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Ground Rules for Good Practice in Developing Laboratories*

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The aim of this paper is to highlight those principles underlying good practice in teaching through self instruction which may be adopted to the needs of the undergraduate engineering laboratory course developer. They provide a basis in educational theory and practice for ground rules for good practice in the development and overhaul of laboratory courses.

INTRODUCTION

IN THIS paper an analogy between developing laboratory courses and developing self-instructional teaching is highlighted. However, this analogy is used to present the requirements for a set of ground rules for good practice in the development and overhaul of laboratory courses, and not to argue for 'walk-in' laboratories. Walk-in laboratories are self-instructional in that students carry out the appropriate laboratory exercises in their own time and without the assistance of supervisory staff [1].

The overhaul of a laboratory course based on principles underlying good practice in developing self-instructional teaching is discussed and an example set of laboratory sheets for one of the experiments is presented. The monitoring of the overhauled course is described.

AN ANALOGY

Laboratory teaching differs from conventional lectures, seminars and tutorials in a variety of ways. Three of the most significant from the course developer's point of view are:

1 the need for the course developer to 'teach in hand';
2. the 'public' nature of the course material;
3. the relative inflexibility of laboratories once they have been set up.

These features are closely related to the most significant features of self instructional learning from the teacher's point of view [2] p. 35.

In planning any laboratory course, four aspects of systematic planning can be presented as four questions:

1. What is trying to be accomplished through the laboratory course?
2. What activities must the student be engaged in if this is to be satisfactorily accomplished?
3. How are the effect and effectiveness of the laboratory course to be evaluated?
4. In the light of evaluation how can we improve the laboratory course?

These four questions are closely related to four questions that concern self-instructional teaching [2] p. 36.

GROUND RULES

An effective set of ground rules for developing an undergraduate laboratory course would help the course developer towards an improvement in the following areas:

1. formulating aims and objectives for whatever laboratories the course developer plans to produce;
2. identifying the background that the student will possess before starting the course developer's laboratories;
3. being realistic about the constraints within which laboratory supervisors and students must work;
4. choosing the subject content of the laboratories and deciding how the laboratories and the content within them might best be sequenced to help the students learn;
5. selecting the appropriate resources;
6. using the resources effectively to produce laboratories from which students do learn;
7. devising assessment tests or situations that will give a fair indication of how the students develop in competence;
8. evaluating the laboratories by criticial analysis;
9. improving the laboratories in the light of evaluation.

These objectives are modifications of the specific objectives of Rowntree's book [2].

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TWO SETS OF APPROACHES TO PLANNING

It is possible to identify the equal balance that must exist between subject-orientated and learner-orientated approaches to planning in the development of self-instructional teaching, must also exist in the development of an undergraduate engineering laboratory course. From Rowntree [2] p. 38:

Subject-orientated

1. Study any relevant examination syllabus and question papers from previous years.
2. Review your own knowledge of the subject.
3. Discuss it with other subject experts.
4. Identify and analyse the key concepts of the subject.

Learner-orientated

1. Establish and analyse the aims and learning objectives.
2. Think of learning activities that learners logically must, or just usefully could, engage in.
3. Recall where people previously had learning difficulties, or had fallen into error, in the subject.
4. Consider how learners' attainments as a result of the course might be assessed.

OVERHAUL OF A LABORATORY COURSE

The main body of the paper considers laboratories in the context of self-instructional learning. Arising out of this consideration, the balanced approach to planning mentioned above is applied to the overhaul of a second-year undergraduate laboratory course on Linear Systems for Electrical Engineers on a four-year thin sandwich course. From a subject-oriented point of view the first three points were covered through lengthy discussions between the author of this paper and Dr J. F. Marsh, Director of the Control Engineering Centre, Brunel University. Having covered these three points, the discussions focused rapidly on the fourth point of the subject-orientated approach. In particular, with regard to the lecture course material, the key concepts were identified as:

1. modelling dynamic behaviour in the time domain and in the frequency domain;
2. the effects of feedback;
3. converting a quantity to be measured into an equivalent voltage.

Having identified the key concepts of the lecture course the first three learner-orientatated points were easily addressed. The aims and learning objectives became the assistance of the students in coming to terms with the key concepts. The major cause of learning difficulties had been highlighted through the discussions. It lay in an appreciation of the relationships between time-domain and frequency-domain models. The learning activities that the students could usefully engage in were limited by the available resources. It was now natural and straightforward to examine the existing laboratory course with respect to its relationship to the key concepts outlined above. Of the six exercises composing the course, three were immediately disregarded as not addressing the key concepts. One exercise was readopted in its entirety as completely addressing the students' needs with respect to the third key concept. One exercise needed to be significantly enhanced. In particular, the purchase of new equipment made it possible to complete the experimental work within two hours. Three hours were timetabled for each exercise. Theoretical work was introduced into the exercise in such a manner as to encourage students to relate theory and practice. Finally, one exercise on modelling dynamic behaviour, which experience showed could not be completed in the time available was divided into two separate exercises, the first exercise dealing with aspects of modelling in the time domain, and the other exercise dealing with aspects of modelling in the frequency domain. Additional basic material on modelling in the time domain was introduced such that the practical work would occupy three hours. The exercise on modelling in the frequency domain was written so as to highlight the relationships between time domain and frequency domain models. Some theoretical work was extracted from a third-year laboratory exercise and introduced here. It was decided to run five three-hour sessions rather than six. Gibbs and Habeshaw [3] (p. 166) point out that the course developer needs to have a very specific idea of what the precise purpose of each laboratory session is. If it doesn't have a clear objective then possibly the course developer would be better off scrapping it. One further exercise needed to be developed, to make up the complement of five. One key concept had not been addressed: the effects of feedback. In order to introduce this concept a large part of a third-year laboratory exercise had to be brought down into the second-year laboratory course. Thus, the overhaul of the second-year laboratory course resulted in a need to overhaul the third-year laboratory course.

The laboratory sheets for all exercises were extensively rewritten. Each exercise was introduced by a stated objective which was followed by details of recommended preliminary reading.

The fourth of the learner-orientated points concerning assessments is covered in a later section.

ON AIMS AND OBJECTIVES

Elton [1] notes: 'an analysis of the aims of the first-year undergraduate physics laboratories showed that the aims fell broadly into two groups, relating respectively to products and processes.

Further, it was found that most of the product aims, e.g. "verifying a physical principle", could best be achieved by very short run and tightly prescribed laboratory experiences, while most of the process aims, e.g. "the acquisition of experimental skills", required considerable freedom in time, procedure and apparatus. It was clear that the traditional laboratory experience of three hours of loosely prescribed procedure and apparatus was a compromise which was ill-designed to achieve either group of aims.'

Each experiment in the laboratory course discussed in this paper has a product-type aim and therefore the corresponding laboratory sheets are written in a manner which lays out a tightly prescribed exercise.

Elton [1] further notes: 'O'Connell and his co-workers developed types of laboratory experience in conjunction with the two groups of aims they were designed to achieve. It was then found that if students were explicitly told what the aims were which they were to achieve, they were much more likely to do so.'

The laboratory sheets for each experiment in the laboratory course discussed in this paper begin with a statement of the experiment's objective which is intended to be as explicit as possible.

ASSESSMENT

Golten and Verwer [4] note: 'Laboratory work and assessment, in our opinion, have conflicting objectives. We regard the laboratory as a teaching/learning environment and certainly at final year level any assessment must be minimal.'

On the overhauled course discussed above each of the students was presented with a copy of the following statement before commencing the overhauled laboratory course:

> The use of the assessment is intended to be *formative*. Its purpose is to aid you in your subsequent learning.
>
> One of the functions of the laboratory reports is to let you know how closely your competences approach the standard expected.
>
> The attainment of the laboratory objectives and your progress towards the attainment of the course objectives, as *perceived* by the member of staff doing the marking is assessed. An impression marking approach is adopted. An overall impression of the worth of the work is obtained and an appropriate mark given. It is not easy to devise an analytic marking scheme when an extended 'own answer' is expected from the student. Analytic points are looked for but the technical standard expected from you for a given mark increases through the year as you have an increasing amount of lecture course background and recourse to discussion with course colleagues who have previously attempted a given laboratory.

Different members of staff take different groups for the same laboratories. Many use demonstrators to do part of the marking. Individual members of staff respond to laboratory reports in slightly different ways. This is not discouraged.

The ways staff seek to teach through written comments on student laboratory reports include the following, Rowntree [2], p. 328:

> Draw learner's attention to facts they have overlooked or misinterpreted.
> Suggest alternative approaches or interpretations.
> Suggest new sources (e.g. other people) from whom learners might get feedback.
> Draw attention to gaps in the learner's reasoning.
> Suggest how learners might present their ideas more effectively.
> Offer comments that will help learners sharpen their practical skills.
> Ask for a further explanation of muddled statements.
> Demonstrate useful short cuts in procedure.
> Help learners reflect how a piece of work might have been improved.
> Point out relationships between the learners present work and their earlier work.

Commend the learners for any unexpected insights, special efforts or improvements in competence.

MONITORING

Boud *et al.* [5] p. 107: 'Monitoring can lead to course improvement by the identification of isolated or pervasive problems—for example, oversights, errors, gaps, repetitions, non-sequiturs, lack of clarity'.

The running of the course was carefully monitored in the academic year that followed. The difficulties the students had in appreciating the relationships between time and frequency-domain models were brought out by the new course. Attention was paid to students' attitudes towards the course. The students were found to be supportive, appreciating the effort made by staff on their behalf. Laboratory marking was completed more quickly than before as the students wrote better reports and the exercises had more structure. 'In terms of decreased workloads the new system could be regarded as successful', Boud *et al.* [5], p. 23.

Boud *et al.* [5], p. 151 note that 'laboratory activities often simply illustrate concepts already understood by students'. With a laboratory course designed to assist students in coming to terms with key concepts (i.e. with product aims) there must invariably be an element of simple illustration from the perspective of the more able students.

While in Boud *et al.* [5] p. 151 the question 'what are the differences for students with low or high ability?' is raised, as still requiring research, no attention is paid to the issue of minimum attainment levels. It is noted that, although the course has not been fully evaluated the changes made, in this context, can be shown to have resulted in an improvement in the minimum attainment levels of students taking the course.

Most of the laboratory sheets were revised slightly to improve clarity in the light of the experience of having run the overhauled course.

The course was not fully evaluated in so far as quantitative information, available through the use of student feedback questionnaires, was not obtained. Although quantitative information is of value, the role of qualitative information obtained though careful observation, of the type described above, is not generally appreciated.

CONCLUSIONS

The conclusion of the paper is that, the main benefit of the analogy between developing laboratory courses and developing self-instructional teaching is that it is possible to identify that the equal balance that must exist between subject-orientated and learner-orientated approaches to planning in the development of self-instructional teaching must also exist in the development of a laboratory course.

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The section 'On aims and objectives' was added in response to comments from Professor J. J. Sparkes of the Open University, United Kingdom.

REFERENCES

1. L. Elton, Cost-effectiveness in laboratory teaching, in G. Squires (ed.) *Innovation through Recession*, Society for Research in Higher Education, Guildford (1983).
2. D. Rowntree, Teaching Through Self-Instruction, rev. edn., p. 35, Kogan Page, London (1990).
3. G. Gibbs and T. Habeshaw, *Preparing to Teach—An Introduction to Effective Teaching in Higher Education*, Technical and Educational Services Ltd., Bristol (1989).
4. J. W. Golten and A. A. Verwer, Teaching and assessment of control engineering with a computer aided design package (CODAS-II), in T. V. Duggan (ed.), *3rd World Conference on Engineering Education*, **3**, Computational Mechanics Publications (1992).
5. D. Boud, J. Dunn and E. Hegarty-Hazel, *Teaching in Laboratories*, SHRE & NFER–NELSON, Guildford (1986).

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APPENDIX

EXAMPLE: LABORATORY SHEETS FOR ONE EXPERIMENT

YEAR 2 ELECTRICAL ENGINEERING AND ELECTRONICS

LINEAR SYSTEMS LABORATORIES

NOTES ON EXPERIMENTS

Dr T. J. Owens 25 November 1991

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Experiment 1

Introduction to analogue computing

Objectives

To be able to simulate first- and second-order linear dynamic response using an analogue computer.

Aims

That the systems engineer be able to identify the form of the response of a system modelled by a first-order or second-order equation to a step input, and conversely, be able to recognise when a particular response is likely to be associated with a system modelled by a first-order or second-order equation.

Introductory reading

Read section 3.8, starting on p. 67, of the set book by Golten and Verwer. Also read section 3.9 to p. 75 of this book, paying particular attention to figure 3.10 on p. 70.

This material covers the standard second-order system and time-domain performance specifications.

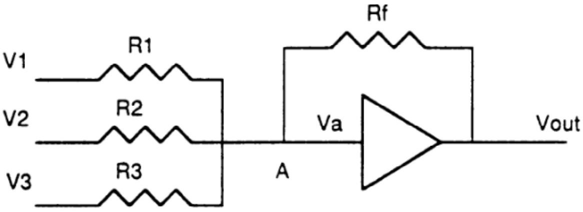
Read pp. 72–74 of the set book by Kamen.

This material covers the op-amp and op-amp realisations of basic operations.

Preamble

In an analogue computer, real variables are represented by voltages which, by the use of operational amplifiers, may be added, subtracted and integrated with respect to time. Nonlinear elements such as multipliers and function generators are commonly provided in addition. Thus the means exist to represent integral and algebraic equations on the computer and hence simulation of a real system is possible. The operational amplifier used is a DC amplifier with a very high input impedance and a very high gain (often in excess of 10 million at DC) and having a sign reversal between input and output. The amplifier is always used with negative feedback as shown below:

(i) *Summer*



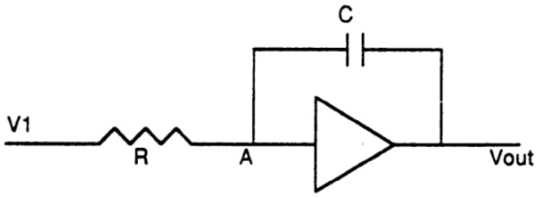
The output V_{out} is designed to vary between −10 and +10 volts and 10 volts is designated a 'machine unit'. Thus the voltage at A has a maximum magnitude of (10/gain) volts and with the large value of gain quoted above, $V_a < 10^{-6} V_{\text{out}}$. This value is small and is ignored in calculation and the point A is called the 'virtual earth'. The equation relating V_{out} to the various inputs is derived by writing the current balance at A.

$$\frac{V_{\text{out}}}{R_f} + \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = 0$$

and so

$$V_{\text{out}} = \frac{-R_f V_1}{R_1} - \frac{R_f V_2}{R_2} - \frac{R_f V_3}{R_3}$$

(ii) *Integrator*



The point A is 'virtual earth'. Writing the current balance at A,

$$\frac{C\mathrm{d}V_{\text{out}}}{\mathrm{d}t} + \frac{V_1}{R} = 0$$

and so

$$V_{\text{out}}(t) = \frac{-1}{RC} \int_0^t V_1 \mathrm{d}t$$

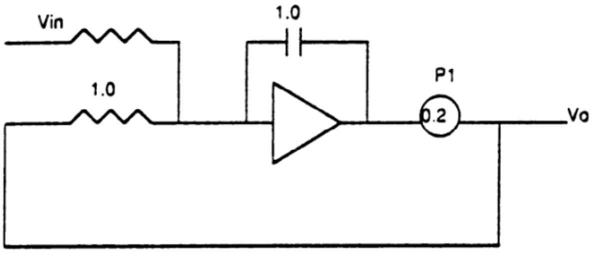
Experiment

(a) Wire up some simple summer and integrator circuits and check that results agree with theory.

(b) Patch up the circuit below and solve the first-order equation,

$$\frac{\mathrm{d}V_0}{\mathrm{d}t} + 0.2V_0 = V_{\mathrm{in}}$$

The time constant of the equation is 5. Verify that this is obtained in practice.

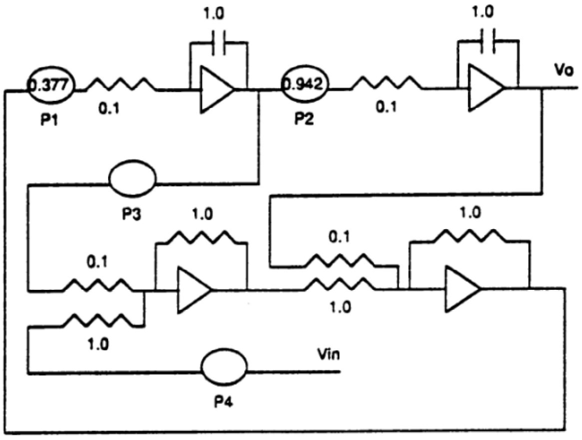


For $P_1 = 0.4$ to 1 in steps of 0.2 apply a step input and measure the time it takes for the output voltage to reach 63% of its final value. Theory gives 2.5, 1.67, 1.25 and 1 s.

(c) Patch up the circuit below to solve the second-order equation:

$$\frac{\mathrm{d}^2V_0}{\mathrm{d}t^2} + 37.7\frac{\zeta\mathrm{d}V_0}{\mathrm{d}t} + 355.13V_0 = V_{\mathrm{in}}$$

The undamped natural frequency of the equation is 3 Hz.



For $\zeta = 0$ to 1 in steps of 0.1 apply a step input and measure the fractional overshoot. Compare the overshoot obtained in each case with that predicted by the theory.