

2009

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### Recommended Citation

O'Dwyer, Aidan (2009) "Using Virtual Laboratories in Control Engineering Education," *Level 3*: Vol. 7: Iss. 1, Article 2.

doi:10.21427/D7QJ07

Available at: <https://arrow.tudublin.ie/level3/vol7/iss1/2>

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## Using virtual laboratories in control engineering education: some experiences

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### Abstract

The twin pressures of the need for students to learn a wider variety of concepts, ideally in a self-learning mode, and the reduction in class contact time has led to the use of increased levels of information technology in control engineering education. This paper reports on, reflects on, and evaluates the author's use of virtual laboratories (computer based laboratories available on the internet) in control engineering modules at DIT, Kevin Street. The use of the virtual laboratories helps in the ongoing evolution of the teaching approach from a traditional didactic lecture and laboratory course to a more learner-centred approach. The author's experience is that student motivation, student self-learning and the enhancement of theoretical understanding and practical ability are significantly increased with the appropriate use of these laboratories, at both undergraduate and postgraduate level.

### 1 Introduction

Engineering is concerned with understanding and directing the materials and forces of nature for the use and convenience of humankind. Control engineering is concerned with the understanding and control of machines, processes and industrial automation systems to provide useful economic products for society. Control engineering is based on foundations of feedback theory and linear systems analysis. It is not limited to any engineering discipline but is equally applicable to aeronautical, chemical, mechanical, environmental, civil and electrical engineering (Dorf and Bishop 2001).

A control engineering educator has the challenge of communicating a wide variety of concepts, ideas and techniques, to provide students of the discipline with both a strong theoretical base and good practical ability. In addition, the educator increasingly has the responsibility of providing students with the fundamental skills that are required for life-long self-learning. Theoretical issues, which often involve mathematical and physical analysis, have tended to be taught in the classroom. Practical ability, which requires intuition and insight, has been traditionally conveyed through extensive laboratory work. However, time available for classroom and laboratory work has gradually been reduced, in response to pressure to reduce class contact hours and the increasing desire to facilitate student self-learning.

This paper reports on, reflects on, and evaluates the author's use of virtual laboratories to increase student motivation, facilitate student self-learning and enhance theoretical understanding and practical ability. The author's experience is that learning efficiency is significantly increased with the appropriate use of these laboratories, at both undergraduate and postgraduate level. Case studies of work carried out with the most interesting virtual laboratories are available from the author.

## 2 Control engineering at DIT, Kevin Street

Modules in automatic control are available in a variety of ordinary degree, honours degree and taught postgraduate programmes at DIT, Kevin Street. Following recent institute policy, most modules are studied in a thirteen-week period and are examined in a semesterised structure. The author has primary responsibility for module development, syllabus design, and instruction in automatic control on the following programmes:

(a) Bachelor of Engineering (B.E.) in Electrical/Electronic Engineering (4 year honours degree, validated by Engineers Ireland). The modules offered (in the newly validated degree) are:

- Introduction to Control (Year 2, Semester 2)
- Control Engineering Major 1 (Year 3, Semester 1)
- Control Engineering Major 2 (Year 4, Semester 1)
- Control Engineering Major 3 (Year 4, Semester 2)
- Time Delay Systems (Year 4, Semester 1)
- Feedback and Control – Origins, History and Development (Year 4, Semester 1)

The latter two modules are elective modules.

(b) M.E. in Advanced Engineering (1 year, taught masters course). Students choose six subjects, followed by a dissertation. Each subject has a yearly class contact time of 60 hours. Advanced Control Systems was one of the six subjects, taken by seven students, in this past academic year.

(c) Other programmes: Automatic control is an elective subject on the following programmes:

- Bachelor of Engineering Technology (in Control and Automation Systems or Electrical Energy Systems) – three year ordinary degree
- B.E. in Electrical/Electronic Engineering (part-time) – four year honours degree
- B.Sc. in Medical Physics and Bioengineering – four year honours degree
- M.Sc. in Sustainable Energy Management – taught Masters degree.

Typically, undergraduate courses, after introducing basic ideas, explore the construction of time domain and frequency domain diagrams (e.g. root locus diagrams, Bode plots, Nichols charts), followed by controller design methods using these plots. Final year honours degree work typically includes process control ideas, adaptive control algorithms, and the analysis of non-linear systems. The M.E. in Advanced Engineering course places more detailed emphasis on, for example, process modelling and controller design.

Since 2001, the author has increasingly used computer-aided design tools to assist in increasing student understanding of challenging topics, to act as motivation for further exploration and to demystify important design ideas. MATLAB/SIMULINK ([www.mathworks.com](http://www.mathworks.com)) has been the platform used, and the author's experiences were reported at EdTech 2004 (O'Dwyer 2004). In addition, some work has also been done

on developing an expert system, to provide a more intuitive ‘virtual instrument’ environment for student learning (see O’Dwyer 2005).

### **3 Outline of useful virtual laboratories**

Over the past two academic years, the author has increasingly begun to use computer-based simulation laboratories available on the internet (simulation based virtual laboratories), in both the lecture and laboratory environment. The author has found virtual laboratories suitable for introductory undergraduate work (for example Crutchfield and Rugh 1998; Forrester 1996; Garcia and Heck 1999; Merrick and Ponton 1996; Poindexter and Heck 1999; Wall n.d.; Yang and Lee 2003) and more advanced undergraduate and postgraduate work (for example Garcia and Heck 1999; Merrick and Ponton 1996; Poindexter and Heck 1999; Wall n.d.; Yang and Lee 2003). The author recommends in particular the work done by Messner and Tilbury (see Messner and Tilbury 1999 and Tilbury and Messner 1999), which will be used extensively in modules in automatic control in the final year of the honours B.E. programme in Electrical/Electronic Engineering. A recent trend is for textbooks to have an associated website, with interactive features; the work of Marlin 2000 and Goodwin et al. 2001 are particularly suitable for more advanced learners. Other interesting perspectives are also available (Aga and Cox 2004; BestTUNE; Blakley 1998; Dormido et al. 2005; Keller 2006; Kozura et al. 1996; Kroumov and Inoue 2001; Paja et al. 2005; Ringwood 1998; Yang 2002; Yu et al. 2004; Zhuang and Morgata 2007). A particularly interesting contribution on implementing a virtual laboratory on a mobile phone is given by Goh et al. 2005.

The development of other types of virtual laboratories, in which experiments may be performed remotely over the internet, has also been the focus of attention (Ahmed et al. 2004; Bhandari and Shor 1998; Bohus et al. 1996; Casini et al. 2003, 2004, 2005; Cheng et al. 2004; Diong et al. 2003; Duan et al. 2005; Fernández et al. 2005; Johansson et al. 1998; Ko et al. 2001, 2005; Koku and Kaynak 2001; Peek et al. 2005; Sánchez et al. 2004; Schmid 1998; Selmer et al. 2005; Shaheen et al. 1998; Srinivasagupta and Joseph 2003; Valera et al. 2005; Viedma et al. 2005); the maturing of this field is evidenced by the recent publication of an excellent ‘how-to’ book by Ko et al. 2004.

Finally, more general publications on the use of interactive and web-based learning in control engineering education are also of interest (see Castellanos 2005; Coppinga et al. 2000; Hassapis 2003; Michau et al. 2001; Petridis et al. 2003; Tan 2005; Zywmo and Kennedy 1999).

### **4 Pedagogical issues**

As mentioned in Section 3, the author has used simulation-based virtual laboratories increasingly, where appropriate, over the past two academic years. This use has been prompted by a number of factors:

- The increasing maturity of these tools.
- An environment where formal classroom and laboratory time is being reduced.
- The increasing diversity of student educational background; for example, students entering the B.E. in Electrical/Electronic Engineering honours degree

programme in the traditional manner (i.e. after the Leaving Certification examination) are now a minority of the total students on this programme. The majority of students have either completed a previous programme (typically at certificate or ordinary degree level in an Institute of Technology), are overseas students (typically from China), and there is a small but growing number of mature students.

- Students increasingly expect technical work that is practical and which motivates independent learning.

The virtual laboratories have been used in two ways.

1. They were recommended as backup to a more didactic teaching approach in lectures and laboratories, for the Control Engineering Major subject in the honours B.E. in Electrical/Electronic Engineering degree programme.
2. They were also used as part of two formal assignments for the Advanced Control subject in the M.E. in Advanced Engineering programme in the 2004–5 and 2005–6 academic years. Submission of formal reports based on the virtual laboratories (Crutchfield and Rugh; Garcia and Heck 1999; Kroumov and Inoue 2001; Merrick and Ponton 1996; Poindexter and Heck 1999; Yang and Lee 2003) amounted to almost half of the continuous assessment marks available for this module, and 14 per cent of the total module assessment mark. Other virtual laboratories were explored in detail in a teamwork environment; yet other virtual laboratories were recommended as backup to a more didactic teaching approach.

Even when the use of virtual laboratories was not obligatory, student feedback revealed that 60 per cent of students did access one or more of the virtual laboratories. The following questionnaire was distributed to both the B.E. and M.E. students in 2005–6 to get feedback on their experiences of the virtual laboratories.

*Please respond to the following. To rate your reaction, please write a number between 1 and 5, with*

- 5 – strongly agree*
- 4 – agree*
- 3 – unsure*
- 2 – disagree*
- 1 – strongly disagree*

- 1 Virtual laboratories were a beneficial learning experience (compared to other exercises).*
- 2 Virtual laboratories are user-friendly.*
- 3 The virtual laboratory complements and enhances my understanding of lecture material.*
- 4 Virtual laboratories are fun and sustained my interest.*
- 5 I became more interested in the material because of the virtual laboratory viewed.*
- 6 There is enough time to perform the virtual laboratory.*
- 7 I would recommend virtual laboratories to others.*
- 8 Any other comments.*

Fourteen replies were obtained (from a total of seventeen students in both courses). On average, students agreed with the statements that:

Virtual laboratories were a beneficial learning experience (compared to other exercises)	<i>average number: 4.2</i>
Virtual laboratories are user-friendly	<i>average number: 3.9</i>
The virtual laboratories complement and enhance my understanding of lecture material	<i>average number: 4.2</i>
Virtual laboratories are fun and sustained my interest	<i>average number: 3.6</i>
I became more interested in the material because of the virtual laboratories viewed	<i>average number: 3.7</i>
I would recommend virtual laboratories to others	<i>average number: 4.2</i>

Students were unsure about the statement that 'There is enough time to perform the virtual laboratories' (*average number: 3.2*). Further student feedback revealed that students felt the virtual laboratories to be time-consuming and that there was little assistance available when having difficulties; in addition, this student response may also be due to the way in which the virtual laboratories were used to support a more conventional teaching approach. In this respect, it is interesting that half of the students who did not access the virtual laboratories gave lack of time available as the reason for not doing so. This feedback suggests that further integration of the virtual laboratories in the subject would be useful.

Overall, student feedback is encouraging, and tends to validate the author's previous experience that the virtual laboratories increase student motivation, facilitate student self-learning and enhance theoretical understanding and practical ability. The experiences gained have shaped the design of the modules in automatic control for the five-year Engineers Ireland review of the B.E. in Electrical/Electronic Engineering, held in May 2006. To allow the wider use of computer-based tools generally, the learning model was changed to one that requires that instruction take place in two-hour blocks, with the lecture room and laboratory simultaneously available for that period. Assessment methodology has also changed; for example, the module, which will use computer-based tools most extensively, will now be assessed completely by a variety of continuous assessment methods.

## 5 Conclusions

The twin pressures of the need for students to learn a wider variety of concepts, ideally in a self-learning mode, and the reduction in class contact time has led to the use of increased levels of information technology in control engineering education. At DIT, Kevin Street, the teaching approach has evolved from a traditional didactic lecture and laboratory course, with associated assessments, to the implementation of a more learner-centred approach over the past two academic years. This new approach has been made possible by the appropriate use of real case studies, information technology tools, and web-based virtual laboratories. Assessment methodology has also evolved. An improvement in learning outcomes has been noted using the new approach; formal student feedback has also been positive. The author is committed to deepening the learner-centred approach in the future, with, for example, the further integration of virtual laboratories in the modules, the inclusion of further industrial



case studies, and the progressive implementation of the modules in an e-learning environment.

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