

Technological Capability in Design

Eddie Norman and Joyce Riley
Loughborough University

One of the cornerstones of the BA Honours degree programme for Design and Technology at Loughborough is the belief that each student should develop a personal capability to use technology. This capability, once developed, can be utilised in all the students' design projects and gives an added dimension to their creativity. A recent article by George Hicks and HMI¹ puts forward the view that:

'... as a society we depend on those with technological capability to produce goods and services for our benefit, as well as to provide a network of systems that underpin other industries. Such people also have a responsibility to maintain and develop that capability continuously and to invent processes that open up new possibilities'.

The products needed in a Western nation will span the range from table mats to supersonic aircraft. In 1977 the Design Council evolved a model of the product design spectrum which indicated the level of industrial and engineering design in each type of product.² Figure 1 shows a slightly modified representation of this product design spectrum indicating sample products in each of three regions. For the products in region C the design considerations are mainly aesthetic. Industrial designers and craftsmen

using inherited and adapted skills of craft-based design and manufacture have produced products for which technology is secondary to other considerations such as appearance, ergonomics and material suitability.

The products in region A are very different; they are highly technical and require specialist engineers and technologists for many parts of the design. Technological considerations can no longer be secondary. This inclusion of technological factors is not a new problem as is clearly illustrated by the evolution of ships from timber sailing-craft to iron steamships.

'... as Russell³ recounts, a great number of the early experiments during the 1820s with large iron ships had been disasters — ships which overturned on launching, ships calamitously under-powered, ships whose stability could be ensured only by adding extra floats or masses of cement ballast. The design of these vessels had been based on erroneous rules of thumb, and on principles supposedly drawn from traditional boat-building experience but which were as it turned out 'misknown, and misbelieved, and mistaught' ... The new naval architecture will work by science, calculation (and) 'headwork' ...'⁴

Clearly it is not possible for a single person to undertake the design of one of these highly technical products alone. Instead, a group of experts cooperating as a team will provide the best mix of engineering skills, technology and aesthetics.

The central region B in Figure 1 is comprised of comparatively small-scale products for which aesthetic factors are important but also a knowledge of the appropriate technology is necessary. Products of this nature require both technological and creative design considerations. However, because designers have specialised in either Engineering or Industrial Design, one of these factors had tended to become secondary to the other. Very often this secondary design process is severely handicapped by the limitations placed on it by the primary process and a compromise solution is then the best that can be achieved.

A recent example of the necessity for technological capability in this type of product design was highlighted in an article on the design of an adult tricycle with either shopping carriers or child seats over the rear axle.⁵ A serious accident was nearly caused by the axle being sharply stepped down in two stages from $\frac{3}{4}$ " to $\frac{1}{2}$ " as it entered the wheel bush. This produced a classic 'notch' effect with high stress concentrations. The rotation of the axle produced cyclical loading which with the 'notch' effect drastically reduced the life of the axle. The material used for the axle was EN1A leaded steel which machines well but has very low resistance to cyclical stress. A good design would have had an endurance life of about 10 million cycles with a factor of safety of 3. However, the cumulative effect of the design faults was to reduce this to 1 million cycles, or about 2 years normal use, with no safety factor to allow for road defects. Any sudden jarring would cause unusually high impact stresses which would cause early failure of the axle. Such failure at the offside wheel bush causes the rider and child passengers to be thrown out into the traffic. A simple calculation on the stresses induced in the shaft would have saved the company involved the embarrassment and cost of appearing on BBC's Checkpoint programme, and having modifications enforced by the

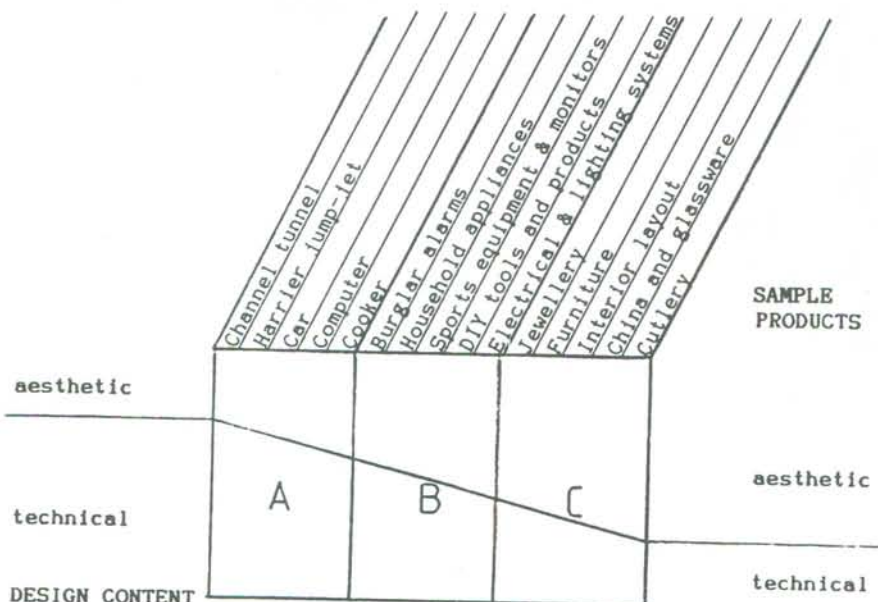


Figure 1: Product Design Spectrum

Ministry of Transport's Vehicle Safety Division.

Products such as the adult tricycle would obviously benefit by having a designer capable of integrating the scientific and artistic aspects of design. The segregation of these two cultures and the understanding from a very early age that an individual is either artistic or scientific makes this process of integration a very difficult task. An early exponent of radical change in educational methods towards integration was A.N. Whitehead.⁶ More recently the Royal Society of Arts in different statements has both echoed the criticism of an education that gives specialist knowledge but no personal capability and highlighted the problems that the cultural divide and its perpetuation present to individuals and society.⁷

Higher Education has recognised that courses can be developed which will bridge the gap between the two cultures,

combining creative flair with a technological and personal capability. The Royal College of Art's Industrial Design School, in conjunction with Imperial College, introduced a new course 'Industrial Design Engineering' in 1980.⁸ This is a two year postgraduate course leading to a Masters degree in Design. The course recruits a small number of students and is intended to provide a boost to British Industry, producing a superior science-based designer with Industrial Design skills capable of bridging the gap between Engineering Design and Industrial Design.⁹ From an initial intake of 4 students, the 'Industrial Design Engineering' course has steadily grown to a current intake of 16. This new design philosophy has also been pursued by Cranfield Institute of Technology, who together with Leicester Polytechnic now offer a Masters degree in Product Design.

At about the same time as the RCA initiative, Loughborough's Creative Design Department decided that technical capability should and could be integrated with design at undergraduate level, with similar aims and ideals to the RCA postgraduate course, and that therefore 'Design and Technology' was a more appropriate title for the department. This idea has been generally gaining ground, with an 'Industrial Design (Engineering)' course at Brunel University and more recently the 'Product Design Engineering' course being launched by the Department of Mechanical Engineering at the University of Glasgow in partnership with the Glasgow School of Art. All of these undergraduate courses are endeavouring to create a completely rounded designer with a good, solid understanding of the scientific principles and their mathematical application as well as artistic and creative sensibilities.

TABLE 1 Course Outline of Year 1 Technology Module

	MECHANICS	ELECTRONICS
TERM 1	<p><i>Statics</i> An understanding of static force systems and structures is given including:— Coplanar force systems, equilibrium and stability. Framework loading and internal forces. Beam and strut theory, Shear force, bending moment, internal stresses, stiffness, and deflection. Design of tension and shear connections. Mathematical modelling of products.</p> <p>****</p>	<p><i>Electronic Systems and Circuit Theory</i> An investigation of electronic systems, their components and simple circuit theory is conducted. The work also includes:— The use of instruments. Introduction to integrated circuits. Project which necessitates the design, assembly and evaluation of a printed circuit board.</p> <p>****</p>
TERM 2	<p><i>Dynamics</i> Linear and angular motion and their effect on mechanical systems are examined including:— Newton's laws of motion. Gearing, torque and moment of inertia. Momentum, work, power and energy of various systems, efficiency, power transmission and matching to requirements. Project such as hill-climb or long distance vehicle to incorporate many of the statics and dynamics concepts gained so far.</p> <p>****</p>	<p><i>Devices and Components</i> Study of common components and how they can be used in circuit design including: Electrical energy and power. Diode characteristics and logic. Zener stabilisation. Introduction to alternating current and its rectification. Use of a transformer. Simple transistor theory and applications.</p> <p>****</p>
TERM 3	<p><i>Fluids</i> Simple hydrostatic and fluid dynamic theory is investigated. The stability of objects in a fluid medium is explored and the principles of wind and water power examined.</p>	<p><i>Design Study</i> This term is devoted to power supply design which necessitates the consolidation and application of all the work to date.</p>

Introducing technological issues to students taking design degrees is not, however, a straightforward matter, and requires careful consideration of appropriate issues and approaches. It is necessary for students to be motivated by seeing the relevance of technology to design and in this way fairly complex issues can be understood and incorporated into their work.

George Hicks, in a recent paper, described technology thus:—

'Technology is a creative and disciplined activity informed by a knowledge of energy and control, of materials, of methods of manufacture and it is supported by many concepts and skills but particularly those derived from mathematics and science. It is guided by the values and attitudes of society and is directed toward the maintenance and improvement of human well-being'.¹

Most new entrants to the degree programme want to combine a creative flair with the application of scientific knowledge but, as they have rarely had this opportunity previously, the first year of the degree programme has been designed to provide the foundation of a breadth of skills in Design and Technology. One of the five main modules of study in Year 1 is 'The Physical Basis of Technology' for which the minimum requirement is the equivalent of GCSE Mathematics and Science. Students who arrive with 'A' level Maths and Physics have rarely learnt to apply their theoretical knowledge and consequently the applications of technology to design is the key feature of this work. The students who arrive with only GCSE level Maths and Science have considerable work to do to grasp the essential theories and application of technology but, if they are motivated and see its relevance, they can do just as well as those arriving with 'A' level Physics or Technology. 'The Physical Basis of Technology' module comprises the study of Mechanics and Electronics by a lecture programme and laboratory investigations to facilitate the understanding and implementation of the fundamental concepts and the appreciation of their applications. Table 1 gives an indication of the technology content of the Year 1 module.

The technological capability developed in Year 1 continues in the 'Technology in Design' core module in Year 2. This is a compulsory module which combines a computing course with the study of systems and instrumentation, pneumatics and computer control. In the systems and instrumentation part of the module, students examine technological systems of different kinds. The pneumatics section of the module teaches useful logic and low cost automation techniques. In the computer control element of the module students learn how to interface and control different systems using a microcomputer. All students undertake a minor project to consolidate each element of the module. In the final term they then undertake a major group feasibility study which integrates the ideas from each area of the course together with group management skills.

In Year 2 the students also have an option to study mechanical and electronic technology in greater depth as a major area of study. Components of Mechanical, Digital and Analogue Systems are studied in the context of design. In Year 3 the 'Technology in Design' option continues and extends the knowledge of technology already gained by the major technology students in Year 2, and seeks to develop a systematic approach to engineering design.

The skills gained in the compulsory, Year 3 'Design Practice' course, combined with the technology skills, are put to the test when the third year students undertake a minor and a major design project often linked with Industry. It has been a great challenge to our Major Technology students to be responsible for technological projects linked with industries where the design and engineering departments are traditionally distinct. Third year students have been involved in professional-based projects with such clients as Austin Rover, Newman Tonks Engineering Ltd., Vickers Medical PLC, Leicester Royal Infirmary and Rolls Royce and Associates. One such project was a new steering wheel design undertaken by a group of students for Lotus Cars. At the outset of the project the company was not convinced that an individual could encompass the highly

sophisticated technical and aesthetic requirements of the design, but have since been very impressed by the work that has been produced. An example of this work is given later in this article.

Another benefit that some of these clients had not previously appreciated is the ability of our students to help the company's two design factions to communicate effectively with each other. This is one area that the Royal College of Arts's initiative wished to cater for and there is no doubt that a technically capable product designer working as part of a team on larger products is of great benefit. From the experience of our past and present students in industry it is clear that technological capability is a considerable asset to a designer. The challenges they meet are great but the rewards are much greater.

Examples of Undergraduate Technology Coursework and Projects

The examples which follow illustrate the meaning attributed to a personal technological capability for undergraduate designers taking the Design and Technology degrees. Examples have been chosen from work done by each of the three year groups and they illustrate the hoped-for progression from the analysis of existing products through feasibility studies and on to the analysis at the design stage of original concepts.

Year 1

Statics The most significant issue which students must understand is the distinction between designing for stiffness and designing for strength. For a beam these are represented by the formulae shown in Table 2. These mathematical models allow appropriate beam dimensions to be calculated. The most common example — that of a bookshelf — is considered in a lecture. Strength calculations will typically yield thickness for wooden shelves of 6-10mm. Students quickly realise the problem, namely that if only strength criteria were applied the bookshelves would be highly curved. If a reasonable figure for the acceptable deflections chosen (say 1mm) then stiffness calculations will yield the thicknesses of 15-20mm which is a more typical shelf depth. Similarly, strength calculations

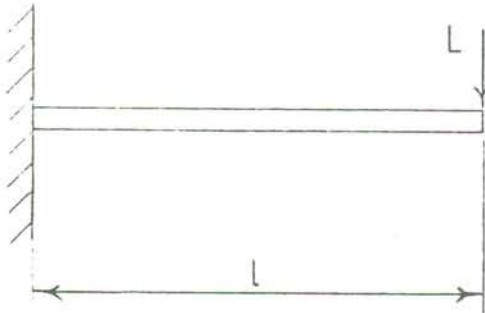


TABLE 2 Designing a Cantilever for Stiffness and Strength

Stiffness

Mathematical

$$\delta = \frac{L l^3}{3EI}$$

Model $3EI$

where δ is the deflection at point l

L is the load

E is the modulus of elasticity

I is the second moment of area

Designer specifies

- i) the load to be supported and its position
- ii) the material
- iii) the acceptable deflection

Strength

$$\frac{M}{I} = \frac{\sigma_y}{y}$$

where M is the bending moment

I is the second moment of area

σ_y is the stress at height y

y is the distance from the neutral axis

Designer specifies

- i) the load to be supported and its position
- ii) the material
- iii) the acceptable deflection

of the frame section for G-cramps, as indicated in Fig. 2, will yield a mild steel section size of the order of 5x10mm. This section size would not fail because the stress level would be limited to around 200N/mm², but undue deflections would make it unfit for its purpose. G-cramp frames are designed for stiffness.

Designing for stiffness is not however always about keeping deflections low — it is about controlling the deflections to be the magnitude you require. Consider the child-proof lock shown in Fig. 3. It must be possible for an adult to open the lock fairly easily, but for a child to have considerable difficulty doing so. A force of about 10N is therefore a suitable design value to calculate the cross-section of the catch which will deflect

and open the lock under adult pressure. The length of the catch, e, is taken as 50mm; its maximum deflection, δ , as 7mm; and the Modulus of Elasticity, E, as 200N/mm², which is typical of many plastics. The deflection formula then gives:

$$I = \frac{Le^3}{3E\delta} = \frac{10 \times 50^3}{3 \times 2000 \times 7} = 30\text{mm}^4$$

For a rectangular section

$$I = \frac{bd^3}{12}$$

where b is the breadth and d is the depth. If b is taken as 6mm then

$$\frac{bd^3}{12} = 30 \therefore d^3 = 60 \text{ and } d = 4\text{mm}$$

Figure 2: Designing for Strength

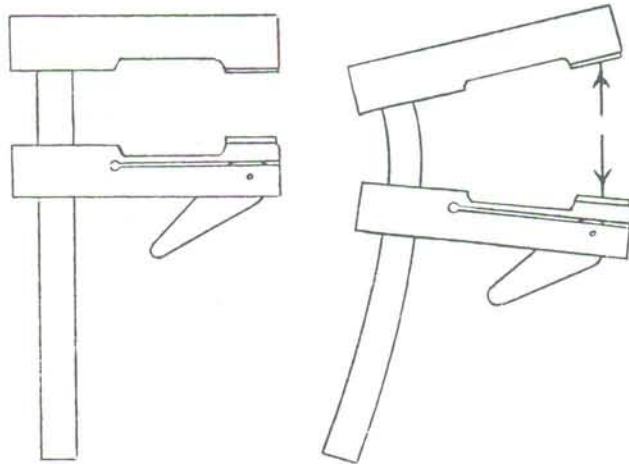
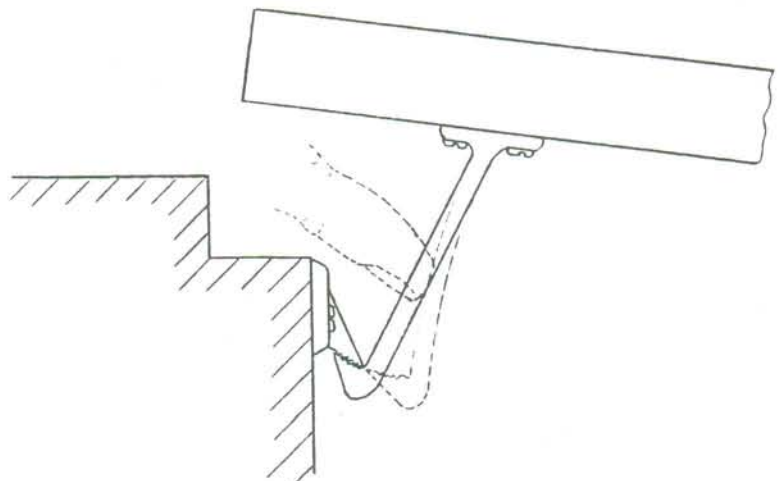


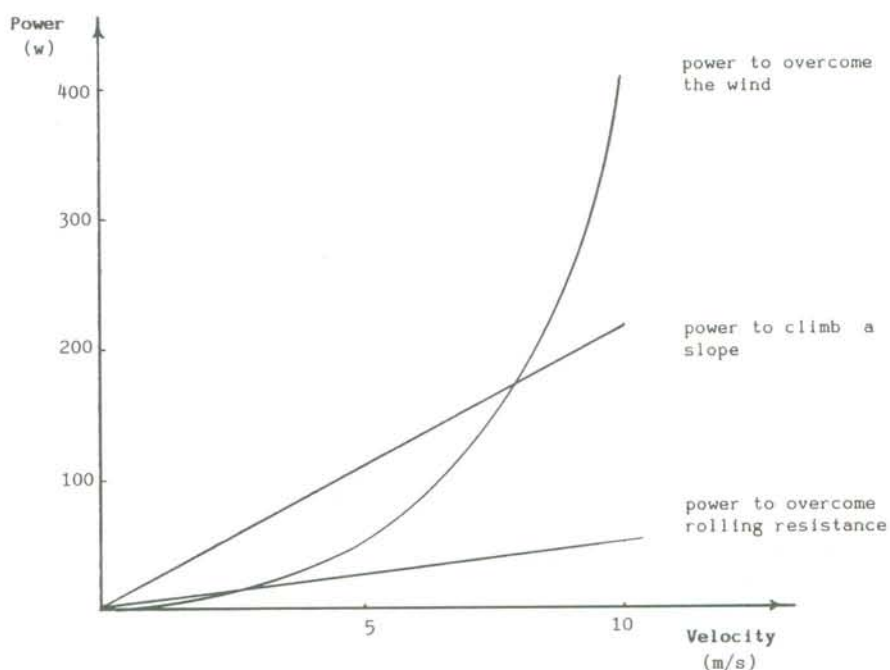
Figure 3: Designing for Stiffness



The section sizes of typical products will be found to be approximately 6 x 4mm. It should be emphasised that when dimensions have been established giving the appropriate stiffness the maximum stress level also needs to be checked.

Dynamics The principles of dynamics are initially introduced to the students in describing motion and the concepts of work, energy and power in relation to machine design. Considerable attention is paid to the bicycle in order to explore the matching of a power source against specific output requirements through a gearing system, and in particular to understand the human as a power source. It is known that over a prolonged period humans can produce 35-40W and trained athletes double this amount. In short periods 200-300W can be delivered quite easily, but fatigue will set in quickly. It is also known that humans operate most efficiently with a pedal cadence of 60-80 r.p.m. Fig. 4 shows the power requirements for a bicycle and students are taught to understand how each of these is calculated i.e.

Figure 4: Power requirements for Bicycle Propulsion



The power to overcome the wind, P_w is given by

$$P_w = C_d A V^3$$
 where C_d is the drag coefficient
 A is the frontal area
 V is the bicycle velocity

The power to climb a slope, P_s is given by

$$P_s = M g V \sin \theta$$
 where M is the total mass
 g is the acceleration due to gravity
 θ is the slope angle

Table 3: Progression in Conceptual Thinking required to Analyse Bicycle Power Transmission

gear developments
for specific gear
combinations

(m)

front chainwheel \ rear cog

49

40

14

17

20

24

28

7.54

6.21

5.28

4.40

3.77

6.16

5.07

4.31

3.59

3.08

speed ranges for
60-80rpm pedal

(m/s)

front chainwheel \ rear cog

49

40

7.54-10.0

6.21-8.26

5.28-7.02

4.40-5.85

3.77-5.01

6.16-8.19

5.07-6.74

4.31-5.73

3.59-4.77

3.08-4.10

Walking speed is
approximately 1.8 m/s

power required to
overcome air and
rolling resistance

(w)

front chainwheel \ rear cog

49

40

212-454

129-270

87-176

58-112

42-77

127-262

79-158

55-166

38-69

28-50

With Cd = 1, frontal
area = 0.4m² and the
resistance at 0.06N/kg
(One horsepower 746W)

Figure 5: Design Exam — Garden Shredder

The power to overcome the rolling resistance, P_R is given by $P_R = MRV$ where R is the rolling resistance

These formulae allow the total output power required for any output conditions to be calculated. Table 3 shows the progression in conceptual thinking required to analyse the power transmission for a bicycle. Students must begin by understanding that for different gear combinations the bicycle moves forward different distances for one complete revolution of the pedals. This distance is known as the gear development. For a pedal speed range of 60-80 r.p.m. this will result in bicycle speed ranges given by:

$$V = \frac{N}{60} \times g_d \text{ m/s}$$

where N is the pedal cadence in r.p.m. and g_d is the gear development in m.

When travelling on the flat, power will be required to overcome the rolling and air resistance, and these power requirements are shown at the end of Table 3. At this point it is possible to consider the matching problem for input and output power. If the rider meets a 1 in 40 slope the power required to go up it at different speeds is known. If the limit on the human power output is known, say 100W, then by looking at Fig. 4 and Table 3 the required gear combination (40/28 giving approximately 3m/s) can be found. Such an analysis shows how bicycle power transmission design has evolved in order to provide the rider with the opportunity to match the power they are prepared to deliver against the output requirements.

Once students have understood these principles they can be applied to a variety of problems. In Third World areas the human is often the best available power supply, and machines for raising water, grinding cereals, transporting passengers and other loads, or charging batteries could all be analysed. Equally, pedal-powered garden equipment for our own society might well have advantages, e.g. lawnmowers or the garden shredder set as a problem in third year Design Exam.

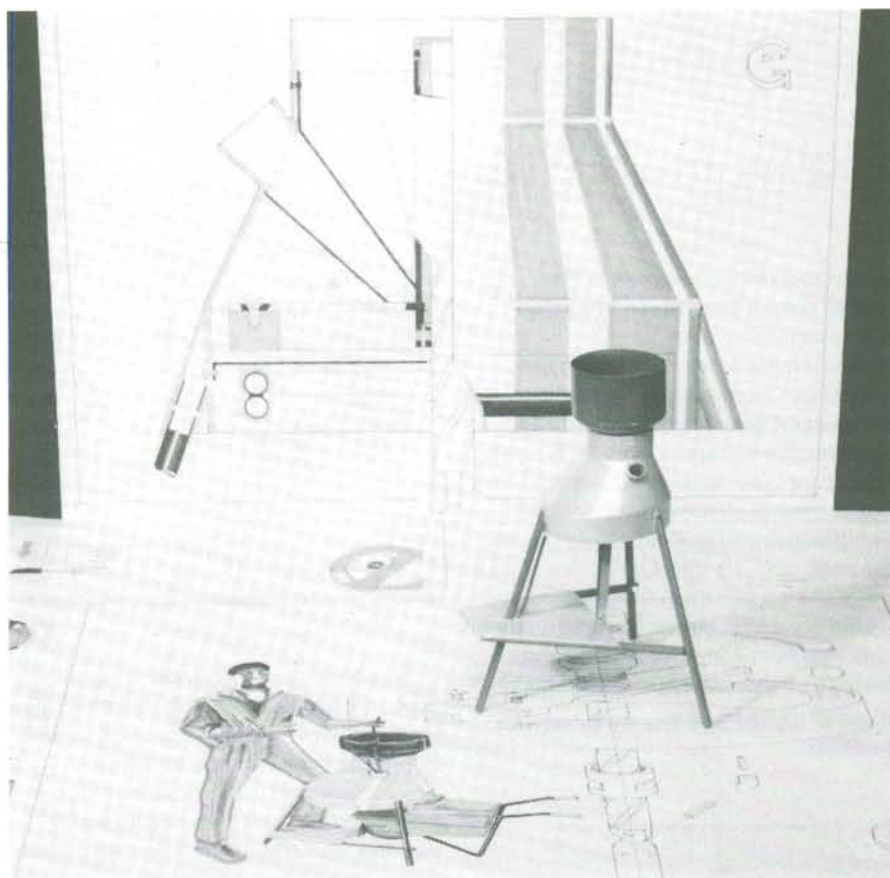


Fig. 5 shows how one student thought the problem might be tackled.

The 555 timer

The 555 integrated circuit can be made to perform a number of timing functions by altering its external connections. The two basic modes of operation — monostable, where a voltage output is produced which goes off after a controllable delay and, astable, where the output switches between high and low output levels at

controllable time intervals — are illustrated in Table 4. Students clearly need to be able to perform the simple calculation associated with the mathematical model, but the more difficult task is seeing how the device can be used to solve a particular problem. For a straightforward timing circuit, say for giving a visible indication of an appropriate exposure time in a darkroom, key questions might be: — how is a trigger signal to be produced for the monostable circuit? or

Table 4: Basic timing functions available with a 555 Timer

	Monostable operation	Astable operation
Circuits		
Output signal		
Components to be chosen	R_1 and C_1	R_1 , R_2 and C_1
Mathematical model	$t = 1.1 R_1 C_1$	$t_1 = 0.7 (R_1 + R_2) C_1$

— how can the termination of the voltage output be made to produce a visible signal?

Fig. 6 shows how a suitable trigger voltage can be produced. With the switch open no current is flowing and therefore the voltage at point A is equal to the supply voltage. When the switch is closed there is effectively a brief short-circuit which will give the trigger signal required.

For the voltage drop to trigger a visible device the circuit must be made to 'sink' (rather than 'source') a current through an indicating device as shown in

Figure 6: Obtaining a Trigger Voltage for the 555 IC

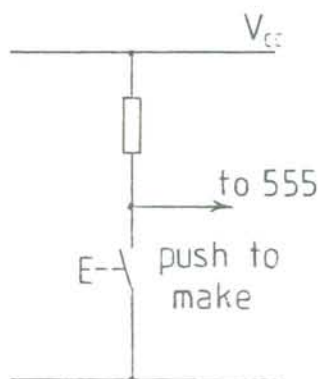


Fig. 7. Whilst V_{out} is high, no current will flow through the LED. When V_{out} goes low the LED will light up. The astable circuit can be used to produce alternating signals to drive an audible device and more advanced students might be asked to consider how an audible indication of exposure time could be produced.

Figure 7: The 555 IC acting as a current sink

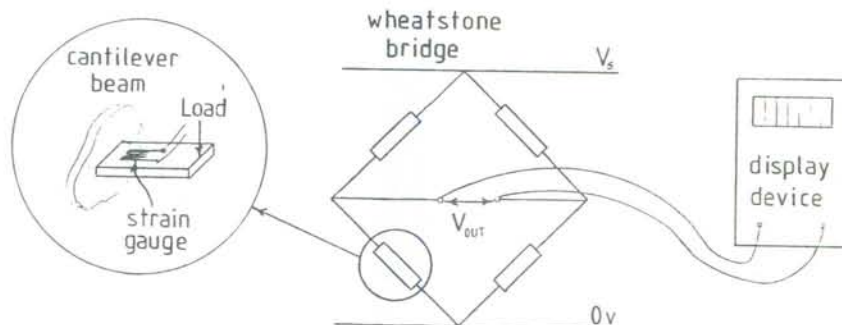
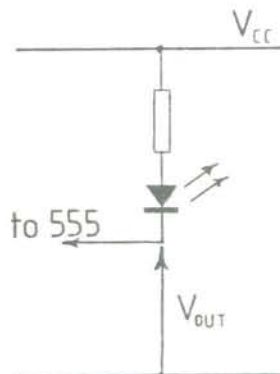


Figure 8: Electromechanical weighing system

Whatever the project, the students need to gain confidence in deciding on a strategy, using the mathematical models to predict performance, building physical models using breadboard or a kit to verify it, and then finally laying out and manufacturing a printed circuit board on which to solder the components. The final stage of fault finding in the completed board is also a key skill which needs to be developed.

Year 2

Instrumental Systems

Students are introduced to the use of the Wheatstone Bridge as a resistance-to-voltage converter and this is used with light dependent resistors (LDR's) to detect changes in light intensity, thermistors to detect changes in heat and strain gauges to detect changes in loading. Changes in light intensity are used in many systems, e.g. to detect burglars, track the sun, indicate daybreak, and switch on artificial lights. Changes in heat intensity are often measured by thermistors in environmental temperature control systems. Strain gauges are also commonly used, for example, in grip strength measuring devices or weighing machines, and a project such as this is often set to the students. The following problem arose originally because of the work done within the Department in relation to Perinatal Care Units with Dr. D.A. Ducker at All Saints' Hospital, Chatham.

'Examine the feasibility of weighing a baby of between 0.5 and 2.5kg to an accuracy of 5g'

Monitoring the weight of a premature baby is crucial in giving early warning of difficulties. Assessing this feasibility depends on being able to consider both the electrical output and a suitable

mechanical configuration. Fig. 8 shows the kind of electromechanical system which will need to be considered. From datasheets it can quickly be established that:

$$V_{out} = \frac{V_s}{4} \cdot G \cdot \epsilon$$

where V_{out} is the bridge output voltage
 V_s is the supply voltage
 G is the gauge factor

and ϵ is the strain

Hence, as typical values for V_s and G are 12V and 2.1

$$V_{out} = \frac{12 \times 2.1}{4} \epsilon = 6.3\epsilon$$

For steel at half its yield stress the strain is approximately 0.002 and hence the corresponding bridge output voltage would be 12.5V. If this corresponded to the 2.5kg load then each 5g corresponds to $12.5 \times \frac{5}{2500}$ or 0.025mV

The students must establish the size of beam to give this strain level for the 2.5kg load (using $\frac{M}{I} = \frac{\sigma}{y}$ and then $\sigma = E\epsilon$),

whilst ensuring that it is large enough to mount the strain gauge and then go on to consider whether 0.025mV can be reliably detected to give the required accuracy. If not, how can a larger output be obtained?

Group feasibility studies

Power exercises machine

Fig. 9 shows a schematic diagram of a powered exercise machine. If the belt is not powered, then it is rather like running on sand. In order to simulate road running it is necessary to accelerate the belt up to running speed. In order to simulate different routes it is also desirable to vary the belt load for set

**Figure 10: Drilling Jib —
J.C. McCartney**

periods to give the impression of going up or down hill. Both as a test of fitness, and also as a safety precaution, monitoring the runners pulse rate is necessary. The design of such a system poses a number of difficult issues, and it is also a good opportunity to apply the knowledge of power, torque and inertia gained from Mechanics, the knowledge of transducers considered in the Instrumentation module and the use of the computer both for system control and data logging.

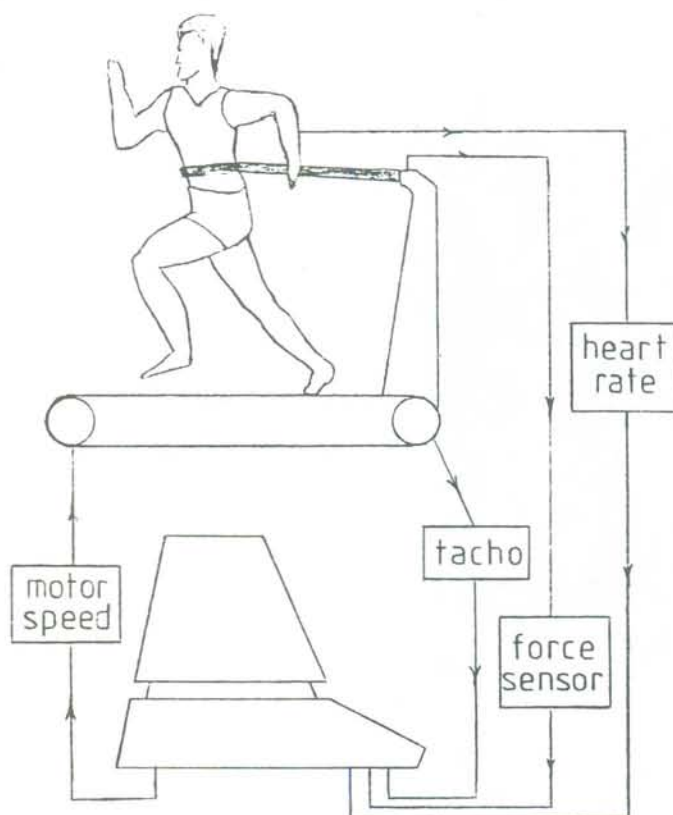
Greenhouse environmental control

The control of the environment in a greenhouse depends on three key problem areas; the air temperature, the air humidity and the soil water content. Each of these needs to be monitored and a means of controlling its level found. How do you monitor the soil water content? An intelligent student soon discovered that this could be achieved by measuring the electrical resistance

between two probes. But when you change the water content, by perhaps allowing water past a valve, you also influence the air humidity. The humidity is also changed if you open a vent to lower the temperature. Such

interrelationships make the development of an effective control strategy an interesting exercise.

Figure 9: Powered exercise machine



Year 3

The student's work in Year 3 centres on their Design projects and three examples are given where work done by finalists has been influenced and enhanced by their knowledge of technology.

Drilling Jig, J.C. McCartney

If you fully understand Newton's third law, then the simplicity of the design of a drilling jig, shown in Fig. 10, will not surprise you. If not then then desire to fix the sliding bars by a mechanical connection, a screwthread, bolt or pin would be different to resist. The force developed by a toggle mechanism will be very high as will be the reaction to it!

Facial steering wheel, Colin Wilson

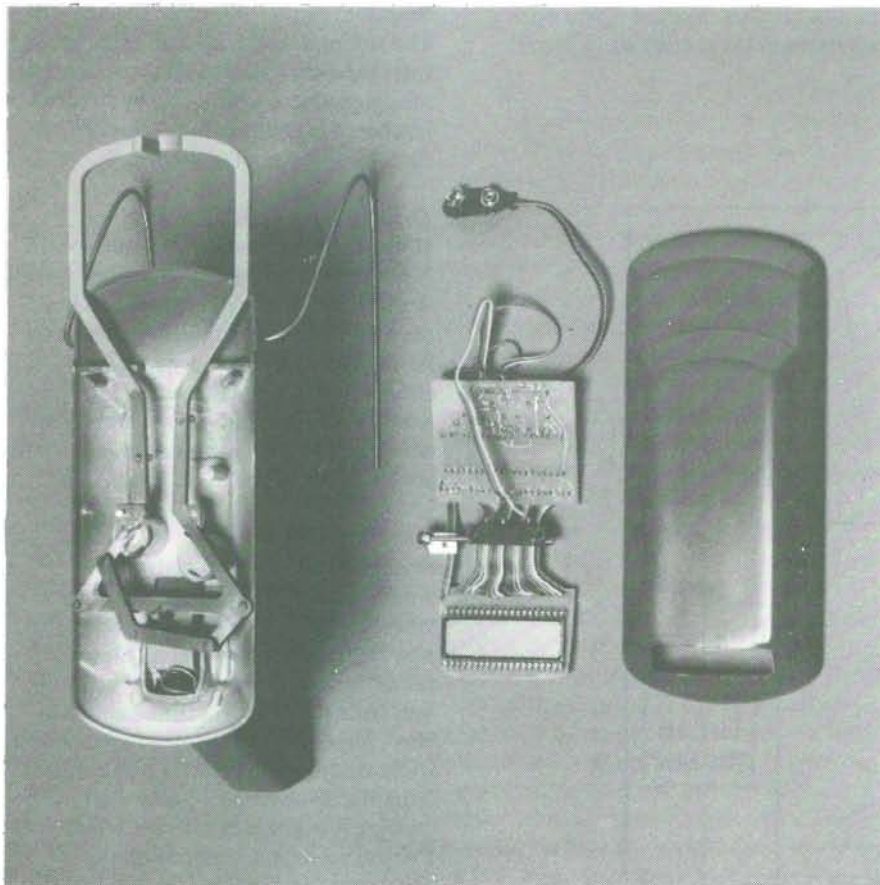
Several of this year's finalists are working on the design of a steering wheel for the Lotus Esprit meeting the new facial steering wheel regulations. Since the introduction of compulsory seat belts the old regulations aimed at chest impacts have become increasingly irrelevant as most injuries now result from the driver rotating and their head coming into contact with the wheel. Preventing injury depends on the deceleration not exceeding 80g and the

Figure 13: Skin-fold Caliper — the final product



Figure 11: Lotus Steering Wheel

Figure 12: Skin-fold Caliper — electrical and mechanical systems



facial pressure not exceeding 1540KPa. Some reasonably straightforward mechanics will allow the required depth of the wheel and the facial area over the hub to be calculated which give the designer the key constraints. It is then necessary to establish the aesthetic and ergonomic requirements within these limits and an acceptable manufacturing cost. The wheel shown in Fig. 11 is very close to a solution and may be one — it remains to finally be proven!

Skin fold caliper, Phil Cooper

The Human Sciences Department required a device to measure the thickness of a fold of skin. This skin fold caliper must apply a constant pressure at any opening and give an electrical readout indicating the gap between the jaws. The mechanical

linkage shown in Fig. 12 provides a linear relationship between the movement of the input transducer and the gap opening and also uses constant tension springs. Fig. 13 shows how the student has integrated their knowledge of electrical and mechanical principles, materials and product design to develop a professional looking and functional device.

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