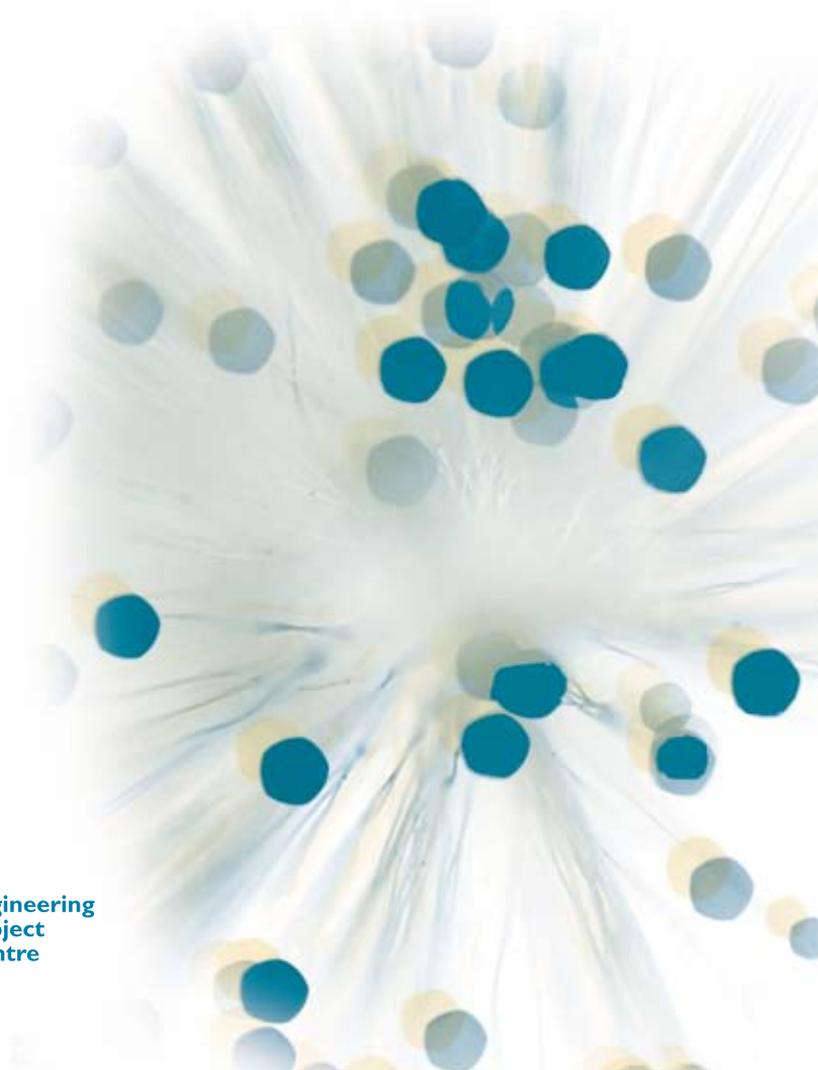


Learning and Teaching in Laboratories

an **Engineering Subject Centre** guide by
Clara Davies



**The
Higher
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Centre**

Author's biography

Clara Davies is a Senior Academic Staff Development Officer at the University of Leeds and is involved in designing and delivering programmes in learning and teaching to support new and experienced staff and those who have a part-time teaching role at the University. Her main interests are in student support and retention. Clara has a background in Engineering, with extensive experience both as a researcher in industry and as a senior lecturer in the School of Engineering at Liverpool John Moores University. Together with two colleagues she has written a book on course design (Butcher, Davies & Highton, 2006).

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Learning and Teaching in Laboratories

Overview

This resource considers the practical challenges of designing laboratory learning within a modern engineering curriculum. It provides ideas and practical guidance for both staff new to teaching and for experienced staff who wish to rethink or reinvigorate their approach.

The resource is structured around a model of course design:

- Aims and learning outcomes
- Design for learning
- Delivery
- Assessment
- Evaluation

Learning goals and models of pedagogy are looked at in terms of underpinning the design of practical work (at both programme and module levels) that is effective in promoting student learning.

Good practice in laboratory teaching, assessment, alternative approaches and ways of ensuring that delivery is accessible to disabled students are considered. The use of learning technologies to support delivery and assessment is also explored.

This resource is a gateway to relevant educational literature and to examples of developments in laboratory learning being supported by the Engineering Subject Centre through its funding of small-scale projects.

Laboratory and practical work in the engineering curriculum

Laboratory and practical work are characteristic features of an undergraduate degree programme in any engineering discipline. In the UK, laboratory teaching can account for up to 50% of the contact time and, additionally, much of students' study time is taken up writing and researching for practical and project reports, with possibly 20–30% of marks at each level awarded on the basis of assessment tasks associated with practical work.

The role and benefits of practical work in the engineering curriculum are to:

- motivate students and stimulate their interest in the subject;
- help them to deepen their understanding through relating theory to practice;
- provide opportunities for students to work together on analysing and solving engineering problems;
- develop skills and attitudes that will enable graduates to operate effectively and professionally in an engineering workplace.

Challenges of incorporating practical work

Trying to incorporate practical work successfully in to the engineering curriculum can present a number of challenges. Laboratory and practical work are expensive to run, sometimes requiring specialist equipment to be purchased that can rapidly become obsolete.

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Practical sessions are time-consuming to organise, manage and assess. Space and equipment can be limited and student cohorts are often subdivided into groups to undertake a rolling programme of practical sessions that is often out of sync with the lecture programme delivering the associated theoretical concepts.

Some degree programmes have overcome these organisational challenges by abstracting all practical work at each level into laboratory skills or practical engineering modules that enable practical skills development to be made more explicit within the curriculum, but the downside of this approach is that theory and practice may become even further divorced in students' minds.

In addition, students are often required to re-produce routine experiments that yield well-known results and to focus on experimental methodology rather than on developing skills of data recording, analysis and problem solving.

Despite the challenges, the application of theory in a practical setting remains an expected and fundamental part of the engineering curriculum.

The challenge now is for programme teams to consider how the knowledge, skills and attributes that we desire to develop through such practical activities can be facilitated in an appropriate, effective and efficient way within an engineering degree programme for the 21st century.

Aims and learning outcomes

UK-SPEC (EC^{UK}, 2004) and QAA (QAA, 2006) define the general qualities and attributes expected of a graduate from an engineering degree programme in terms of:

- Knowledge and understanding
- Intellectual abilities
- Practical skills
- General transferable skills

These standards, although they do not prescribe a curriculum, can be used to categorise the different types of aims to be developed through practical work and to assist in the design of learning and teaching strategies to achieve them.

Many of the desired qualities can be developed through practical or project work but it may be that some learning goals can be achieved effectively and more efficiently without the need for hands-on laboratory experience.

Before starting to design individual classes or experiments, programme teams first need to agree which of the key learning goals at programme level are best achieved through practical work. These opportunities for laboratory learning can then be mapped across all levels of the programme and it can be made clear to both staff and students how practical work fits into the bigger picture.

Gibbs et al. (1997) recommend that the design of practical work should take a pragmatic approach, targeting only those aims that can be realistically achieved given the resources available. They

recommend concentrating on achieving **higher level aims** (i.e. those that go beyond learning the specific use of equipment), such as:

1. Developing experimental, design, problem-solving and analysis skills
2. Developing data-recording and analysis skills
3. Familiarising students with equipment techniques and materials
4. Developing practical skills
5. Developing communication and interpersonal skills
6. Developing technical judgement and professional practice
7. Integrating theory and practice
8. Motivating students

A key goal for the study of engineering in HE is to facilitate students' development as autonomous, lifelong learners and to equip them as graduates to start a professional engineering career. An important general goal for the laboratory-based learning elements of engineering study in HE is to foster students' understanding of the process of scientific enquiry and the ways in which knowledge is created and validated, fitting well with a common institutional goal of linking research and teaching.

Implications of models of student learning

There are a number of underpinning pedagogies, models of student learning, that have relevance to teaching and learning through laboratory or practical work and that can be adopted to promote achievement of the desired goals.

Constructivism

The models described below are based on constructivism - a theory of learning that indicates that we learn by building on and amending previous actions, experiences and knowledge. Constructivism recognises that students do not come to us as a blank canvas but that learning takes place by changing and adding to pre-existing knowledge or understanding. Design of laboratory learning needs to consider how to bring in and build on students' prior learning.

Experiential learning

Experiential learning is a process of learning through experience - or 'learning by doing' – the rationale often used for the inclusion of laboratory-based activities in the curriculum. The most popular model of experiential learning is that developed by Kolb (used also as a model for continuing professional development and lifelong learning).

Figure 1 represents the four stages of the Kolb learning cycle: doing, reviewing, concluding and planning. The model indicates that the cycle can be entered at any stage but all stages must be followed in sequence for learning to occur. It is apparent that there is no direct link between learning and doing (i.e. theory and practice).

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Figure 1. Stages of the Kolb learning cycle (Kolb, 1984)

Design of laboratory learning needs to enable students to go through all four stages. Elements of **reflection and planning** need to be built-in in order to actively encourage students to make the connections between their practice-based experience and theoretical concepts.

Enquiry-based and problem-based learning

Enquiry-based learning (EBL) is "an environment in which learning is driven by a process of enquiry owned by the student" - see the CeTL for EBL based at Manchester University:

www.campus.manchester.ac.uk/ceeb/eb/

EBL is a student-centred approach in which teaching staff act as facilitators. Real-life scenarios are provided that act as triggers for students to investigate topics for themselves, either practically or through searching library resources. As a design approach, EBL has clear

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potential to achieve a wide range of learning goals for engineering students: teamwork, experimental design and analysis, information literacy and as a way to encourage autonomous learning and creativity.

An EBL approach can be used to design small-scale investigations and project work that may be conducted via practical or laboratory activities.

The School of Engineering at Manchester University has implemented a school-wide Problem-Based Learning (PBL) approach - a subset of EBL - the early stages of which were undertaken as an FDTL project by a consortium of UK universities – see www.pble.ac.uk/ - and this too has relevance for the design of practical project work.

See also Houghton (2004).

Design for learning

At the programme level

There are a number of different approaches to designing practical work. Table 1 (adapted from Hazel and Baillie, 1998) shows five design options that differ in the extent to which they are 'open' (i.e. foster student choice and autonomy). The designs progress from teacher-led demonstrations, where all aspects of the laboratory are given by the teacher, to student-led projects in which all aspects of the design are open to the student.

Table 1. Levels of autonomy for types of laboratory activity

Level of autonomy	Type of laboratory activity	Givens			
		Aims	Material	Method	Answer
0	Demonstration	Given	Given	Given	Given
1	Exercise	Given	Given	Given	Open
2	Structured enquiry	Given	Given in part or whole	Open in part or whole	Open
3	Open-ended enquiry	Given	Open	Open	Open
4	Project	Open	Open	Open	Open

QAA and UK-SPEC state that for students to achieve a satisfactory understanding of engineering they will need to have significant exposure to hands-on laboratory work and substantial individual project work and that the curriculum should include both design and research-led projects which are expected to develop independence of thought and the ability to work effectively in a team – a **variety of approach** is needed.

Students given experimental exercises throughout their degree programmes, where only the results are variable, may be ill-equipped to respond to challenges presented by independent project work. If creativity and innovation are to be fostered then students need to be involved in the design of experiments and to develop an understanding of the uncertainties and inaccuracies of outcomes from the outset.

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This has implications for the design of laboratory and practical activities at programme-level, as students need to be helped to make the transition from tutor-led to student-led approaches and to develop the skills necessary for independent learning through exposure to experimental design and project work at early stages in their degree.

The types of practical work and the skills developed by each need to be mapped across the programme to enable progression to independent project work and to ensure that approaches are not overused or the same skills assessed repeatedly.

At the module and session level

Laboratory classes are often organised around module topics. This can be effective in that they can mirror the theoretical sessions, enabling students to draw links. However, modularisation can prevent students from making links more broadly across their curriculum and efforts must be made to counteract this.

The possible uses and design considerations for the five types of approach are given in Table 2 (adapted from Hazel and Baillie, 1998):

Table 2. Possible uses and design considerations for different approaches to laboratory activities

Demonstration

- To show features of a piece of equipment and how it works.
- To demonstrate a particular concept or theory.
- Effectively a “show and tell” approach but could be made more interactive by students being asked questions to prompt thinking.

Exercise

- To use a skill or technique accurately.
- Students follow a procedure to obtain a known outcome – a traditional approach that cannot achieve all goals for practical work and tends to focus on procedure rather than enquiry.
- Students need to know the aims and why it is important to them, their learning and to potential careers.
- Can be improved by providing a motivational context such as students being given choice (e.g. of which equipment to use by evaluating the outputs and limitations of each).

Structured enquiry

- To foster a deep approach to laboratory learning by encouraging students to take personal initiative (e.g. planning, experimental design, choice of variables, selection of materials and methods).
- Students are presented with a problem or series of research questions that can be based on real life, together with suggestions for resource materials and a range of equipment/ materials to choose from.
- The range of possible outcomes produces individual student solutions and opportunities for collusion and plagiarism are reduced.

Open-ended enquiry

- As above, with more decisions and experimental design considerations resting with the student.

Project

- As above but more major pieces of work that simulate real-life research and development.

Delivery

As with any teaching session, planning and structure are required. Students need to be clear about the learning goals at the outset - what they are doing and why - and need to leave knowing what they are to do afterwards with their results and in preparation for any assessment tasks.

To prepare, staff will need to have tried out any experiments for themselves, become familiar with health and safety procedures, identified any pitfalls or things that can go wrong and know how to rectify them or where to get help.

Introduction and context

Laboratory sessions need a short introduction to set the context, although this needs to avoid becoming a mini-lecture, and could provide:

- An overview of the session
- Safety briefing and laboratory rules
- Learning outcomes
- Links to other parts of the programme
- What students are expected to get out of it
- Instructions or demonstration
- Expectations for participation and level of autonomy
- Invitation for questions

During a laboratory session an 'ideal' laboratory facilitator:

- ✓ Is approachable – friendly, available, helpful
- ✓ Is proactive as well as reactive – recognises those having difficulties and those who are coasting
- ✓ Encourages active participation by students and counters the 'freeloaders'
- ✓ Has a positive attitude to the subject material, class and students – a good role model
- ✓ Emphasises learning 'process' and 'product'
- ✓ Gives students opportunities to practise skills and learn from their successes/failures
- ✓ Encourages students to integrate their learning with other aspects of their studies
- ✓ Draws comparisons and parallels between laboratory work and professional practice

Summary and conclusion

Time should be built in at the end of a session to answer questions and to prompt students to review and reflect on what they have achieved. Links to other classes, assessments, and the real world can also be made at this point.

Questioning skills in the laboratory

A key skill in facilitating laboratory-based learning is by effective questioning, e.g.:

- Asking open questions that encourage students to talk - can you elaborate on that... why do you think that happens ... what do you think will happen ... can you give me an example of ... where do you think that has relevance...
- Giving time for students to think and answer
- Structuring your questions by breaking them down into smaller, more manageable parts

Training and supporting demonstrators

Many of the qualities required by teachers in supporting and facilitating laboratory work are also required of demonstrators. As a module leader or manager of laboratory teaching sessions you will need to ensure that any demonstrators are fully briefed for their role by being provided with relevant safety instructions, module context, learning outcomes, resource materials and assessment criteria to enable them to undertake the duties required.

Demonstrators should be given initial training in learning, teaching and assessment that provides basic understanding of underpinning pedagogy and also introductory teaching skills that will enable troubleshooting if situations arise.

It may be necessary to moderate any marking undertaken by demonstrators and to provide opportunities for them to receive feedback on their demonstrating from both students and staff.

Assessment

As with the design of laboratory classes, programme teams need to be clear from the outset what they are trying to achieve through their assessments of laboratory learning and to recognise that it may not be necessary to assess everything all of the time.

Laboratory reports

Report writing is a skill highly relevant to the engineering profession but laboratory reports are time consuming to produce and to mark. When assessing practical reports the same skills are often assessed repeatedly. Current concerns regarding over-assessment mean that workloads placed on both students and staff can make it unfeasible to assess full reports for every laboratory activity undertaken. Assessment of laboratory reports can be streamlined by using:

- Feedback sheets
 - structured around the report format
 - list of common errors, with ticks against
- Model reports – give out an example of good work for students to compare theirs against
- Peer and self assessment – students marking each others' or their own work
- Student selection of laboratory to report on (e.g. only two out of four to be written up)
- Sampling of reports by staff (e.g. students have to write reports for all laboratory classes but only two out of four will be marked).

Alternatives to laboratory reports

Different parts of a laboratory report can be selected to assess in progressive tasks – abstract, literature review, evaluation of the research or testing methodology, data analysis and presentation of results, discussion in relation to theory – with feedback specific to each aspect provided for each task. Gibbs et al. (1997) suggest the following alternatives to traditional report writing:

- Group reports
- Presentation, verbal report
- Conference paper
- Writing a 'user manual' or guide
- Poster
- Laboratory workbook
- Instant report submitted at end of lab
- Laboratory exam

Assessing laboratory learning processes

Many assessment methods only assess the 'product' of learning rather than the learning 'process' that students undergo. Ways of assessing learning processes include:

- **Direct observation** - of practical skills (e.g. assessment stations like in an Objective Structured Clinical Examination (OSCE))
- **Reflection**
 - on how the group worked
 - on what to do differently next time
- **Planning** - of experimental work
- **Time management** – via a log book or laboratory work book

Alternative approaches to laboratory learning

Many of the qualities and higher level learning goals traditionally gained through laboratory-based investigation can be achieved without undertaking any hands-on practical work.

“Hands-off” practical work

An enquiry-based learning approach can be used to develop a deeper understanding of theoretical concept(s), presenting a real or simulated scenario or problem that can be solved outside the laboratory by:

- designing a procedure or protocol
- designing or selecting equipment
- investigating equipment that is not functioning correctly
- responding to a ‘case study’ of a real world problem from industry/commerce.

An example from Hazel and Baillie (1998):

- How do polymers behave under different conditions?
- Design an experiment to investigate the viscoelastic properties of polymers.

Gibbs et al. (1997) suggest that students can be given a **raw set of real data** (e.g. manufacturer’s data or data obtained from industry or derived previously by staff or students) and be required to do one or more of the following:

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- analyse the data and present the results in a report, complete with a discussion linking the theory and practice.
- undertake an error analysis of laboratory measurement systems.
- interpret the data and suggest what further experimentation is required.

Similarly, students can be given a scenario in which to role play that will actively encourage independent learning.

'As technical lead for the development of a new product you are required to investigate/design a test to determine ... and to make recommendations to your manager.'

Students are thus prompted to investigate and evaluate:

- British Standard (BS) or other testing specifications
- COSHH regulations
- Instrumentation specifications/limitations
- Manufacturer's data
- Scheduling and costing.

Computer-assisted laboratory work

Computers can be used to assist in both the delivery and assessment of laboratory work. Several computer-based simulation packages are already available and many of these have been evaluated as case studies for the EASEIT-ENG project (see page 22).

Some engineering departments have developed their own learning technology to assist laboratory teaching. Several departments have taken steps to shorten the

timescale for the return of feedback, using simple programming techniques to generate electronic feedback based on coded comments that can then be emailed out to students.

Smart laboratory instruction sheets (SLIS)

Nigel Poole, Department of Systems Engineering
Coventry University

www.engsc.ac.uk/an/mini_projects/smartlabsheets.asp

The SLIS project presents traditional engineering laboratories on a personal computer using Microsoft Word documents that incorporate Visual Basic for Applications macros. The approach allows students to receive help and advice from the computer on various aspects of the experiment and to enter results directly via the keyboard. Feedback is given on formative exercises and a final summative test is automatically assessed.

Virtual laboratory work

A number of engineering departments are using learning technology to develop virtual laboratories which can have benefits for student learning as well as accessibility and cost.

The use of on-line practical classes to reinforce theoretical concepts in engineering and construction courses

Wayne Hall, School of Engineering, University of Plymouth
www.engsc.ac.uk/an/mini_projects/tensile/tensile_laboratory.html

This project has developed a series of interactive simulations and movie clips to reinforce theoretical concepts in a structures module. The web link has e-practicals based on virtual tensile tests available for teachers to use with their students.

ReLOAD : Real labs operated at distance

*Martin Levesley, Mechanical Engineering,
University of Leeds* <http://reload.leeds.ac.uk/>

The ReLOAD project enables real engineering science experiments in the area of dynamics and control to be undertaken remotely via the internet and through partnerships with HEIs across the world. The website demonstrates the technology and allows access to the experiments and associated teaching material.

Development of a web-based telelaboratory for process control engineering

Zoltan Nagy, Loughborough University

This Engineering Subject Centre funded project aims to enhance the teaching and learning of process dynamics and control by developing an interactive software environment in Labview that combines the concepts of virtual and remote real experiments. The aim is to develop experimental rigs which can be used in the classroom to illustrate theoretical concepts of process control with real-time experiments on real processes.

Accessibility of laboratory work

The Disability Discrimination Act (DDA) which is now embedded in the Equality Act (see www.equalityhumanrights.com) states that it is unlawful for education providers to treat disabled students less favourably for a reason related to their disability. Under the legislation HEIs are required to make **reasonable adjustments** to prevent disabled students being placed at a substantial disadvantage and for these adjustments to be **anticipatory** rather than in reaction to a need.

Laboratory and practical sessions, in particular, can present barriers for disabled students to access and participate in what are key aspects of the engineering curriculum. Although Health and Safety legislation has priority over the DDA, it is good practice to consider alternative approaches and adjustments that can be made, irrespective of whether disabled students are *likely* to participate, to enable disabled students to participate in such activities.

Laboratory accessibility for disabled students

*Marion Hersh, Electronics and Electrical Engineering,
University of Glasgow*

www.engsc.ac.uk/downloads/accessible_labs.pdf

The Engineering Subject Centre commissioned a short guide on how to make engineering course laboratories accessible to all disabled students and covers teaching aims, location, equipment, lab environment, timing and preparation. There is also a case study on evaluating the accessibility and use of a laboratory by a student who uses a wheelchair and a blind member of staff.
www.engsc.ac.uk/downloads/Disability/hersh.pdf

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Further accessibility considerations for the design and planning of laboratory learning are given in Doyle and Robson (2002), Waterfield and West (2002), Milsom et al. (2006) and Gravestock (2006).

Evaluation

Departments will often have standard feedback sheets for module evaluation that are not wholly relevant for evaluating laboratory learning and teaching. It may be necessary to devise a specific questionnaire, but in order to do so it is necessary to be clear about what is being monitored and to determine an appropriate method and time to do this, for example:

- goals, aims, objectives
- learning outcomes
- teaching plans, delivery, resources
- the student experience.

Evaluative and advisory support to encourage innovative teaching – engineering (EASEIT-ENG)

www.easeit-eng.ac.uk/

EASEIT-ENG was a TLTP3 project that developed a standardised evaluation method for engineering learning technology materials and produced an evaluation manual. The resources could be adopted for use in identifying and evaluating learning technology materials to support laboratory and practical work

www.engsc.ac.uk/resources/easeit/index.asp

The project team reported their reflections on the project, including a list of case studies conducted:

www.engsc.ac.uk/downloads/scholarart/easeit_eng_reflect.pdf

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Interaction

We would like to hear your views and feedback on this publication to help keep the guide up to date.

There is an interactive version of the Guide, where you can comment on each paragraph individually, or on sections as a whole, this can be found at www.engsc.ac.uk/teaching-guides

How does it work?

To view a section, click the section name in the Table of Contents on the left. The paragraphs within the section are shown in one column, with a box on the right showing the comments which have been submitted by other readers. Next to each paragraph, there's a small grey speech bubble. Click on this to bring up the comment form. Please abide by our moderation policy or your comment will not be published.

What happens next?

The feedback and discussion received will be reviewed by the Centre and author, and views and suggestions will be incorporated into new editions of the guide.

If you have any queries about this document or the process behind it, please contact us at enquiries@engsc.ac.uk

About the series:

This is one of a series of peer reviewed booklets looking at various aspects of teaching and learning aimed at all those involved in engineering education. The complete series is also available on our website.

About the centre:

The Engineering Subject Centre is one of the 24 subject centres that form the subject network of the Higher Education Academy. It provides subject based learning and teaching support for all engineering academics in the UK.

The Centre's Mission is:

to work in partnership with the UK engineering community to provide the best possible higher education learning experience for all students and to contribute to the long term health of the engineering profession.

It achieves this through its strategic aims: sharing effective practice in teaching and learning amongst engineering academics; supporting curriculum change and innovation within their departments and informing and influencing policy in relation to engineering education.

**The Higher Education Academy Engineering Subject Centre
Loughborough University
Leicestershire
LE11 3TU**

**tel: 01509 227170
email: enquiries@engsc.ac.uk
web: www.engsc.ac.uk**

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