factors which should be integral parts of every project we undertake.

The importance of this project in terms of the students' motivation to learn mechanics is evident. This integrated activity is vital to student learning and its absence is the central problem which 'service teaching' is likely to face. It is only possible for the mechanics to be taught effectively if it is integrated into the course structure. Equally, the benefits to design practice activities of such integration are also evident.

Summarising discussion

Discussion of the issues raised in this paper is on-going within the Department of Design and Technology at Loughborough and we hope that writing this paper has opened up this debate to other colleagues. The essential pedagogy adopted in the Foundation Technology (Mechanics) module is a balance of the teaching of fundamental principles in a product design context and the development of selected skills (e.g. the use of software for the analysis of beams). An understanding of fundamental principles is what is needed if new concepts are to be modelled. However, carrying out out such modelling is dependent on the development of the capability to perform the required analytical techniques. It is necessary to be able to see what is required and then be able to execute it, if the designer is to help themselves. If they are to seek help, it is being able to see what is required which is most vital, so there is a strong argument for the teaching of fundamental principles to take precedance over skill development, if such is necessary.

This article effectively supports the findings of the Myerson report quoted earlier. That is, an engineering specialist reorganised his material and rethought his delivery to suit the particular needs of Industrial Design and Technology students. A harmonious long term relationship has been established between technology and design practice staff over many years and the engineering specialist is a full-time member of the industrial design staff. The special contribution this paper seeks to make concerns the understanding of the subtlety of the details, in terms of mechanics content, strategies for teaching and learning and course management.

It is tempting to extrapolate findings beyond the particular technological area of engineering mechanics and beyond the context of Industrial Design and Technology at Loughborough, but this is both unnecessary and dangerous. General findings could only emerge from a large number of studies establishing a body of evidence relating to a variety of technological areas and design courses. Studying the knowledge required of materials processing, electronics, computing or human factors might lead to entirely different outcomes even for this degree course. The value of this, and any subsequent case studies, lies in their contribution to the development of such general understanding of the relationship between design activities and their related technological knowledge base.

In the Department of Design and Technology at Loughborough University students continue with Design Practice projects in their second and in their final year when major pieces of product design are undertaken. Students who continue to study mechanics after the first year are encouraged to have a considerable depth of mechanical design principles evident in final year project work. Many of the best graduates from the Department demonstrate high levels of capability both in technology and industrial design within their project work. This is a rare talent in new graduates and such individuals are usually highly employable. This is partly the incentive to pursue the philosophy of integrating industrial design and technology in the degree course, to produce such graduates. This process begins in the first year with Design Practice, Foundation Technology (Mechanics) and Foundation Technology (Electronics)and the integrated projects which result.

The comments from the students above are encouraging to the authors because they seem to confirm that the students agree with the underlying philosophy of the course, even if some find the reality of the teaching and learning experience particularly demanding at times! The Design Practice Mechanical Product project has been fine-tuned over the years in the light of the student feedback and the authors' reviewing the outcomes. This needs to continue, particularly to help the students with the efficient integration of mechanical design principles and industrial design practice.

Loughborough University degrees will follow a semesterised pattern in 1995/96. It will be interesting to see how such collaboration across modules (Mechanics and Design Practice) can be accommodated in the future. It is suspected that semesterisation may be something of a barrier to the type of integrated project work which appears to be so beneficial to our students. This would be a shame.

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Sparks J J *The nature of engineering and the physics it needs* Physics Education, Vol.28, No.5, September 1993.

Appendix 3

The following paper was written with equal contributions from Eddie Norman and Tony Hodgson based on the research concerning the flexible learning pack on Energy.

- Hodgson, A R and Norman, E W L, 'The use of diagnostic testing and a flexible learning pack to replace lectures and practicals in the use of energy', in Course design for resource based learning: Art&Design, Wilks M and Gibbs G (eds), The Oxford Centre for Staff Development, Oxford, 1994, pp.45-50.

4. Annexes

These are all available from Eddie Norman for inspection, analysis or examination.

1. Initial drafts of teaching materials and sample student work relating to the Foundation Technology - Mechanics module (1985-86).

2. Chapter 1 - 'Design', Chapter 2 - 'Designing', Chapter 5 - 'Materials processing' and chapter 6 - 'Material and process selection' from *Advanced Design and Technology* (Norman, Eddie, 1990 in Urry, Syd (ed)).

3. Survey report concerning the revision of *Advanced Design and Technology* by Nina Konrad, which was conducted on behalf of Addison Wesley Longman Schools Division in March 1997.

4. Flexible learning materials on *Energy* developed for the year 1 Foundation Technology module taken by Industrial Design and Technology undergraduates at Loughborough University.

5. Flexible learning materials relating to software calculation packages for the analysis of structures developed for the year 1 Foundation Technology module taken by Industrial Design and Technology undergraduates at Loughborough University.

6. Resource pack for KS3 Design and Technology *Kites: Flexible Structures*, Philip Allan Publishers Ltd., June 1999.