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A First-year Course in Experimental Method*

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This paper describes a course in experimental method that has been running for 25 years in the Department of Mechanical Engineering at Brunel University. The course has a number of distinctive features, one of which is its heuristic approach with the emphasis placed on the acquisition of skills and understanding. The philosophy of the course is discussed, and developments that have been introduced over the years are described.

INTRODUCTION

AS A BROAD generalization, it is safe to say that in most engineering departments laboratory work is seen as supporting associated lecture courses. Only occasionally are the aims and objectives of laboratory work examined and defined in their own right and not in a subsidiary, supporting role. Yet, laboratory work is capable of contributing so much more to students' educational experience once this restricting knot is cut. Good teaching involves not just the transmission of knowledge, but also the development of understanding and skills. It is particularly in the latter two areas that laboratory work has so much to offer.

In 1968 what was then a highly innovative course in Experimentation for Year 1 students was introduced within the Department of Mechanical Engineering at Brunel. An early account [1] described one feature of the course, the application of dimensional analysis as an aid to experimental method. A more comprehensive description [2] of the course and its aims appeared in 1974. In the mid-1970s, the distinctive features of the course attracted the attention of educationalists elsewhere (Haave at Norges Tekniske Hogskole in Norway) and, as a consequence, a similar course was established [3]. It is of interest to note that the course continues to run in Norway. Some 25 years have elapsed since the course's inception, and it is an appropriate time to review the developments that have taken place over that period, particularly as, like many universities, Brunel is in the throes of changing from a term-based arrangement to a semesterized system. The course ran for the first time in its semesterized form in 1993/94.

EDUCATIONAL AIMS OF EXPERIMENTAL WORK

Before the experimental method course is discussed in detail, it is appropriate to set it in context in the educational programme as a whole, and, more specifically, to examine the overall philosophy regarding the teaching of laboratory work within the Department of Mechanical Engineering at Brunel. Laboratory work, project work, computer exercises, activities in design studios and drawing offices together provide a rich diversity of educational experiences. These activities can be justified on many grounds, including the fact that some students find it easier to learn about engineering in these varied environments rather than in the lecture room. There are, however, more compelling reasons why these activities should be an integral part of undergraduate programmes in engineering. Looking at the role of Year 1 laboratory work, the course can be seen as an introductory component which is part of a coherent laboratory programme extending over the life of the degree course. The programme starts with the introduction to the methodology of experimentation; this is followed by consideration of instrumentation and the measurement of physical properties; only when the foundations have been laid is there a close association between scientific investigations in the laboratory and a related taught course. As Brunel University moves towards a fully semesterized scheme, the systematic development of experimental work is being incorporated into this new structure. The course in experimental method, formerly in Term 1 of Year 1, is now in Semester 1. The measurements course, formerly spanning Year 2, now appears in Semester 2. Under the former term-based system, all degree courses in the department were four-year thin-sandwich courses, and the more general laboratory work appeared in Years 3 and 4. This activity has now been rescheduled to Semesters 3 to 6, and the flexibility of the

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semester scheme also caters for four-year thick sandwich degrees and three-year full-time degrees.

The methodology used for standard, traditional laboratory classes is often structured round the use of a prescriptive hand-out; the student is asked to follow a series of instructions, and in this way the student reaches a predetermined destination by following a route prescribed by the teacher. The linear progression through the traditional experiment, from the stated objectives to the expected result, is unrepresentative of the processes of solving real-life problems, whether they be in the fields of design, research or organization. A further disadvantage of this approach is that if the subject of the experimental study has not been reached in the related taught course, then a short briefing on the theory also has to be given to the students. Not only can this be an inefficient duplication of effort, but frequently the required analytical background is out of phase with what is currently being taught. This can lead to the student having difficulty in understanding the theory underlying the experiment. Students can respond very negatively to this type of educational experience.

It is useful to list the characteristics of the different approaches, in order to contrast the aims of the present course with those of more conventional laboratory courses. This is done in Table 1.

The laboratory work defined in Category A is primarily concerned with the assimilation of knowledge, whereas the laboratory work in Category B gives priority to the development of a range of intellectual skills.

CONTENT OF THE COURSE IN EXPERIMENTAL METHOD

The Brunel first-year course in experimentation has the following features:

1. The course serves an overall educational objective of providing the student with a diversity of educational experiences which enhance the development of understanding and skills, as well as facilitating the assimilation of knowledge.
2. The course exists in its own right and no compromise is made in order to support lecture material delivered within the remainder of the educational programme.
3. The framework for the course is a series of experiments in mechanics of a problem-solving kind, intended to provide the student with a number of intellectual challenges.

The course in experimental method starts with an induction programme involving lectures and seminars. This programme lasts for three weeks after which, in the term-based scheme and in the first year (1993/94) of the semesterized programme, the students entered the laboratory for a period of six weeks. For 1994–95, under the semester system, students will spend nine weeks in the laboratory and undertake three experiments.

The induction lectures

For most students the laboratory programme is quite different from anything they have previously experienced, and so it is important that some background preparation is given. The induction lectures cover the following:

1. An introduction to experimental method. The student is taken through all the main stages: (i) planning, including the establishment of objectives; (ii) action (carrying out the experimental work); (iii) analysis; (iv) presentation and interpretation.
2. The topics of curve-fitting, sources of experimental error and error analysis, and dimensional analysis.
3. The preparation of written records, including the student's personal log-book, and report writing.

Supporting the lecture programme, the students are set a range of problems in the fields of curve-fitting, error analysis and dimensional analysis. These are discussed in the seminars.

In the laboratory

The simplest way of illustrating the challenge that students meet in the laboratory is to quote a typical experiment. A group of students is given a range of long bars of rectangular cross-section. Some bars are of the same width, others have the same depth. Most of the bars are of mild steel, but there are also bars of duralumin, brass and wood. A firm stand into which the bars may be clamped is

Table 1. Aims of laboratory work

Category A	Category B
(a) Illustration of theories and phenomena	(a) Development of organizational skills
(b) Practice in experimental method	(b) Development of decision-making skills
(c) Familiarization with equipment	(c) Development of interpretational skills
(d) Development of manipulative skills	(d) Development of analytical skills
(e) Practice in communication	(e) Practice in experimental method
	(f) Practice in communication

provided. Students have access to micrometers and metre rules, an accurate timing device and data on physical properties. The question posed to the students is: what factors influence the frequency of oscillation of a cantilever beam? In setting out to answer the question, a voyage of discovery unfolds. The students are encouraged to work as a team. They have to decide on their objective(s), to consider the geometrical and physical properties that might influence the phenomenon, and to plan how they will investigate these factors, to investigate whether dimensional analysis will reduce the total amount of testing required and so on. As they make their decisions they discuss them with and justify them to the supervisor, who typically looks after four experiments. The supervisor might also pose questions that the students had not thought to address. Through systematic testing, the group of students should find that the frequency, f, is proportional to the depth of the beam, d, is inversely proportional to the square of the length of overhang, l, is independent of the width, w, and is directly proportional to $(E/\rho)^{1/2}$, where E is Young's modulus and ρ is density. It might also be necessary for the students to demonstrate that f is independent of the gravitational acceleration g. Combining the results of individual tests is often an intellectual challenge to the students. Ultimately over the course of the nine hours allocated, the students should be able to come up with the law.

$$f = k\,\frac{d}{l^2}\sqrt{\frac{E}{\rho}}$$

where k is a constant, a law that the students will see again in due course in a lecture on dynamics. They will establish this result swiftly if they take advantage of dimensional analysis.

Whatever approach they adopt they should be able to determine a magnitude for k of about 0.16 and should be able to estimate a tolerance band defining the uncertainty in the value of k due to experimental error. But it is not the end-point that is important in this course; much more important are the personal skills that the students have learnt along the route.

The experiments currently in use are posed in the following way:

What are the factors that influence:

1. The frequency of oscillation of a cantilever beam?
2. The frequency of oscillation of a spring-mass system?
3. The rate of flow through a small-bore tube?
4. The time to drain a liquid from a cylindrical vessel through a circular orifice in the base?
5. The drag acting on a sphere falling through oil in a tube?
6. The frequency of oscillation of a piece of pegboard?
7. The frequency of oscillation of a tri-filar suspension?
8. The deflection of a loaded, simply supported beam?
9. The time for an annular body to roll down an inclined plane?

In all cases some simple pieces of equipment and appropriate measuring devices are available to the students who have to devise the experiment from beginning to end.

Some experiments are original in concept, whilst others are adaptations of traditional engineering experiments. The experiments do not depend on any knowledge of mathematical models of the situation under investigation, though any effort by the student to explore the subject further, by the application directly of a mathematical analysis, or by consultation of textbooks, is encouraged. However, it is emphasized that the derivation of knowledge in these ways is not a substitute for the experimental approach, but rather should be viewed as a complementary or supporting exercise. The reason behind this attitude is as follows: if the experimental approach were simply bypassed, the opportunities to develop personal skills would be reduced.

Over the years there has been an increase in student numbers. The laboratory can cope reasonably comfortably with approximately 40 students, and an absolute maximum is set at 48 students in one session. There are 12 experiments—several of which are duplicated—so that students work in groups of two, three or four.

It should also be stated that, because students have a multiplicity of ways of approaching their problem, the supervisors must be flexible in thought and able to cope with the diversity of approaches adopted by the students. There are a few preferred paths, of course, and notes on these are provided for the supervisors to consult. The rewards of supervising this intensely intellectually demanding work are considerable.

RECENT DEVELOPMENTS IN THE COURSE

Much of the existing course would be instantly recognizable to the first cohort of students who experienced the initial programme 25 years ago. However, there has been some fine-tuning, and perhaps some subtle changes in emphasis have also been introduced. The details of the main changes over the past 10 years are set out below:

1. Many of the early lectures were on video; this medium is not now used. All of the induction lectures are given personally by the course leader.
2. The number of experiments undertaken by each student in the term-based scheme was originally three, but in 1989/90 this was reduced to two. In recent years, three afternoons of three hours,

giving a total of nine hours, have been spent on an individual experiment. This new arrangement ensured that there was sufficient time for the student to attend to all aspects of the work. Formerly, only six hours were allocated per experiment and it was usually the same topics—often error analysis and the combination of results from separate tests—that were inadequately treated when time was short. The arrangement involving nine hours per experiment has been retained in the semester scheme. In 1993/94 only two experiments were undertaken, but from 1994/95 a reorganization of the teaching programme will allow time for an expansion to three.

3. It is interesting to reflect that, in the early years of the course, calculations were routinely carried out using a slide-rule. Significant time-saving has come about with the universal availability of the calculator, in all its different versions. As a matter of policy, students are required to analyse the results of their first experiment without recourse to computers; this is so that students have the opportunity to understand clearly the mathematical processes involved in, for example, curve-fitting and error analysis. However, subsequently, students are given access to simple curve-fitting programs on computers in a neighbouring laboratory to speed up the analysis of data whilst the experiment is in progress.
4. In the past, log-books were collected for marking. When this was done some students felt uneasy about submitting their notes in a raw state and attempted to tidy them up, rather as they might for a report. The distinction between the log-book and a report became rather blurred. To emphasize the fundamental difference between the two, it is now established practice that the log-book is regarded as the property of the student and stays with the student at all times. The log-book is no longer marked; instead towards the end of each session in the laboratory, the supervisor comments on the strengths and weaknesses of the record and initials the log-book to signify that the discussion has taken place.
5. In place of the log-book assessment, students are now required to submit a mini-report, based on their first experiment. This is limited to a maximum length of five pages of A4. It is expected to include a diagram of the apparatus. The main emphasis is on (i) the aims of the experiment; (ii) the results; (iii) the interpretation of the results; (iv) an assessment of errors, and (v) conclusions. Students are advised to omit descriptions of the apparatus, experimental procedure and detailed theory.
6. Students are required to submit a formal report based on their second (or third) experiment. In the past, when log-books were still marked, the student would have had a free choice as to which experiment was the subject of the formal report. A complete lecture within the induction period is devoted to report writing, and in the formal report the student is expected to demonstrate all aspects of good report writing—with full attention to the structure and presentation, sound mathematical analysis and comprehensive coverage.
7. With the introduction of the semester-based programme, instruction in word-processing and graphics is now provided in a parallel module entitled 'Communications in Engineering'. Whereas 25 years ago reports were mainly handwritten, now all reports are word-processed. In the academic year 1993/94, on an experimental basis, students were required to submit the mini-report for assessment not only as part of the experimentation course but also for the 'Communications in Engineering' module. Although there was no obvious inconsistency between the main objectives of the task defined in both modules, the focus and emphasis were different. Consequently, the outcome of this experiment was judged to be not entirely satisfactory and so it will not be repeated in 1994/95.

CONCLUDING REMARKS

The course is shown to provide a diverse educational experience covering a range of topics which are not included in the majority of teaching programmes. There is only one substantial disadvantage of the course and that is its requirement of a higher staff/student ratio than that of conventional laboratory courses. In overview, it is argued that the benefits derived from the course substantially outweigh the disadvantages. To this day, the course retains many features that were present when it was launched. After 25 years, it can hardly be described as innovative, yet, to many individuals coming across the course for the first time, it has a freshness of approach which is the subject of much favourable comment.

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