By mind and hand: the importance of manufacturing artefacts in the education of engineers

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Abstract
There was a disturbing tendency in the 1970's for engineering programmes to become over theoretical in content and divorced from the professional aspects of engineering. There was little time devoted to manufacturing in the lecture syllabus let alone actually making artefacts within the practical elements of the course. The Design course was identified as the venue to integrate the engineering science course material leading to design and make exercises as constituent parts of project work.

Increased student interest, enthusiasm and understanding have been observed.

A variety of levels of manufacture are described from traditional modelling to computer assisted manufacturing. Comment on computer aided engineering is also included together with proposals for computer assisted testing of student designed artefacts.

Introduction

Traditional mechanical engineering courses of the 1970's had a preponderance of theoretical material in them which was largely mathematically based. This was evident in the principal subjects of Dynamics, Solid Mechanics, Fluid Mechanics and Thermodynamics. This was a sign of the times being the result of the stimulus of the space programme and the race for ever more sophisticated technology. While solutions to engineering problems could to some extent be carried out using pure mathematics exact solutions to real engineering artefacts were few and far between and then only for very simplified models.

The dissatisfaction of students in this situation is dealt with by Entwistle[1] particularly regarding professional relevance. Students expect an emphasis on engineering rather than on academic subjects and he claims that in lacking the perception of relevance the student's learning shifts to a surface mode rather than understanding in depth. This is heady stuff but its proof is observed in the retained attention and enthusiasm of the students who manufacture the subject of their designs.

The Finniston report[2] gave further support and respectability to the inclusion of manufacturing topics in engineering courses with the reference to 'Fabrication and use of materials' as a fundamental requirement of engineering degree courses carrying the BEng title.

Lecturers in Engineering Design were aware of the emphasis on mathematics and the increasingly analytical nature of engineering degree programmes. There was clearly a need for a measure of creativity and synthesis in this situation to leaven the students' intellectual diet and to attempt to integrate the theoretical subjects in a practical context. Within this environment grew the design and make project in Engineering Design courses. In parallel with this movement in design education was the development of economic computing and attainable CAD /CAM/CAE systems for student use. This has assisted in achieving sophisticated design and make exercises with credible analysis and enjoyable investigation. It is proposed that this is a highly effective way to induce learning and satisfaction. Experience in this area will be described.

Design and Make

It should be explained that one can run 'paper only' exercises but inevitably the practice becomes wooden and pointless if some first hand experience of the artefact involved is not achieved. It has been found in operating the design and make programme at Dundee that the students attention and enthusiasm is stimulated and retained if it is believed the design will actually be realised.

Early examples of work in this area used simple materials and modelling techniques which the students could master and produce reasonable attempts at realisation. This approach is still extremely useful but limits the scope of three dimensional design possible. The development of numerical control machines and their availability in college workshops opened up a new area of possibility in design and make leading to learning opportunities of design for manufacture to be included. This allowed models to be cut out of the solid and took the process one more step nearer industrial reality. This highlights the effect of IT

(Information technology) on educational methods in engineering education and this effect was enhanced farther in the 1980's with the general availability of easier to use finite element methods which allow complex models to be analysed 'soft' using a computer. The model could then be manufactured and tested to compare results with the FE analysis.

The advent of cheap computing in the form of the PC computer has also transformed the approach to draughting with professional level CAD systems being used in the first year of the course. However the writer still believes in introducing CAD after an introductory period of pencil and paper exercises.

Examples of work

Year 1

In the first year care has to taken to keep the project achievable yet not too trivial, real but not too difficult.

The ball bearing delivery dispenser.

The requirement is to deliver three steel balls from a hopper on to a conveyor system in an automated assembly process. Simple actuation is allowed of a push pull nature. The student will by this time have been introduced to a systematic design procedure and will be expected to create a design matrix of ideas to solve the problem , evaluate them to assess feasibility and produce a synthesis i.e. a drawing of the device envisaged. CAD may be used in this case . Manufacture in the first year is mainly by use of balsa wood , pins etc. and group work is practised.

While some students may have modelled this is likely to be the first time that they are making an artefact they have designed. However in recent years there is evidence of increasing competence in this area by those pupils who have experienced Design and Technology at school.

Learning outcomes: effect of gravity, friction, presence of the third dimension.

Another is:

How far can you drop an egg without breaking it?

The requirement is in the title and it is made clear that demonstration of application of a design method is required and attempts to predict the result will be favoured. Materials of construction are limited to two sheets of A2 cartridge drawing paper and lightness is a virtue. The better students will spend time thinking how best to optimise the design and it is heartening to hear that questions are being asked in the Dynamics class about forces likely to be experienced in such a case. Data on egg fracture force is given.

Learning outcomes: gravitational acceleration, dynamics of non-rigid bodies, shock absorption, stiffness as a function of shape, integrity of construction.

Year 2

Initial Block

If the artefacts being designed are to have realism and precision there is a need to involve the student in machining the artefact. The way to sustain interest in this is to allow ownership of the design and to encourage adoption of any particular style wished within the size of a standard block. Most shapes in engineering are arcs and straight lines and these are readily embodied in a design using the initials of the student cut in relief into a solid block. The problem now is how to manufacture it! Students are not expected to be craft competent either in course or thereafter and in any case the workshop would soon be overwhelmed by a class of say 30 creative clients. The solution lies in allowing the student to programme a milling machine to produce the part which only then requires a technician to execute the programme under the students supervision. The package used to assist manual NC programming is ANIMA for milling. Manual programming is used in order to allow familiarisation with co-ordinate input and the 'G' and 'M' codes used for machining. An example block is shown in Fig 1.

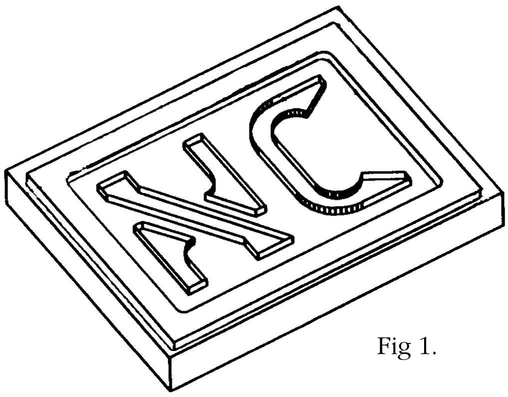

Fig 1.

Learning outcomes: Aesthetic aspects of design, design for manufacture, manufacturing technology, fragility of shape, computer aided design, introductory computer aided manufacture.

While the solution could be realised in metal we have, in the interests of expense, tool life and the technicians nerves, restricted the material of manufacture to blocks of polystyrene foam.

Year 3

High strength to weight ratio beam. Design, make and test.

In many areas of engineering the object is to obtain the maximum strength with minimum weight which is a nice problem in optimisation. The problem given is that of designing a simply supported beam of low mass to carry a guaranteed central load. External dimensions are fixed, nothing can be added and the shape is to be designed by machining away material. The central deflection is also to be predicted. The material used is expanded polystyrene foam.

The solution involves assessing the distribution of stress in the beam and identifying areas which could be removed. This induces a study of solid mechanics and structural mechanics plus forays into the theory of elasticity.

This study has a lot to it and introduces the third dimension not only in the manufacturing sense but in the elastic behavioural sense. The student finds that a vertically loaded beam can show, in addition to the vertical deflection, horizontal deflection as it approaches a transverse failure mode. This type of failure is associated with highly optimised beam cross sections where the second moment of area in the vertical direction has been maximised and that in the horizontal direction is small.

The project also allows application of finite element analysis. which falls into the generic grouping of computer aided engineering (CAE). These packages are now available for PC use (e.g. ANSYS, COSMOS etc.) and the beam can be investigated for stress distribution, deflection and, if required, natural frequencies and heat transfer. The application of the finite element method in undergraduate projects is dealt with in greater depth by Middleton.[3]

Manufacturing is carried out by programming the beam to be cut by NC milling and this time a higher level CAM package is used (e.g. PEPS) which can import a CAD drawing. The CAD drawing is then used, via a boundary tracing technique, to automatically generate the NC programme. An example beam is shown in Fig 2.

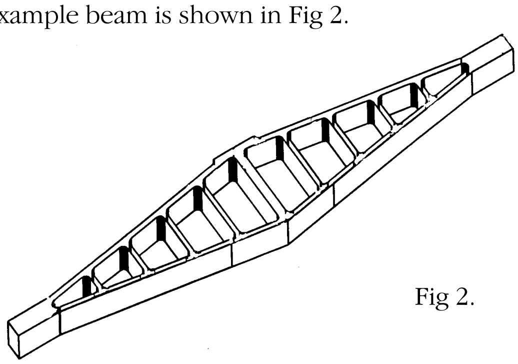

Fig 2.

Testing is carried out by loading incrementally with dead-weights and measuring deflection on their beam. This is an exciting exercise to be contrasted with conventional tests on established experimental equipment. A development for next year is to conduct the loading in our new testing machine which has a pc attached for recording the results and allowing computer aided testing.

Learning outcomes: Application of elastic theory, experience in optimisation, experimental planning, agreement of test criteria, design for manufacture, application of CAD/CAM, teamwork.

The next stage

Now that component level manufacture has been realised the aim is to move to whole machine assemblies in the machine design class. This has always been a desired goal but was only realised in the honours year project. Now that students have had a taste of manufacturing their design there is a natural wish to extend this to other examples. A new requirement will be included in any proposal which is that the parts must be suitable for NC manufacture.

A proposed example

As part of the second year syllabus the students are required to study small engines by dismantling and reassembly and reporting on the exercise. It is proposed that a test rig be designed and manufactured to test these small engines under load and measure their power and fuel consumption. this is felt to be within the second year competence and trials will be carried out soon. IT will feature strongly in the exercise in ways described above but extended to assemblies of parts.

A note on sharing experience in design.

SEED (sharing experiences in engineering design) is a body of engineering design lecturers which meets annually in conference and publishes course support material for designers. There are to date three compendia of design projects[4] drawn from the experiences of members and these include projects which may be taken to the manufacturing stage.

Conclusion

There is little doubt that the education of the engineering student is improved by manufacturing the artefacts which they design. There is enthusiasm, interest and improved application and integration of other subjects studied. This means that there is increased understanding of the whole programme of studies causing a synergy which leads to an improved education.

References

1 Entwistle N. et al , 'Success and failure in Electrical Engineering courses in Scotland', summary of a report to the SED, Department of Education University of Edinburgh, (1989).

2 The Finniston report 'Engineering our future; Report of the committee of enquiry into the engineering profession', London, HMSO, (1980).

3 D. E. S Middleton, 'Better than guessing the stressing; applications of the finite element method in an undergraduate course', pp35-49, in 'Finite Element Analysis; Education and Training', Elsevier, London, (1990).

4 SEED Curriculum for design, Compendium of Design Projects, SEED in association with the Design Council, (1988). (Further compendia in 1989 and 1991)