The Royal Academy of Engineering

Educating Engineers in Design

Lessons Learnt from the Visiting Professors Scheme

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Visiting Professors in Principles of Engineering Design

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Edited by

Professor Ken Wallace FREng
Engineering Design Centre
Department of Engineering
University of Cambridge

And what do we need to teach? We don't. We need to give the opportunity to gain experience and awareness in multi-disciplined team environments and let the confidence of youth loose on a prepared world. What can we give students in a university department? Experience of working in multidisciplinary teams working on realistic projects. The Visiting Professor's role in this is to develop appreciation of the power of ideas and the value that transferring knowledge can have.

Professor Chris Pearce FREng
Visiting Professors 2002 Workshop

Educating Engineers in Design

ISBN 1-903496-17-9

February 2005
Published by
The Royal Academy of Engineering
29 Great Peter Street, London SW1P 3LW

Tel: 020 7227 0500 Fax: 020 7233 0054
www.raeng.org.uk
Registered Charity Number: 293074

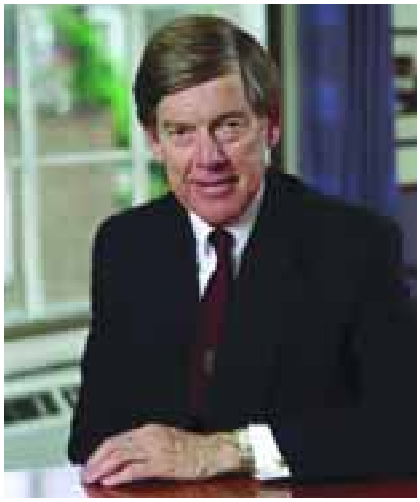
Foreword

The world is changing rapidly, with a trend towards globalisation, international supply chains and widely dispersed design and manufacturing teams. Engineering products and the processes by which they are created are becoming increasingly complex. It is essential that engineers address the whole life cycle of the systems and products they create to ensure they meet the long-term needs of society. At the same time they must use natural resources wisely and produce the minimum impact on the environment.

The task of educating engineers for their future roles in society is both daunting and exciting. Building on the strong developments in design education that started in many universities during the 1980s, the Academy has made a truly significant impact through its Visiting Professors Scheme in Principles of Engineering Design. This can be seen from the examples of good practice set out in this book.

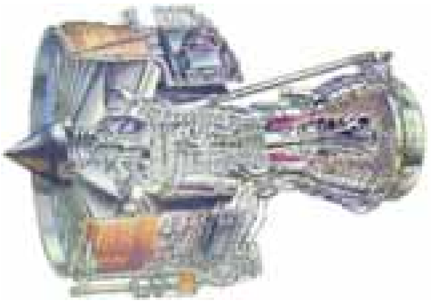
Over 200 senior engineers have contributed their knowledge and time to the Scheme since its inception in 1989. In collaboration with the universities, the Academy looked for individuals with strong links with the commercial world, both industrial and professional, and substantial and distinguished experience. Both design education and industrial practice have benefited. The Visiting Professors ensured that current industrial practice, technical and managerial, was introduced into design education and project work in the universities. They also provided a channel for a flow of ideas and research results back into industrial practice.

The Academy is committed to inspiring the next generation of engineers. To that end the Visiting Professors Scheme has made an outstanding contribution to date – and will continue to do so for many years to come. On behalf of the Academy, I would like to express our deep appreciation to all those who have made the Scheme such a success.



Lord Broers FREng FRS
President
The Royal Academy of Engineering

Preface



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Prompted by the importance placed on engineering design education by the accreditation bodies of the professional institutions, many excellent developments in design education took place in the 1980s in university engineering departments. The Academy recognised the need to maintain the momentum during the 1990s. During this decade the financial pressures on universities increased and threatened design education because of its resource-intensive nature. Due to changing academic career patterns, it also became increasingly difficult to recruit academic staff with experience of engineering design in industry. The Academy helped to overcome some of these challenges through the introduction of its Scheme for Visiting Professors (VPs) in Principles of Engineering Design.

The VP Scheme was established in 1989 and since then has provided additional impetus and resources, along with much needed up-to-date industrial experience. There are currently around 120 VPs, working with 46 universities, bringing a wide perspective and practical experience of design to undergraduate and postgraduate courses in engineering departments.

The aim of this book is to distil good practices in engineering design education from the VP Scheme by:

- setting engineering design education in context
- presenting ten examples of good practice selected from the Scheme
- summarising the lessons learnt.

As part of a series, a VP Workshop was held at UMIST, Manchester, in April 2002, with the title: ***Lessons from the First Twelve Years of the VP Scheme***.
The central aim of this VP 2002 Workshop was to look at examples where departments had developed their courses though the help of the VPs to embrace engineering design and cope with the pressures of change. Examples of the contributions made by a number of VPs were presented and considerable time was set aside for discussion.

This book was conceived as an essential outcome of the VP 2002 Workshop, describing the lessons of the successful operation of the VP Scheme since its inception. The book identifies the key aspects of design education, drawing on the experience of the VPs and the academic staff at the universities, and records the work of those courses that present insights into good practice. The book also serves as a marker of the contributions and achievements of over 200 VPs who have worked within the Scheme (see Appendix 1).

The ten examples have been selected to cover a range of good practice. Each has been set out in a similar style so that the main ideas and lessons can be identified quickly. It is clear that through undertaking design projects students:

- enhance their understanding and enjoyment of engineering
- increase their technological repertoire
- appreciate the integration of design and analysis
- learn how to work in multi-disciplinary teams
- develop leadership, management and communication skills
- appreciate the importance of professional responsibility
- become motivated towards their engineering studies.

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In the views expressed by the VPs and academic staff alike, engineering design is fundamental to the teaching of engineering, which can sometimes focus too narrowly on the engineering sciences and mathematics. A wider approach to design education encourages a systems approach to solving engineering tasks, integrating the analytical techniques taught in the engineering sciences and developing the latent creative abilities of the students. It is the view of the VPs that design projects not only provide motivation for engineering but also help to develop a whole range of skills that are valuable whatever subsequent career path is pursued. It is also their view that design in its wider context should be a major integrating theme running through all engineering courses.


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The ideas and lessons outlined in this book are intended to be helpful in developing existing engineering design courses and projects and in establishing new ones.

Acknowledgements

Many have contributed to the compilation of this book, both directly and indirectly, and their help and support are gratefully acknowledged.

Contributors include:

- Hugh Norie FREng and James Armstrong FREng
- the members, past and present, of the Design Matters Group of The Royal Academy of Engineering
- the Visiting Professors in Principles of Engineering Design, past and present
- the academics at the universities involved in the Academy's VP Scheme
- David Foxley, Manager, Engineering Design Education, The Royal Academy of Engineering
- Bill Addis, Editor of the Proceedings of the Visiting Professors 2002 Workshop
- Chris McMahon, University of Bath, and Bill Ion, University of Strathclyde
- Mari Huhtala, University of Cambridge.

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Chapter 1
Background and synopsis

Importance of engineering design

The decisions made by engineers have a widespread and long-lasting effect on the quality of life and on the quality of the environment. The results of the work they do can improve life and living conditions in many ways and give people the opportunity to develop fuller roles in society and to shape its future direction.

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Decisions of such importance should be based upon the accumulated and carefully considered experience of generations of engineers. Those making such decisions need to have a deep understanding of the natural laws and the societal context of their work, and to base their judgements upon this understanding.

Because of the wide impact of many of their decisions, engineers need integrity, independence, impartiality, responsibility and competence, and, frequently, discretion. They are trusted by society to make wise and fruitful decisions, occasionally on a global scale, acknowledging cultural differences and limitations of resources – human and material.

Global economic developments are changing the industrial world rapidly and involve increasingly challenging international and cross-cultural needs, along with ever tighter regulations. Products are often designed by multi-disciplinary teams that are no longer co-located, placing great reliance on sophisticated IT systems. Products, and the processes by which they are created, are getting ever more complex. In order to achieve shorter lead times, several of the traditional product creation processes now have to be undertaken in parallel, an approach referred to as Concurrent Engineering. New technologies such as biotechnology, nanotechnology and photonics are having an increasing impact, as are the many new materials and production processes. With companies moving from simply providing products to providing total service packages, the importance of whole life modelling, right through to the decommissioning, recycling and disposal of products, is constantly increasing. It is clearly impossible to include all such developments in undergraduate engineering courses, so the emphasis must be on providing students with a solid grounding in engineering fundamentals and their context, and preparing them to work adaptably and across disciplines throughout their lives.

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Nature of engineering design

Design can be described briefly as: (1) identifying the needs a new project has to address; (2) having the vision to conceive solutions to those needs; and (3) delivering the solutions (Armstrong, 2002). The design process begins with the identification of a new idea, a specific market need or a new technology. The design team then has the challenge of conceiving a solution to that need, which may fall into one or more of the following categories:

- major one-off project, e.g. hydro-electric scheme, large bridge, shopping complex
- consumer product, e.g. kitchen kettle, motor vehicle, personal computer
- process, e.g. chemical plant, traffic management, food distribution, or
- system, e.g. computer software, telecommunications system, mail delivery.

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It is critical to identify and formulate needs accurately. The perceived 'wants' of clients and customers are not always what they need in reality. Part of the professional skill of engineers is the ability to recognise these differing requirements, and to reconcile them.

After formulating the needs, the significant creative process of design begins. This involves meeting the requirements of fitness for purpose, safety, quality, value for money, aesthetics, constructability, ease of use, efficiency of production etc.

It is vital throughout the design process, and the subsequent delivery of solutions, to respect the quality of life in an emerging global society and to give high priority to reducing environmental impact and increasing sustainability.

Educating engineers in design

The needs of industry are changing, but the creative process remains the same in a wide range of contexts. A major benefit of the VPs is their knowledge of contemporary needs and relationships. This contact with practitioners is highly valuable as it is sometimes difficult for permanent academic staff to keep in touch with current practices.

The design process is much more understandable to students in the context of real projects and case studies. They should therefore be given every opportunity to practise design by undertaking appropriate projects.

Engineering design education is a resource-intensive activity that requires staff time and project space, both expensive. However, it is essential that students realise how the abstract concepts of analysis and theory relate to what they will be doing in practice. If this does not happen, they can easily become disillusioned and disappointed by what can appear to be very theoretical and demanding studies. Any move to reduce design in the curriculum in order to save money must be resisted vigorously.

With the reduction in the availability of sandwich courses, it is more difficult for students to experience engineering in practice. Tuition fees have increased the need for many students to work their way through university. Consequently, vacations are often taken up making money, thus further diminishing the opportunities to obtain exposure to engineering practice. Bringing real practice into undergraduate engineering courses becomes even more important.

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Visiting Professors


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The Academy's emphasis on the importance of design education stemmed from concern that, despite several examples of design teaching being very effectively introduced into the undergraduate curriculum, some engineering courses were tending to concentrate too much on individual technical disciplines and on theory, often in considerable depth, and tending to neglect some of the wider issues that surround the real application of engineering. To be successful, engineering education has to be embedded in the realities conditioning its practice, and these realities are worth teaching from the very beginning of an engineering course. The design process is therefore of fundamental importance in an engineering course and benefits all students, even if they are not going to pursue careers in design.

Experienced engineers, such as the VPs, have much to convey to young engineers, and in passing on their experience there is also the opportunity for the VPs themselves to appreciate more deeply the nature of their work and the processes they use. The role of the VPs in describing their processes through case studies and guiding project work is of tremendous value. And the experience of the VPs has confirmed that teaching enlightens the teacher at least as much as the student!

As can be seen from the examples of good practice in Chapter 2, the VPs have helped to raise the prominence of engineering design in many engineering courses, developed new design education strategies and integrated design across different engineering disciplines. They have also contributed their special expertise to design project supervision and case studies. This has forced some rethinking about the place of design in formal engineering teaching. In the most successful courses, as judged from both the performance and interest of students and the response from industry, design has been integrated with other course elements to create a logical and effective whole. At the same time, the disciplines needed for a proper treatment of design have become clearer, requiring a greater range of subjects to be covered. In some cases this has led to a major restructuring of courses to bring design to the centre of engineering teaching. VPs have also been valuable in bringing realism and balance to project work, sometimes directing and supervising projects themselves.

There is no doubt that engineering design has gained a higher profile in universities due to the introduction of the Academy's VP Scheme. One of the Academy's questions is whether this trend needs to go further, and if so what action may be necessary, or whether there is now sufficient momentum for the trend to continue naturally. The general response from industry and the professions to the VP Scheme has been positive, with firms that have traditionally been close to research and education giving strong encouragement.

The challenge

Changes are continuing to take place in the aims and needs of engineering education. School leavers are taught differently, with less mathematics, and they often have less experience in everyday life of the concepts of engineering. Student aspirations are also changing as the challenges of their future careers become apparent. Industry and the professions are looking for greater breadth in their graduates, as well as greater specialisation in particular cases. At the same time, financial constraints and disciplines are being imposed more heavily on undergraduate teaching, tending to lead to more formulaic, results-based syllabuses. Some engineering departments have overcome these constraints with exceptional results, as illustrated in the examples of good practice in Chapter 2.

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Further challenges will come from Government and the new Engineering and Technology Board; from the professional institutions' changing views on course accreditation; and from universities themselves in relation to organisation and funding. The Engineering Council UK (ECUK) and the professional institutions have recognised the need for good engineering design education in university courses. Design is clearly stated as one of the five specific learning outcomes in the UK Standard for Professional Engineering Competence[1] (UK-SPEC), recently published by the ECUK (http://www.uk-spec.org.uk). In this climate, clarity will be essential in setting out the real objectives of engineering education.

The past few years have witnessed the development of 4-year accredited MEng courses. These have been increasingly seen by many students as the preferred route to Chartered Engineer status. These courses have the time, and can be structured, to deal properly with engineering design. They can also form the basis of effective collaboration with industry on project work particularly in the last two years of each course. This has helped to build permanent relationships between individual departments and industrial firms, has placed practical project work at the centre of courses and has inevitably aided engineering design education. The challenge is to maintain the momentum.

However, with the increasing financial pressures on many students, 4-year courses can be too expensive for some. For such students, UK-SPEC provides another route with a 3-year Bachelors Degree with honours plus 'appropriate further learning to Masters level'. The lessons learnt from the VP Scheme are equally important and applicable to this route, though they may be slightly more difficult to implement.

There has been much discussion as to whether design courses should be 'added on' to engineering science courses or be an integrating theme that provides justification and motivation for the engineering science topics. The clear view to emerge from the VP Scheme is that, ideally, design should be a major integrating theme running through the teaching of undergraduate engineering. Although many agree with this concept, there are significant challenges in implementing it, not least of which is the continuing spread of modularity with the attendant pressure to avoid integrating themes that are not appropriate for all students taking a particular set of modules. Design, with its emphasis on project work, is resource intensive, and universities are always under pressure to reduce unit costs. With the current university career structures, finding staff with the relevant experience and commitment is increasingly problematic.

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There are two specific goals for the next phase of the VP Scheme. The first is to seek funding to reimburse the VPs for the time they spend at the universities and thus ensure that their support and expertise continue to be available. The second is to campaign for more resources to be allocated to the universities specifically to fund design education. Projects, especially design, build and test projects, are expensive to run as they require funds to purchase materials and components and to provide appropriate supervised workshop facilities where the production and testing of prototypes can take place. This hands-on experience not only reveals the challenge and excitement of design to the students but also helps build up the technological repertoire that many of them lack when they start an engineering course.

The influence of design in engineering courses enhances the overall educational experience and stimulates commitment to the practice of engineering. It is

[1] UK-SPEC replaces SARTOR – Standards and Routes to Registration.

rewarding for staff as well as students, and, when VPs from industry are involved, it serves also to highlight the significance and value of the work of engineers. The expansion of engineering design does not mean that the teaching of basic engineering science becomes less important. As some of the examples of good practice show, the use of Problem Based Learning and project work can make students want to learn more engineering science in order to realise their projects. Applications in project work can help students to see the elegance of mathematics and the sciences in the context of the needs of society. A solid grounding in engineering design contributes towards maintaining throughout adult life that creative drive so evident in the young entrants to the profession.

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Chapter 2
Examples of good practice


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Introduction

The ten examples of good practice which demonstrate how the wider issues of design can be brought into university courses have been developed in close collaboration with the VPs and academics at the respective universities.

The overall aim of design education is to develop the ability and confidence of students to apply engineering fundamentals to the design of products and systems. There is no doubt that this can be achieved by exposing students to design tasks of graded scope and complexity and supporting them with lectures and supervisions during the execution of these tasks.

Teaching engineering design, with its emphasis on synthesis, is clearly different from teaching engineering science, with its emphasis on analysis – but the two must be seen as partners. All products and systems depend on physical processes and material properties to function. One of the important objectives of a design course is to give students the confidence to apply the engineering fundamentals they learn in their engineering science courses to analyse and evaluate the design concepts they create.

The traditional method of teaching an engineering science, such as Mechanics, is to give a series of lectures supported by handouts and worked examples. Problem sets are provided for the students to work through, and support is given when they run into difficulties. Final assessment is usually through examination. The problem sets focus on analytical problems, with 'correct' solutions, and in most cases the required analytical models are given to the students in the questions. Undergraduates are well practised in this approach, but often run into difficulties when tackling design problems. These difficulties include:

- developing their own analytical models
- realising that there is no 'correct' solution
- appreciating the iterative nature of design
- visualising in three dimensions (3-D)
- communicating with limited engineering vocabulary
- paying attention to detail
- coping with incomplete information
- coping with their lack of technological repertoire and knowledge of existing solutions.


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When planning an engineering design course that includes lectures, case studies and projects, it is helpful to have an overall framework. To supplement the examples in this chapter, a basic framework is described in Appendix 2. The ten examples of good practice come from:

1 University of Birmingham
2 University of Brighton
3 University of Bristol
4 University of Cambridge
5 University of Leeds
6 Loughborough University
7 University of Newcastle
8 University of Manchester
9 University of Plymouth
10 University of Strathclyde.

The contributions made by the VPs cover a very broad spectrum. In order to assist comparison and help identify the key lessons, each example is presented under the following headings:

- Focus
- Description
- Achievements
- Lessons.

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THE UNIVERSITY
OF BIRMINGHAM

University of Birmingham

Focus

Strategic input to the Engineering Faculty and specific input to setting up an inter-disciplinary MEng design project.

Description

From their initial appointments in 1996, the three VPs worked together as a team at faculty level rather than within the five discipline-based engineering departments. They considered, from their different perspectives, the needs of industry and their implications for the teaching of engineering. Through wide consultation with staff and students, they gained an understanding of the teaching practices and of the opportunities for and constraints on the introduction of new initiatives. From the outset, the VPs found that the organisational framework of the University was not conducive to collaborative working across engineering disciplines.


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The VPs formed a collective view that emphasised the importance of inter-disciplinary approaches and the need to acquire an appreciation of broader engineering issues. Management and communication skills were seen as vital aids to a successful career in industry, as was experience of effective teamworking. A strong message which emerged was that engineering courses should provide a springboard to attain additional skills, through realistic challenges and learning experiences so that individual students have the versatility to cope with the increasing demands of globalisation. The courses should focus on:

- design and project work, including teamworking and communication skills
- a good grounding in engineering fundamentals
- interaction with industry
- design projects based on actual live projects.

The VPs recommended a common first year for all engineering students, based on their view that it is vital for engineers in each sub-discipline to have an understanding of the elements of the other principal disciplines, if they are to provide the visionary leadership which is vital to industry's future. However, the introduction of a common first year was not possible without organisational changes so, pragmatically, the VPs decided to focus in the short-term on encouraging each department to consider broadening its curriculum to teach an appreciation of other disciplines. As an immediate first step, it was proposed to introduce inter-disciplinary design projects into the MEng courses. At the same time, the possibility of introducing long-term organisational changes would be pursued.

In March 1999, one of the VPs accepted a short-term appointment as Director for Strategy Development for the Schools of Engineering. He became a member of the Vice Chancellor's Engineering Review Group, set up to consider organisational options for Engineering. This Group recommended a single School of Engineering, under an Executive Head. An Engineering Advisory Board was set up to establish the new organisation, and all three VPs became members. The new organisational structure has now been introduced and a common first year has been established for four of the five disciplines.

Achievements

The new inter-disciplinary group projects are a great success. Using their contacts within industry, the VPs assemble a portfolio of projects designed to address industrial design problems of real significance. The types of project favoured are those with broad implications and a number of alternative solutions. A balance of practical and theoretical work is sought to help the students to see the relevance of various aspects of their engineering studies as well as gain an appreciation of inter-disciplinary team working. Teams of 6 to 8 students, involving 2 or possibly 3 engineering disciplines, undertake the projects. The projects are designed to require about 300 hours of effort from each student over two semesters and to represent about 25% of the total credit for the year.

The approach adopted in implementing the scheme is to prepare briefing packs giving sufficient information to enable students to apply for the project of their choice. Introductory presentations are made, involving the VPs and engineers from the companies. Where appropriate, visits to the companies are arranged as a means of obtaining background information. Day-to-day supervision is provided by the academic staff, supported by occasional visits from representatives of supporting companies. The teams are required to undertake a formal review process approximately halfway through the projects and produce final reports and presentations at the end. Academic staff, VPs and representatives from industry attend these team presentations.

A specific issue, which emerged from the joint third year projects for chemical and civil engineering, was the inadequate ability of the students to conceive and develop ideas visually. As a result, freehand sketching was introduced into the 1st year of the Civil Engineering course and this led to a significant improvement in visualisation and concept portrayal.

The continuation and further development of the inter-disciplinary design projects is judged to be worthwhile and should prove easier to organise, given the established framework for the activity and the new organisation. Moreover, it is judged that the continued involvement of VPs is essential to ensure the flow of suitable projects from industry.

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Lessons

- It is important to establish a clear set of educational needs.
- It is necessary to work at faculty level rather than departmental level, and organisational changes are often required before true inter-disciplinary activities can take place.
- There is a need for courses to be more exciting, interesting and relevant to students.
- A common first year for all engineering students has many advantages.
- Sketching skills are important for all engineers.
- Inter-disciplinary projects have proved popular with the students and are perceived to have made valuable contributions to the needs of engineering education and industry.

University of Brighton

University of Brighton

Focus

Establishment of a 'Design Forum' and supporting activities to enhance the importance of design across all engineering disciplines and ensure that design is part of the underlying culture.

Description

Design had been a central theme within most of the engineering courses at Brighton from the mid 1970s. When the VPs joined the University in 1991, the strategic decision was taken to encourage collaboration between the three disciplines involved: Civil, Electrical and Mechanical Engineering. The aim was to share good practice, to develop a common approach to design, and to facilitate more inter-disciplinary projects, mirroring engineering practice in industry.

It was decided from the outset that the VPs would not be used primarily to deliver lectures to undergraduates. The VPs would work with academic staff on the development of a more design-oriented curriculum and the introduction of innovations to enhance the students' experience of design. However, they would provide some 'hands on' project tutoring and some specialist case study lectures.

The VPs were invited to join the appropriate discipline-specific Industrial Advisory Boards to ensure that the profile of design was raised within each area. In addition, a 'Design Forum' was established, chaired by the Dean of Faculty, including all the relevant Heads of School, together with colleagues from the Faculty of Art. In addition to the VPs, a number of industrialists were invited to ensure that best practice was introduced and new developments recognised.

The Design Forum produced a strategic plan and identified eight criteria to measure the success of the scheme. These criteria included the number of inter-disciplinary projects mounted, the number of students selecting design-orientated topics in their final year individual projects, and the number of local companies attracted to work with the Faculty.

Achievements

After much debate, a formal model of the design process was produced that was acceptable to all three disciplines. Notwithstanding this formalisation of the design process, a 'low bureaucracy' design management approach was pioneered by one VP and used successfully in early student design activities.

All the engineering courses in the Faculty now contain more design, and the syllabus in many areas has been enhanced through the input of the VPs. For example, thermodynamics modules now contain more reference to the practical constraints of designing IC engines, and materials modules contain more work on material selection for design. Identifying user needs, appreciating cost constraints and managing the design process now figure more explicitly in many courses.

Students now undertake realistic, open-ended design activities that encourage more creative thinking. All the main engineering courses include group design work concentrated into 'Design Weeks' scheduled during term time. These Design Weeks allow the students to focus on projects of a more realistic scale than is possible with short, weekly sessions of one or two hours. This has not only raised the students' enthusiasm for design, but also highlighted weaknesses in their design abilities.

A particular achievement is that students are increasingly required to maintain a record of all their design activity in a 'portfolio'. This, coupled with a number of project display periods when students present the state their design has reached, enables the objective and professional criticism of the VPs to be fed back more directly to students. Justifying the selection of materials and components is a common focus during such periods. The 'hands on' engagement of the VPs has proved to be very beneficial.

Several popular new courses have been launched successfully within the Faculty as a direct result of the growth in design interest, including: BSc Product Design; BSc Design and Technology; and MSc Product Innovation and Development.

Growing interest in design is reflected by an increase in design-related Knowledge Transfer Partnership (formerly Teaching Company) Programmes mounted within the Faculty.

The wealth of benefits arising from the VP initiatives will continue to enrich students, staff, the University and local industry.

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Lessons

- It is important that the VPs are senior industrialists, have substantial experience of 'real' design, show an enthusiasm for working with students and are relatively local to the university.
- It is possible to agree a common model of the design process that can be adopted across all the engineering disciplines.
- Design Weeks, the portfolio approach and project display periods, during which the VPs interact directly with students, are particularly successful.
- Open-ended design work is very time-consuming to plan, facilitate and assess.
- The acceptance of cross-faculty, inter-disciplinary cooperation is one of the most significant achievements of the VPs.
- Continued vigilance is required to ensure that the progress made in design teaching is not halted or put into reverse as a result of the many other pressures on resources and particularly teaching staff time.

University of Bristol

Focus

Philosophy and structure for a new 5-year undergraduate MEng course in Engineering Design.

Description

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The group of VPs developed the idea that Bristol could and should put on a new degree course that would help to satisfy some of the needs of the engineering industry in the UK. The VPs wanted the students to leave the course with:

- leaderships skills
- multi-disciplinary engineering skills
- a strong theoretical understanding
- well developed modelling skills
- a specialisation
- an understanding of economic, business, environmental and political issues.

In 1997 one of the VPs proposed a special Course in Engineering Design that would educate future leaders of industry by:

- attracting and engaging the enthusiasm of the best students, including those who might otherwise have been lost to engineering
- providing a strong base in mathematics and theory
- using design exercises to set theory in context
- including all engineering disciplines, but with students treating one in depth.

The VPs suggested the key set of studies that the students should follow was:

- mathematics – including control and signal processing
- physics – including the properties of materials and surface chemistry
- structural mechanics and dynamics
- fluid dynamics and thermodynamics
- electronic design and software design
- the use of computer tools in design – including CAD, FEM and simulation
- management.

The VPs provided drive and motivation to set up the new course and to ensure that it was supported by sponsoring companies. They then contributed by giving lectures describing the nature of engineering design in their own industries; arranging visits from recent graduates working in the VPs' companies; running design seminars where multi-disciplinary teams of students attempt conceptual design tasks in the VPs' areas of expertise; supporting the multi-disciplinary design projects; and giving an annual public lecture on engineering design.

Achievements

Outstanding students have been selected and the course is up and running. It is a general engineering course with a design theme running through it. The course maximises the use of available modules from the five discipline-based departments at Bristol and provides specialisations in 13 subject areas including Aerodynamics and Propulsion, Design Information Systems, Embedded Computer Systems, Process Engineering, and Water Resource Engineering.

A particular innovation has been a new set of modules called Research and Communication that run through all years of the course. These modules introduce the ideas of 'understanding' and 'back of the envelope' calculations. The Research and Communication modules are used to help form abilities that are seen as necessary for engineering leaders:

- good at finding things out
- excellent at communicating
- understanding the basics of engineering, economics, commerce and law
- good at doing rough calculations.

As part of these modules, individual students are asked to research subjects that cause difficulty, to write a short paper and to teach the other students about their topics. Finally, a set of questions is written by each student to test if the other students have understood. The students enjoy this approach and are motivated by it. They are also given numerous opportunities to practice 'back of the envelope calculations'.

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Lessons

- Personal drive from the VPs and links with industry are critical to success.
- The new degree is motivating the rationalisation of the Engineering Science teaching.
- With such a challenging course, the students are under a considerable strain. This is addressed in two ways: (1) the third year of the 5-year course is spent in industry; and (2) a special set of modules called Research and Communication is provided, getting the students to find out things for themselves and communicate their findings to their colleagues.
- The sponsoring companies provide a valuable input to the student selection process.

University of Cambridge

Focus

Contributions to teaching strategy and design research strategy, along with hands-on support of a novel 3rd year Manufacturing Engineering Project.

Description

From the outset, it was decided to utilise the special expertise of the VPs rather than involve them in routine teaching, which is seen as the role of the academic staff. The VPs therefore helped to develop design teaching and research strategies, and only supported teaching in specific areas. The first group of VPs joined the Department in 1991 and was affiliated with the new Engineering Design Centre (EDC), which had started that year.

In their first two years, all undergraduates follow a common course covering the fundamentals of engineering. In their third and fourth years, they can select from a wide range of specialist options. For many years design has been a unifying theme running though all four years of the course. In the first year, students receive lectures on product design and tackle a structural design project. The lectures describe the nature and context of engineering design and introduce the basic ideas of systematic engineering design. In the structural design project, undergraduates work in pairs to design, build and test a lightweight structure out of aluminium or steel.

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Second year project work involves teams of six students designing and building an autonomous mobile robot from a kit of parts. Modern design often requires an integrated system to be designed by a multi-disciplinary team and this design, build and test project is intended to simulate this. The design content of the third and fourth years depends on each student's specialisation. In their third year, all students complete two design projects, which are their sole activity during their third term. In their fourth year, a single major project occupies around 50% of each student's time and industrial collaboration is encouraged.

Up to 44 students are able to opt to specialise in Manufacturing Engineering in their third and fourth years. As part of this course they undertake a specially developed project that requires them to work in teams of up to five to prepare a technical and business proposal for the establishment of a new enterprise, either as a small business or as a division of a large corporation. This project is singled out for special discussion as one of the VPs has devoted a considerable amount of his time and expertise to it.

This particular project aims to give the students an understanding of the role and interdependency of the main functions within manufacturing industry including sales and marketing, design and development, manufacturing and factory design, and finance. The students are simply given a market need and project context and have to prepare a proposal for a new business venture to produce and market a product that they have designed.

The project is in three main phases. In the first phase, students choose a product concept and use marketing methods to refine, select and specify its desired characteristics. They also estimate the size and nature of the market for the product.

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During the second phase, a detailed design is developed and each team begins to consider the problems associated with product manufacture. In the third phase, solid models and drawings are produced, the detail design and production plan are completed, the factory layout is designed and an overall business plan prepared, in which the students are expected to explain how the venture could make a profit.

Presentations by each student both during and at the end of the project are valuable for developing communication skills, monitoring the progress of the project and providing milestones for the students to meet. There is a substantial industrial input to the content and assessment of the project, and a local bank manager advises each group on its business plan.

Achievements

The VPs integrated well with the department and contributed to strategy development, research supervision and project teaching. They have been full members of the appropriate Teaching Committees and of the EDC's Steering Committee. One of the VPs chaired the EDC's Steering Committee for over a decade, and the success of the Cambridge EDC owes much to the contributions from the VPs.

Direct contributions were made to the Manufacturing Engineering Project for ten years. Hard-earned experience of new product development and new business start-ups in industry was passed on by one VP to the would-be student entrepreneurs. Moreover, as many projects now make extensive use of electronics and information technology, his industrial experience of automation systems and communications technology was put to good use.

The project has been an enormous success and receives excellent feedback from the students. Several students have gone on to start their own companies.

Lessons

- Selecting the VPs after wide consultation with staff of the Department means that they integrate quickly into the teaching and research activities.
- It is important to capitalise on the special expertise of the VPs.
- VPs help to raise the profile of engineering design.
- Selecting VPs in different disciplines encourages the integration of design across the various disciplines.
- Regular presentations by the students throughout a project are a great motivator.
- It helps to make projects more realistic if as many outside people as possible are involved.
- Choosing a business context for a design project provides a realistic setting and encourages the students to address financial issues, which are often missing from student projects.

University of Leeds

Focus

Establishment of a Global Engineering Design Team (GEDT) project linking students and staff from the University of Leeds and Arizona State University, supported by industrial mentors from Rolls-Royce and Boeing.

Description

A VP was used to develop and support the setting up of the Global Engineering Design Team (GEDT) project. The motivation for this project was that manufacturing industries are becoming more global in nature, especially in their supply chains. Undergraduate engineering students rarely address this trend or have the opportunity to participate in international teams that are not co-located. Furthermore, international companies have a desire to explore closer global relationships with their current or prospective supply chain companies. For these reasons, Arizona State University and the University of Leeds started the GEDT project. The goal was to create a single team of students on a company-sponsored design project that required continual global teamwork and communication, and would thus help prepare the students for Design in a Global Environment.

A theme that emerges is the need to educate engineers not only in engineering science and the processes of engineering design and manufacture but also in so-called 'soft skills' that are important in the application of engineering knowledge within a business environment. These skills include lifelong learning, inter-disciplinary teamworking, leadership, management, entrepreneurship, initiative, communication, and experience of other cultures and languages.

The first GEDT project was the optimisation of a generic helicopter engine exhaust system. By the end of the project, the students should:

- have completed a broad-based industrially relevant project, satisfying the needs of all the stakeholders
- have worked in a global team, tackling issues of teamworking, project planning, communication, and cultural diversity
- be able to apply logical reasoning based on a firm knowledge of engineering science, and be able to demonstrate sound professional judgement
- be able to demonstrate powers of independent critical judgement.

Achievements

The first GEDT project successfully selected excellent students, met customer expectations, improved understanding of different cultural attitudes and coped with the culture shock. The main learning outcomes have been improvements in dealing with open-ended problems, communicating skills, understanding concepts (in some cases, appreciating a lack of this understanding), planning, managing and teamworking, including trust.

The following set of key requirements has been established, which are useful for engineering design team projects in general:

- a clear educational strategy must be established that facilitates experiential learning within a global context and is achievable to a schedule that matches the stakeholders' constraints
- it is important to balance the needs of all stakeholders and establish learning objectives that encapsulate all their needs
- the project should be realistic in that it represents the type of task a graduate may encounter in industry
- the student team has to be trained in team building, leadership and project management. In addition, specific technical support and advanced communication facilities are essential if the team is to operate in an integrated manner
- several mentors, both industrial and academic, are needed to provide the wide range of support required
- to provide a level playing field for the whole team, it is essential that assessment is consistent
- the concepts of continuous improvement and integration should be part of the culture.

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Lessons

- It is possible to set up a major industrially based project linking universities in two countries supported by industries in those countries.
- It is important that industrial mentors are seen as customers for the output of the project as well as its mentors.
- It is important to provide as much industrial realism in the project as possible.
- The fundamental benefit is the learning opportunity such a project affords to all those involved.
- During the first project it was observed that the students tended to

  – rely on what they knew as opposed to what they needed to know

  – not know how to use tools

  – apply their effort ineffectively

  – not know how to motivate and engage people

  – not appreciate the importance of detail in design

  – run into difficulties because of their lack of industrial experience.

Loughborough University

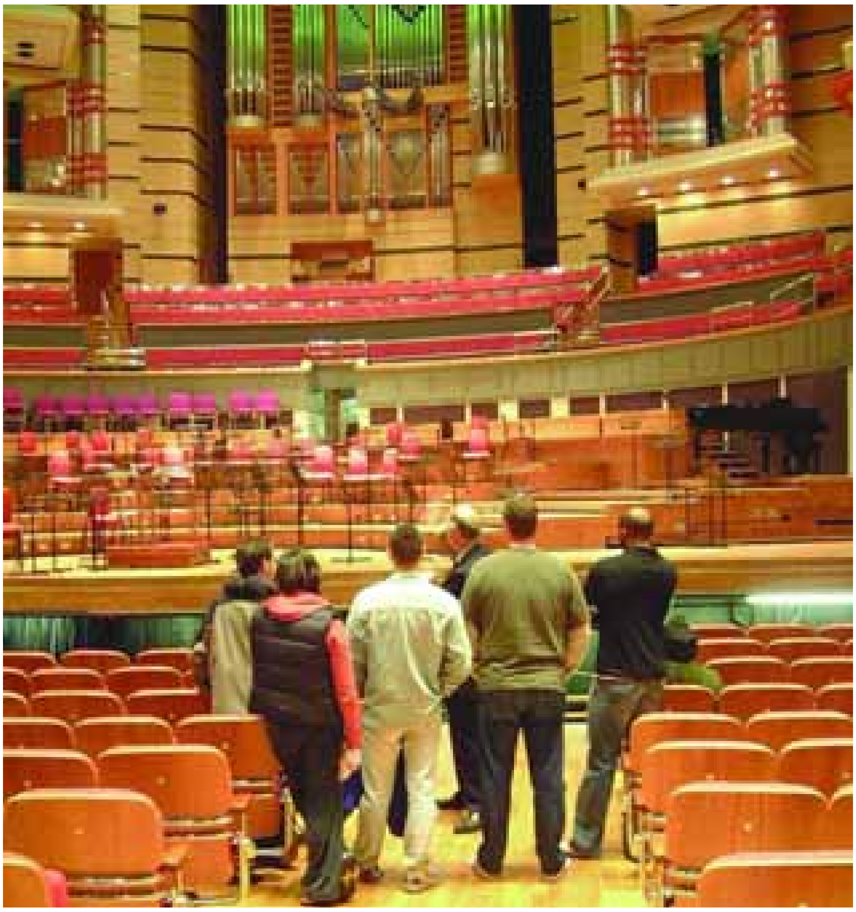
Focus

Integration of research and postgraduate teaching for a new MSc course in Building Services Engineering.

Description

A VP was used to develop and enhance the design process related to building services engineering, to encourage and support research and to assist with the MSc teaching. It is natural that research should be a major component of the relationship between a VP and a research-based Department. His activities fell under the following headings:

- raising the international profile of the Department
- providing general guidance and collaboration on EPSRC funded research
- supervising collaborative research projects
- giving lectures for design elements of the new MSc Programme in Building Services Engineering
- arranging specialist lectures for staff and students
- helping to maintain the industrial relevance and impact of the Department's research and teaching in Building Services Engineering.



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Achievements

A successful new MSc design programme in Building Services Engineering has been established, drawing upon the internationally leading research being undertaken in the Department.

One of the objectives of the programme is to show the importance and capability of software as an aid to design and to explain how it achieves results that can be used in decision-making. In addition, issues associated with the selection of appropriate software are introduced. In the context of design, two approaches are demonstrated:

- a broad overview of strategy – ventilation analysis
- a detailed analysis of the performance of a single space – thermal comfort prediction.

Lectures have been introduced that emphasise the following important concepts:

- computer programs contain models
- models are not the 'real world'; they are only someone's version of the world
- the problem, as described to the program, is a model.

Specialist lectures are organised for staff, researchers and students covering areas that are either new developments of, or are outside of, the normal Building Services Engineering curriculum. For example, Arup Research and Development was commissioned by the Chartered Institution of Building Services Engineers (CIBSE) to rewrite the section of the CIBSE Guide (a main design handbook for the industry) that deals with the calculation of static and dynamic heat flows in buildings. A description of this work, together with the major revisions in other sections, was presented.

Lessons

- It is important to link research and design teaching at postgraduate level.
- A good understanding of the relevant physical processes and engineering principles is essential to support design teaching on a specialist MSc course.
- It is helpful to hold regular group meetings at which the research programme is discussed. These provide an opportunity to look at the relevance of the research projects to industry and to see how further collaboration might be encouraged.
- Research-based teaching is a valuable means of converting graduate engineers into professionals, such as Building Services Engineers.

University of Manchester

Focus

Creation of a common design teaching philosophy across four departments, along with the development and delivery of a unified design teaching structure and approach for the 4-year undergraduate MEng engineering courses.

Description

The three VPs were used initially to review the design teaching in the four departments (Aeronautical, Civil, Mechanical and Electrical Engineering) and to identify gaps in current practice. They promoted engineering design best practice and encouraged cross-disciplinary and inter-disciplinary aspects of design across the departments. They then encouraged team activities in design teaching and project work, provided industrial case studies for design exercises, invited guest lecturers, participated in project definition and implementation and assisted with the job specifications for new appointments.

Their initial observations were that commitment to design teaching in the departments had diminished and that the time for design had been squeezed out of the 3-year courses. For instance, the 'design week' had been lost due to modularisation. The syllabus had expanded to cover commercial studies and professional development at the expense of design, which had also lost out to numerical methods. Some felt that students needed to be taught engineering science in the 1st and 2nd years before they could be taught design.

Their more specific observations across the departments were that: (1) design ranged from non existent to active enthusiasm; (2) there was little integration across the modules; (3) analysis and design were not integrated; (4) design often focused on sizing and detailing of individual elements; (5) students had too much of a problem defined; (6) there seemed to be little taught on materials behaviour; and (7) the 4-year course provided an opportunity to develop the design teaching.

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Achievements

The status of and commitment to design were raised so that it was seen as a fundamental part of engineering education. The VPs participated in curriculum development for the 4-year course, which included design as a theme common to taught modules in all disciplines. This resulted in viable and durable changes to the design teaching, in particular the introduction of Problem-Based Learning (PBL) across all disciplines. The key elements of PBL are: (1) content is introduced through tackling practical problems; (2) a team-based approach to solving these problems is adopted; (3) gaps in content knowledge are filled through active research and learning; and (4) practical problem solving is reinforced by taught theory.

A cross-school Industrial Liaison Group was established to enlist further commitment and support from industry. The new 4-year course structure is:

Year 1 Teaching to Learn

- common first year with 50% PBL

Year 2 Design as an Integrator

- start of specialisation
- applications modules based on engineering design

Year 3 The Professional Engineer

- complete transition to specialisation
- group design project, research project and industrial placement

Year 4 Research and Specialisation

- specialisation options
- research project

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Lessons

- The experience and fresh perspective of the VPs are useful for conducting a thorough review of current practice.
- The status of the VPs helps raise the profile of design teaching across disciplines.
- VPs can help to bring different teaching groups together to agree a common course structure.
- A formal Industrial Liaison Group helps enlist more support from industry and secure case studies, project support and guest speakers.
- A PBL approach is effective and popular, as well as being mutually compatible with design teaching.
- VPs provide valuable direct support for student projects and the provision of case study material.

UNIVERSITY OF
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University of Newcastle

Focus

Strategy development through Boards of Study and Industrial Advisory Boards; development of a new module on the Management of New Product Introduction; and hands-on teaching and project supervision in each engineering discipline.

Description

The activities undertaken by the VPs include undergraduate lecturing, running workshops, supervising group project work, attending Boards of Studies, contributing to Industrial Advisory Boards, and setting up new engineering modules. Each of the six VPs contributes in the department most closely related to his expertise as summarised below, with engineering design and the teaching of design as the common theme.

Chemical and Process Engineering: lectures on process economics, project management and design; advice to design project groups; assessment of the oral presentations of the design groups; supervision of design projects; and development of case study material to cover areas such as: product development (washing powder), the Byker waste reclamation plant, and the treatment of 'produced water' on offshore oil and gas platforms.

Civil Engineering: advice and support on the development of the Integrated Design Project; lectures and workshops on key design principles and the interaction of civil engineers with others working in the built environment; and a discussion of professional design experience that helps introduce a holistic integrated design theme.

Electrical and Electronic Engineering: setting up a project management module, delivering keynote lectures and supervising the coursework; encouraging much more use of formalised methods in the planning, execution and reporting of the projects.

Marine Technology: lectures describing how design relates to both technical and commercial aspects, especially for made-to-order products; design for production and product lifecycle; client-contractor relationships; effective use of computer aided design and project management tools; advice and support for student projects; membership of Board of Studies for new MTEC course.

Mechanical, Materials and Manufacturing Engineering: advice and support on approaches to design teaching in various course modules; illustration of current and emerging techniques by way of real-life worked examples; support for final year projects.

Achievements

The VPs, working together, developed and delivered a 24-lecture module entitled 'Management of New Product Introduction'. This faculty-wide module introduces: design innovation; business planning, organisation and marketing; intellectual property; concept development; product realisation (including lifecycle design) and risk management. It is supported by visits to companies and by group projects.

- *Chemical and Process Engineering* – the Byker case study workshop is considered an outstanding success, with teams of undergraduates playing the roles of the press, the public, the local council, engineers, etc., to present the case for and against the plant. Each presentation is video recorded. The workshop has now been taken up and developed further at the Universities of Oxford and Aston.
- *Civil Engineering* – the accreditation Panel of the Joint Board of Moderators is of the opinion that the Integrated Design Project is a good example of best practice.
- *Electrical and Electronic Engineering* – the students complete individual coursework to familiarise themselves with the project planning software. This is followed by a group project, which includes: generating an outline plan, establishing the requirements specification, producing P&L and cash flow analysis, calculating IRR for three alternative new product ideas and selecting the best idea.
- *Marine Technology* – the team projects give the students a feel for the realities of working with engineers from other disciplines towards a stated objective within time, budget and quality constraints. The lectures emphasise the importance of design for lifecycle.
- *Mechanical, Materials and Manufacturing Engineering* – this department has introduced: experience-based learning relating to management of risk as product design evolves; the use of a structured design process; an appreciation of the need for product advantage; and design to cost principles.

Lessons

- The VPs bring professional design experience into the undergraduate degree programme and help develop design research projects.
- If a group of VPs work together, it is possible to develop faculty-wide modules, such as the one on Management of New Product Introduction.
- VPs can make important strategic contributions through membership of Boards of Studies and Industrial Advisory Boards.
- Case study workshops, such as the Byker waste reclamation plant study, where teams of undergraduates take on the roles of the press, the public, the local council, the engineers, etc., to present the case for and against the plant, are very successful and very popular.

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University of Plymouth

Focus

Setting up a new first-year design module entitled Design as a Generic Tool that encourages a holistic understanding of engineering design.

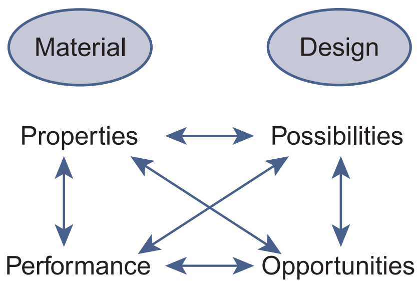
Description

A critical aspect of the education of undergraduate engineers is instilling a real appreciation of the seamless interrelationship between design and engineering, and developing the confidence to produce useful solutions to a range of engineering design projects. These attributes are often only partly assimilated in traditional engineering programmes, probably because they depend on the development of a number of high-level skills, including holistic problem analysis, creative thinking, and multi-layer synthesis.

To help develop these high-level skills, an innovative first year design module entitled Design as a Generic Tool has been set up with the help and support of the VPs at Plymouth. The VPs provide lectures and illustrative case studies for the module.

This module lays the foundations for fostering a technologically based, innovative and creative, holistic design identity. This is achieved through development of critical and analytical skills, coupled with experience in professional teamwork, and confidence in the management of engineering systems. The concept of concurrent integrated design is used to create a holistic view of the engineering design spectrum of activities. The content of the module is divided into five main areas:

- appreciating the multi-faceted nature of design – design perceptions from, for example, an architect, a product designer, and engineers from other disciplines
- formulating a design envelope – requirements, constraints and criteria
- understanding the interactions between design, materials, processing, manufacture, and service requirements (Figure 28)
- fostering innovation – brainstorming, looking for elegance, lessons from failures, looking for new twists to old ideas, and the use of TRIZ
- understanding the human dimension of design – environmental impact, the ethical considerations of its impact on society, sustainability, ergonomics, and the behaviour of teams.



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Achievements

The module ran for the first time in the 2000/01 academic year and achieved very positive student feedback. It makes extensive use of the web to provide relatively sophisticated, and extensive, resources to support lectures and project work. This gives immediacy to its multi-disciplinary content, allows multi-media presentations, and fosters the concept of synthesising knowledge gained from different 'knowledge pools'. Students pursuing degrees in marine technology, mechanical engineering, electrical engineering, and composite materials are placed into groups early in the module for two design projects. The stress of establishing the groups and working with people in different disciplines, even at this early stage, provides an incentive to access technology 'outside the comfort zone'. This often encourages

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innovation to occur through the implementation of new technology. This has also been encouraged through the use of on-line Computer-Aided Peer Assessment of individual project work, guided by genuine examples of marked essays and a detailed mark template.

Individual interaction and participation in the group projects is also monitored via on-line peer assessment, in which the mark allocated to the project is discriminated individually using confidential peer perception of relative levels of input from each member. This process is moderated through incorporation of minutes of the group meetings into the design project report. Insight can then be obtained into problems in group management and the efforts made at resolution.

Available indicators demonstrate that this module is successful in improving how well students understand the role of design in engineering. It also seems that it persuades them to take a more thorough, innovative and multi-disciplinary view of project work. Outcomes from this include a more enlightened view of the breadth of course content, coupled with an increased willingness to engage in cross-discipline discourse.

In particular, the following learning outcomes have been achieved: enhanced creativity; facilitation of egoless team work; increased flair in presentations; enhanced confidence when tackling a disparate range of engineering projects; increased awareness of the integration of design into the total product creation process; awareness of the cost and profit drivers in engineering; and increased insight into reasons for engineering 'failures'. As formation of the groups and arranging meetings proved troublesome for a sector of the class, a computer-based 'student portal' is used to provide private internet space to groups for communication and file exchange.

Lessons

- If integrating projects are incorporated early on in an engineering course, thinking processes do not become entrenched and it is easier to encourage innovative, 'networked' thinking.
- Facility with the engineering design process is a life skill that can be applied to any problem.
- It is important to encourage a more holistic view both of engineering and of the structure of the undergraduate degree.
- This holistic view feeds through into higher levels of motivation for other modules, which are then seen to be a more integral part of the education of an engineer.
- Learning can be reinforced through detailed case studies of failures in the engineering design process. These include failures arising from structural, project management, and market misconceptions.
- The web is an effective way of supporting the students and providing immediacy to the course.
- Moderated peer assessment can be used to gauge individual interaction and participation.
- The formation of multi-disciplinary teams can prove difficult and needs to be handled with care.

University of Strathclyde

Focus

Support for industry-based design projects in the final two years of the engineering programmes.

Description

The aim is to help the students understand the realisation of engineering products from design through manufacture to operation within a business and environmental context. The Design, Manufacture and Engineering Management (DMEM) Department has provided a dedicated design and make laboratory and studio space to support this.

The undergraduate degree programmes offered by DMEM contain a large amount of project work, undertaken both individually and by teams. Projects commence early in the first year and gradually increase in size and complexity throughout the courses. MEng students undertake two industry-based team projects in their last two years, the first requiring 400 hours of student effort and the second 800 hours. These team projects have the generic title *Product Development Project* (PDP). The PDP is where the VPs make their major contribution.

The PDPs are conducted by multi-disciplinary teams of four students. The teams are multi-disciplinary in that students from different under-graduate degree programmes are mixed together. They are selected by the module leader, who attempts to balance the teams in terms of ability and to ensure that each has a blend of skills including analytical, creative, artistic, CAD, marketing, management and manufacturing technology. Each project is conducted in association with an industrial partner, who sets the initial brief in association with one of the VPs or a member of staff. The specific learning objectives are:

- to plan, control and lead a design project from inception through to the manufacture of a prototype, meeting the requirements of the customer, client and company
- to integrate engineering, design, management, business, and information to ensure the efficient running of a design project
- to understand the nature of a design team, the various roles, disciplines and responsibilities, and the need to blend constructively individual strengths and weaknesses
- to appreciate the role and responsibilities of a team manager, as organiser, guiding influence, catalyst and project champion
- to understand the need to document and communicate design information throughout a project.

The VPs help with the PDP in two ways. Firstly through their industrial contacts they identify, visit and negotiate with companies who may benefit from a student project. Secondly they attend the weekly team project sessions together with the academic staff to provide tutorial support and input to the design process and project management of each team.

The Department has maximised the VPs' contribution by giving them time to recognise that universities operate in a different way to industry, making them full members of the PDP teaching team, and giving them a clear and focussed role in the Department. More generally, the visiting professors contribute to the Department through membership of the Industrial Advisory Panel and the promotion of the Department within their network of industrial, government and local authority contacts.

Achievements

The students find the PDPs one of the most frustrating but also worthwhile parts of the course. In addition to promoting teamworking skills, students claim that the projects increase their confidence in giving oral presentations to, and communicating with, industrial managers, some of whom are in senior positions.

No attempt is made to protect the students from the frustrations of consultant-client communications. Requests for information and meetings are not always met with the promptness that the students would wish for, and product specifications change as the companies see the projects progress and observe what the students are capable of achieving. Students must continually balance the academic requirements to pass the module with the desire to design products that will be accepted by the companies. The Department considers these frustrations as part of the learning process. The weekly contacts enable staff and VPs to monitor how the teams are coping with the frustrations and offer appropriate advice.

Students consistently comment that the input of the VPs is very worthwhile. They see the VPs as 'outsiders', which has two positive effects. Firstly the VPs are able to provide an independent arbitration service between the academics and the companies. Secondly they are perceived as engineers who have real experience of the product development process.

Teams also ensure all information is logged, using a software package called BSCW that enables web-based data management. Staff, visiting professors and companies have access to BSCW.

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Lessons

- Working in teams of four on real projects for industrial sponsors helps to meet the educational aims of the Department.
- It is important that the VPs have the appropriate personalities to work with staff and students.
- Having 'been there and done that' gives the VPs credibility with students.
- It is important that VPs are still active in design or design management; have a good network of contacts; live and work near the University; are able to devote regular time to their role; and are responsible to a single department.
- Because the ethos of working in teams is inculcated from the first year, conflicts between team members are rare, as are instances of individuals failing to contribute to the team effort.
- Web-based communication has proved effective.

Chapter 3
Summary of good practice

Role of VPs

In those universities where design education needed to have its role enhanced and the curriculum updated, the VPs have made significant contributions by raising the profile of design, establishing new design teaching frameworks and courses, and setting up multi-disciplinary case studies and projects in collaboration with industry. The VPs have acted as advisors and reviewers, promoters and negotiators, motivators and inspirers, as well as mentors and assessors. The VP Scheme has endorsed the following three concepts that underpin good practice, namely:

- design provides an **integrating theme** for the study of engineering
- **multi-disciplinary team projects** are the best way to introduce students to the technical and organisational complexities of design. Much is gained from undertaking these projects in collaboration with industry where appropriate
- design provides a strong **motivation** for students to study engineering science with interest and enthusiasm.

At the strategic level the VPs have:

- reviewed design courses across disciplines and brought fresh insights that have invigorated staff and students
- encouraged changes at senior levels in the universities
- emphasised the importance and value of experiencing design in engineering education
- resolved issues arising between disciplines
- set up multi-disciplinary committees and industrial liaison groups
- brought universities and industry closer together.

A general lesson is that a design teaching programme needs to have a clear framework. To provide a starting point, a basic framework is described in Appendix 2. Another valuable resource was built up during the 1980s and 1990s by engineering design educators under the heading Sharing Experience in Engineering Design (SEED). The teaching support material is available online at http://www.co-design.co.uk, a web-site sponsored by The Royal Academy of Engineering, The Institution of Engineering Designers and SEED. SEED is now the Design Education Special Interest Group of The Design Society (DESIG), see http://www.designsociety.org.

Lessons learnt at the operational level include:

- Design should be introduced from the very start of an engineering course, even though the engineering vocabulary and repertoire of the students may be lacking.
- A common first year for engineering students of all disciplines should be considered whenever possible.
- Design weeks greatly increase the level of motivation and participation as they allow students to focus on their design projects.
- Formal presentations by the students at regular intervals during their projects not only improve their communication skills but also provide useful opportunities to judge progress.
- Problem Based Learning (PBL) sits naturally with design teaching and can bring many advantages.
- The fundamental partnership between engineering science and engineering design should be emphasised throughout.
- With the growth of modular courses, introducing a design theme becomes more challenging, but is still possible and is rewarding for students as it brings coherence to the curriculum.

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Multi-disciplinary design projects

The methods available to deliver a design course include lectures, case studies and projects. Although much useful information about tackling a design task can be put across in lectures, supported by case studies, a strong message to emerge from the VP Scheme is that undertaking design projects, particularly in multi-disciplinary teams, is the best way to develop engineering design ability in students.

Design projects can tackle a simulated or a real task; be undertaken individually or by a team; be paper-based or involve building and testing a model or prototype; and can focus on one discipline or be multi-disciplinary.

During the first two years of, say, a 4-year MEng course, simulated projects are frequently used as the teaching and the resources can be carefully planned and matched to a specific aspect of the design process and to the knowledge and ability of the students. In the final two years of a course, when the students have developed design and analysis skills and built up sufficient technological repertoire, real projects can be tackled, often in collaboration with industry or a university research project. This collaboration can present those supervising such projects with some difficult decisions. Should they allow the students to go up a blind alley realising that this will be a valuable educational experience, but might disappoint the customer?

Projects can either be undertaken by students working individually or in a team. Both have their place. If students work individually, specific guidance and assessment are straightforward. When working in a team, students acquire many group skills, such as leadership, management, teamworking, and communication, as well as individual skills,

Multi-disciplinary team projects:

- inspire students through providing real and challenging tasks
- encourage the development of group and individual skills that cannot easily be acquired in other parts of an engineering course
- bring an industrial context into undergraduate studies
- demonstrate the advantages of multi-disciplinary teams
- depend for their success on a solid understanding of engineering science fundamentals
- increase the confidence of students when working on real world design tasks
- help prepare students for their subsequent careers.

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such as creativity, decision making, working under pressure, and time management. However, assessing each member of the team individually becomes more difficult. There is no doubt that the benefits of working in teams, especially multi-disciplinary teams, far outweigh any assessment problems that might arise.

Design, build and test projects provide a much richer experience. Testing what they have designed and built, possibly in competition with other students, both increases motivation and really brings home lessons about designing that no paper-based project possibly can. However, design, build and test projects require far more resources.

Many of the VPs have helped set up and run multi-disciplinary team projects in collaboration with industry.

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There are many issues associated with setting up and running engineering design projects. Each new project must, of course, be matched to the particular engineering course, the expected learning outcomes and the resources available. It is very difficult to replicate the true complexity of industrial practice in an academic setting, even with projects undertaken in collaboration with industrial partners. When selecting projects, every attempt should be made to ensure that they provide the students with the opportunity to experience all stages of the design process. Many of the challenges, pressures and excitement of commercial design can be experienced by students if they take part in national and international design, build and test competitions. These competitions generate enormous enthusiasm and motivation – and provide students with very tangible feedback of the success or otherwise of their design process. Examples of such competitions include:

- Formula Student – www.imeche.org.uk/formulastudent
- Eurobot – www.eurobot.org/eng
- Shell Eco-Marathon – www.shelleco-marathon.com

There are numerous other design competitions. These are frequently linked to specific engineering disciplines and information about many of them can be found on the websites of the professional institutions.

It is important to help students understand the value of:

- managing the project carefully
- ensuring effective teamworking
- establishing the correct requirements at the beginning of a project
- coping with complexity, both technical and organisational
- knowing when to create a new solution and when to build incrementally on an existing one
- planning for the whole of a product's life cycle
- minimising the impact on the environment
- applying modern analysis and simulation tools appropriately
- using modern communication methods efficiently
- retrieving and organising information effectively
- estimating and monitoring costs
- understanding the role and value of physical models and prototypes
- attending to the detail design requirements – 'The devil is in the detail'.

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Appendix 1

List of Visiting Professors in Principles of Engineering Design

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Listed below, in alphabetical order of their host universities, are the Visiting Professors who have contributed to the Academy's VP Scheme since it started in 1989. Their numerous contributions to making the Scheme such a success and their many lessons that this book has attempted to capture are gratefully acknowledged.

University of Aberdeen Gilbert Herries, Duncan Michael, Ramsay Spence, Ian Stewart

University of Aston David Butterworth, Michael Cahil, Jose Lopez-Merono, Jonathon Wood

University of Bath Arthur Fowkes, Stephen Moore, Jorgen Nissen, Ivor Owen, Alec Parker, Colin Seabrook

University of Birmingham Gerald Clerehugh, Duncan Hodgson, Ernest Irwin, Tony Marriott, Graham Oates

University of Bradford Charles Sandbank, John Smith, Graham Thompson

University of Brighton John Bergg, Alan Crouch, Jack Izatt, Lionel Lake, Frank Miles, Paul Wesley

University of Bristol Roland Bertodo, Robin Brown, Jeremy Davies, Chris Elliott, Horst Peters, Michael Shears, Ted Talbot

Brunel University Bob Gibbon, Peter Hills, Peter Isherwood, Chris Pearson, David Reedman, Peter Wallin

University of Cambridge John Drane, Roy Farmer, Peter King, Meirion Lewis, Ian Liddell, Robert Mair, David Melford, Andrew Palmer, John Parnaby, Ivan Yates

University of Cardiff David Colliver, Peter Dietz, Ron Midgley, Scott Steedman

University of Central Lancashire Peter Liddell, David Witt

City University London Martin Fry, Clive Leyman, James O'Sullivan, Peter Tromans

Coventry University Glynne Bowsher, Peter Foyer, Peter Hills, Charles McCaskie

Cranfield University Peter Hills, Paul Wiese

De Montfort University Sami Ahmed, David Lindley, Martyn Paradise, James Randle

University of Dundee Ian Cameron, Peter Gibson, David Young

University of Durham Mavis Doyle, Svend Trinder

University of Glasgow Robert Beaty, Chris Moore, Jim Reid, Norman Taylor, Brian Veitch

Heriot-Watt University George Hazel, Sandy MacFarlane, Charles Radford

University of Hertfordshire John Guppy, Jon King, Ian Mays, Brian Rofe

University of Hull Richard Batchelor, Peter Deasley, John Elmore

Imperial College London Brian Cane, John Coplin, Brian Dyson, John Hannis, Ken Lillie, Sue Lyons

Kingston University Christopher Binnie, Jack Houldsworth, Paul Murray

University of Leeds Raman Narayanan, John Roberts, Richard Taylor

University of Leicester Ken Jackson, Peter Jones, David Munday, Chris Rodwell, Jeremy Wheeler, Philip Williams, Stephen Williams, Jeffrey Williams

University of Liverpool Peter Gough, George Moore, Malcolm Sabin

Loughborough University John Banyard, Gerald Clerehugh, David Gardner, Michael Holmes, Al Humrich, Peter Nevitt, Bob Pendlebury, Gwilym Roberts, Tony Stevens, Michael Withers

University of Manchester Glenn Birchby, Brian Day, Stuart Lewis, Mike Mansell, John Mills

University of Newcastle Robert Fielding, Les Grant, John Grant, David Horsley, Bill Oliver

University of Nottingham Gordon Higginbotham, Geoff Kirk, Colin McChesney, Andrew Pickard, Howard Taylor

Open University Paul Wiese

University of Oxford Roger Booth, Edmund Booth, Bob Brewer, John Coplin, Edmund Hambley, Jock Hill, Raymond Lohr, Hamish Rankin, Paul Thompson

Oxford Brookes University Peter Brett, John West

University of Plymouth John Menzies, James Quinn, Gerry Shaw, Geoff Skates

Queen Mary University Mike Collins, Geoffrey Kirk, Robert Parkinson, Stephen White

Queen's University Belfast Stephen Brown, Lawrence Dewhurst, John Hill, William Millar

Royal College of Art Michael Ashby

University of Salford Philip Hamilton, John Milnes, Chris Pearce

University of Sheffield Gordon Brown, Neville Burton, Richard Gostling, Ian Henning, Ken Holliday, Pam Liversidge, Robert McKittrick, Jim McQuaid, David Parsons, Geoff Stone, David Walters

University of Southampton Paul Ahm, John Amner, Bob Cripps, Gordon Hodson, Edmund Hollinghurst, John Walker, Jane Wernick

University of Strathclyde Martin Bell, Frank Binnie, Martin Gordon, Arthur Slight, Jimmy Smith

University of Surrey Chris Blow, Jan Guidoboni, Richard Harris, Philip Hayman, Raymond Lohr, Peter Mason, Stephen Nightingale, Peer Rugaard, Ian Willcox

University of Sussex Rod Edwards, Colin Newell, Roy Simons, Len Trevillion

University of Ulster Stephen Brown, Lawrence Dewhurst, John Hill, William Millar

UMIST Dennis Allan, David Grundy, Anthony Richardson, John Roberts, James Taylor

University of Warwick Trevor Crisp, John Miles

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Appendix 2

Framework for engineering design education

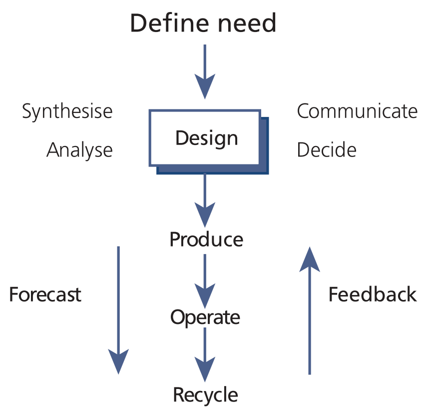
A broad definition of engineering design is:

Engineering design is the process of converting an idea or market need into the detailed information from which a product or system can be made to satisfy all the requirements safely, economically and reliably.

In order to explain the design process effectively, it is helpful to have an overall framework. Design methods and guidelines can then be described within the context of this framework, and their application in practice demonstrated through projects. A starting point is provided by James Armstrong in his booklet ***Design Principles – The Engineer's Contribution to Society*** (Armstrong, 2002). Armstrong's high-level model of product development encompasses three key stages of realisation:

- Need – all design begins with a clearly defined need
- Vision – all designs arise from a creative response to that need
- Delivery – all designs result in a system or product that meets that need.

The *need* might arise from a good idea, a new technological development or a carefully researched market requirement. In order to turn this proposal into a concrete system or product, a design team with *vision* must be established to undertake the complex sequence of activities necessary to define what is to be produced. If *delivery* of the system or product is to be timely and cost effective, then the design team must be provided with adequate resources, including finance, facilities, tools and information.



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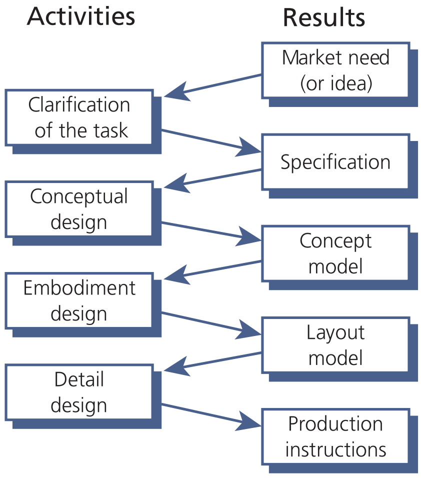
A slightly more detailed model of product development is shown in Figure 37. After a *need* has been defined, the creative activity of *design* is supported by inputs from other key functions such as production, marketing, research, development, quality assurance, sales and customer service. Progress depends on making *decisions*. During the design stage the aim is to ensure that the proposed product will be economical to *produce*, that it will *operate* to specification safely, reliably and economically, and that it will be possible to *recycle* it at the end of its useful life. Where recycling is not possible, careful consideration should be given to safe decommissioning and environmentally benign disposal. Decisions depend on the accuracy of *forecasts*, ranging from broad customer requirements to detailed engineering stresses in a component. The design team as many solutions as possible and *analyses* them to predict how these solutions will perform if realised. Forecasts, and the decisions based on them, often turn out to be in error and corrective actions have to be taken. Simple models, such as that shown in Figure 37, mask the complex iterative nature of the product development process. The stages often merge and because of errors and unknowns many steps have to be returned to and repeated. For complex products, extensive development programmes involving costly prototype testing are necessary before they can be released for production. Large quantities of information, obtained from repositories and specialists in many different fields, must be handled during the design process. Since large, widely dispersed design teams are often required, *communication* becomes a major issue. Continual *feedback* from all stages of the process provides essential information for improving the system or product.

Design problems are often described as being 'open-ended'. By this it is meant that they do not have 'correct' solutions, though some solutions will clearly be better than others. Several solutions must be developed before the best can be selected through evaluation against the criteria. This is an iterative process involving many feedback loops during which information is updated to improve both the criteria and the solutions.

A general strategy for tackling complex problems is to break them down into smaller, more manageable sub-problems and to tackle each sub-problem in turn. In line with this strategy, the design process can be split into a number of main phases, and each phase then broken down into a number of steps. A model showing the four main phases of the design process, starting with the crucially important clarification of the task phase where the true need is defined, is shown in Figure 38. Details of the phases and steps, which often have to be undertaken concurrently, along with appropriate methods and guidelines to tackle each step, can be found in standard texts on engineering design (Pahl & Beitz, 1998; French, 1999).



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The model of the design process shown in Figure 38 can give the impression that each phase of the design process is completed before the next one is started. This is seldom so. The phases merge and are frequently repeated. The detail design of long-lead time items will have to be undertaken and the sourcing of materials and production started before the design of other, less critical, items has been completed. In the past designs tended to be passed to the production department without careful consideration having been given to process planning and the procurement of materials and bought-in items. Also, at times, little attention was given to how easily a product could be maintained in service and then disposed of and recycled at the end of its useful life. It is therefore vital to emphasise the importance of starting to plan for production, materials procurement, maintenance and disposal early in the design process.

Although a systematic approach to design is advocated, it is important to emphasise that such an approach must be applied flexibly and adapted to suit the particular project being undertaken. It is not intended to replace intuition, inventiveness or insight, but rather to support and enhance these qualities by disciplining thinking and helping to focus on important aspects of the problem.

It is important to recognise that because of the time constraints on their studies, and consequently the limited time they spend on engineering design, students can still fail to appreciate two important characteristics of new product creation – even if this framework is used.

The first characteristic is that in order to deal with the complexity of many products, they evolve incrementally. Experienced designers have a large repertoire of past design solutions to draw upon and have a wide knowledge of and feel for standard parts, material properties, and production and assembly processes. Undergraduates do not have this repertoire.

The second characteristic is that attention to detail is critical. What distinguishes a safe and reliable product is often not its conceptual design but its detail design. Undergraduates often consider the detail design phase to be less important than the others. It should be pointed out that many excellent concepts fail in the market though lack of attention to detail. Because of time constraints in undergraduate courses, it is seldom possible to undertake the full detail design of a product of significant complexity.

The four phases of the design process can be summarised as:

- **Clarification of the Task**
  The starting point for the design process is an idea or a market need, often stated in vague, and sometimes contradictory, terms. Before the subsequent design phases start, it is important to clarify the task by identifying the true **requirements** and **constraints**. The result of this phase is a **design specification** (design brief or requirements list), which is a key working document that should be continually reviewed and updated as the design develops.
- **Conceptual Design**
  In this phase, concepts with the potential of fulfiling the requirements listed in the design specification must be generated. The overall functional and physical relationships must be considered and combined with preliminary embodiment features. The result of this phase is a **concept model** (drawing).
- **Embodiment Design**
  In this phase, the foundations are laid for detail design through a structured development of the concept. In the case of a mechanical product, the result of this phase would be a detailed **layout model** (drawing) showing the preliminary shapes and arrangement of all the components, along with their materials (Ashby, 2005).
- **Detail Design**
  Finally, the precise shape, dimensions and tolerances of every component have to be specified, and the material selections confirmed. There is a close interrelationship between the shape of a component, its material and the proposed method of its manufacture. The result of this phase is a set of detailed **manufacturing instructions**.


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ISBN 1-903496-17-9

The Royal Academy of Engineering
29 Great Peter Street, London, SW1P 3LW

Tel: 020 7227 0500 Fax: 020 7233 0054

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