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Converting the physical to the virtual: providing a laboratory experience for distance learners in engineering

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Face-to-face modules on the full-time Masters in Renewable Energy Systems Technology at Loughborough University involve students collecting data from physical laboratory experiments. Conversion to distance learning mode, due to demand from industry for the skills and competencies acquired, raised the problem of providing a comparable laboratory experience. The solution adopted was to develop a number of virtual laboratories to enable distance students to experience the same experiments as their face-to-face peers, the focus in both modes being on interpreting the data generated. The virtual laboratory described in this paper was designed to provide activities requiring students to review content covered in study notes, enhancing the learning associated with their progress through the experiment. This paper will provide evidence to show that distance students were not disadvantaged and that student evaluative feedback has been generally positive.

Keywords Virtual laboratory; Active & interactive learning

1. Introduction

The Master of Science (MSc) in Renewable Energy Systems Technology (REST) at Loughborough University has been running in full-time, face-to-face mode since 1993. It was developed by academics in the Department of Electronic and Electrical Engineering. REST MSc develops student understanding of a range of renewable energy technologies, over eight modules, at an advanced level. It is designed for people wishing to pursue a professional career at managerial level or to undertake further research.

As the REST MSc qualification became increasingly recognised there was greater demand for the course from those working in industry, especially in the renewables sector. It became clear that there was a need for a version of the course for those who were not able to study full-time, due to their personal circumstances. In 2000, after application to the UK Engineering and Physical Research Council, the Department was successful in gaining funding for five years to develop a flexible and distance learning version of the REST MSc. The following section briefly explains the way in which the course was converted to distance mode and identifies the problem created by the need to provide a laboratory experience.

2. Converting the course

The distance learning version of the REST MSc utilises internet technology to offer students an experience comparable to that of their full-time peers. Resources such as study materials (notes, tutorials, past exam papers and video lectures) are provided via a website (with secure login). In order to aid those students who may have difficulties with internet connections (e.g. low bandwidth, lack of a reliable service provider) the module materials are also available on CDROM, in particular any digital videos of lectures. A range of communication and collaboration tools (asynchronous email, discussion forum, group-work area and synchronous web-conferencing) are used to enable social interaction and collaboration and students are supported by the course learning team whose role is the encouragement and facilitation of that interaction, something which has been considered an essential element of online learning for many years [1-3].

Table 1: Physical laboratories of the REST MSc programme.

Module	Physical Laboratory
Solar Power 1	Using different photovoltaic panels to analyse power curves under different environmental conditions
Water Power	Optimise the blade or nozzle arrangements of three different water turbines
Biomass 1	Record the effects of fluctuating load on anaerobic digester performance

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It was a relatively straight forward process to convert the full-time student materials for distance learning however, it was more difficult to design a comparative laboratory experience. Each module is assessed by exam (75%) and coursework (25%), with the exception of one module which is only assessed by group work. In five of the modules conversion was straight forward because students were doing either computer-based exercises or group work which in distance mode could be supported by the synchronous & asynchronous technology tools. However, three of the full-time modules have physical laboratories, see **Table 1**. It is important for students to learn how these experiments are conducted but the main emphasis, in both modes, is to collect and analyse the data generated; the way in which these experiences were converted for distance mode is outlined in the next section.

3.Designing the labs

When considering how to convert the laboratory experience various options, such as instructive data sheets and videos of the experiments, were contemplated. It was important to ensure that students were tested on the same knowledge and skills [4] in both modes, however harnessing the affordances of the internet-based technology allowed us to develop a virtual software version of the physical laboratories in order to create a more active and illustrative experience for learners. The two issues regarding distance mode highlighted by Abdel et al [5], lack of hands-on experience and no on-site instructor to answer questions, were also issues here. While Hall et al argue that "practical work is an essential part of the curriculum" [6, p.56] we would contend that as the REST MSc course aims to provide a level of understanding suitable for students intending to work at a professional level, it is not necessary for them to be able to physically manipulate laboratory equipment. Moreover as Bourne et al [7] point out the days of "hands-on" engineering are over, having been replaced by simulation, so this enabled something more akin to a real world experience to be offered. It is also worth pointing out at this point that the face-to-face experience is far from ideal due to the hazardous nature of the materials being used: a technician actually carries out the experiment and provides data read out for face-to-face students, so the distance cohort are in effect missing little. The use of communication tools to support regular interaction and facilitate the querying of expert tutors and peer support provide virtual on-site help. Furthermore in all the coursework activities it is the ability for the student to interpret data, synthesise meaning and communicate this in a logical and coherent manner that is assessed, not the ability to carry out the physical laboratory.

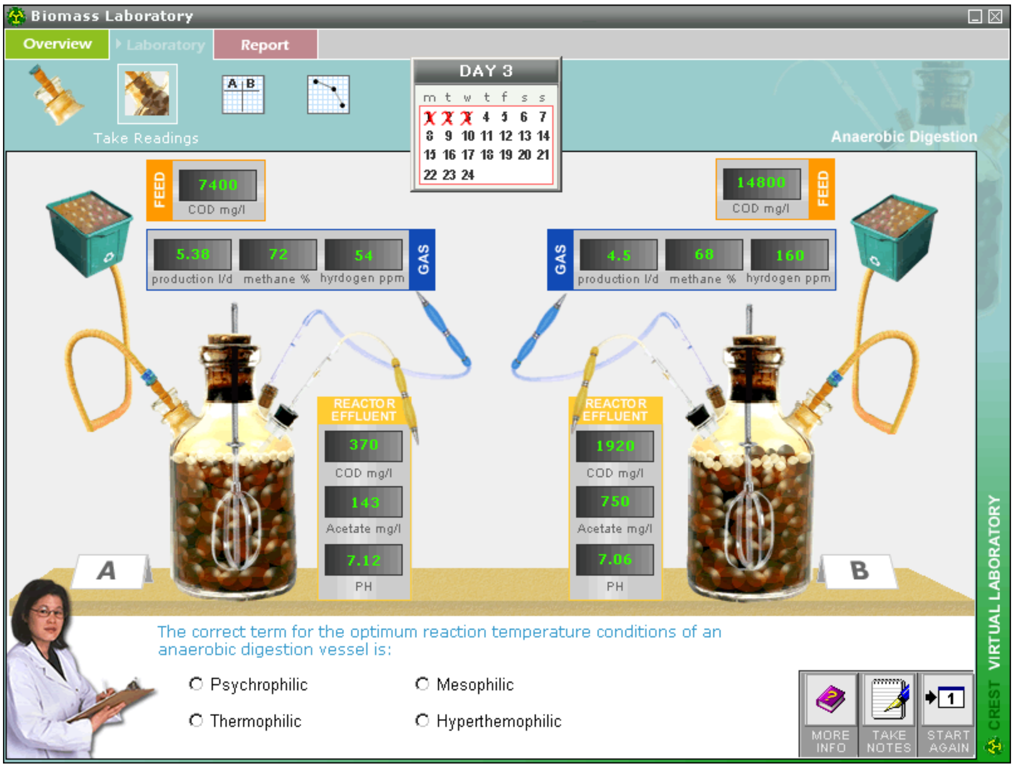

Fig. 1 Screen shot of the software illustrating a virtual representation of the biomass experiment, showing status at day 3 and interactive question.

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The particular virtual laboratory referred to in this paper (see **Fig. 1**, Biomass laboratory) requires the student:

- to become familiar with the tests used to monitor digester performance,
- to use this data to predict or judge treatability of biomass such as various types of animal effluent,
- to analyse and interpret a set of data from an experiment in which the operational performance of 2 anaerobic digesters were compared under conditions of steady organic loading and fluctuating organic loading respectively.

The software package simulates the process of the experiment, so that the lab is 'set up' for the experiment and the two digesters are loaded with effluent. The simulated experiment is programmed to generate data for the real time equivalent of 24 days. Each day or stage of the experiment the student has to answer questions on what they have learnt (from the study notes and video lectures) in order to carry on to the next day and to collect the data generated by the experiment. A key element of distance learning is activity "learners are usually expected to do something with the ideas they are learning about" [8]. At periodic intervals (usually every sixth day of the experiment) the student is prompted to examine this data and to take notes in the individual 'electronic notebook' provided by the software (see **Fig. 2**).

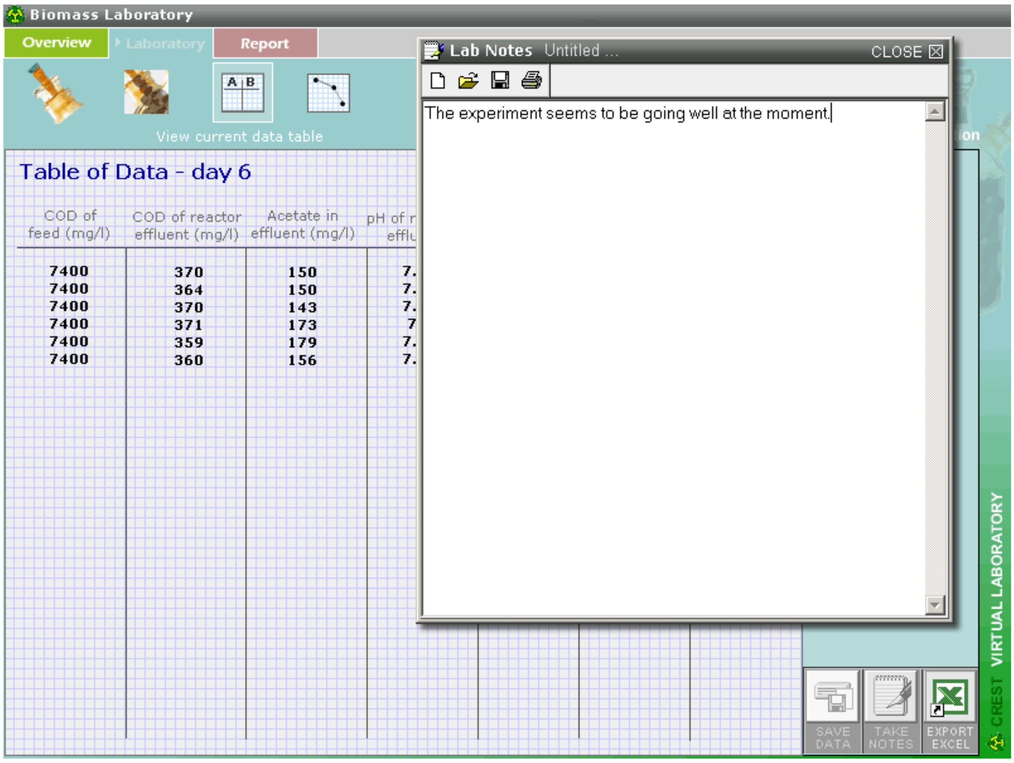

Fig. 2 Screen shot showing 'electronic notebook' (in the foreground) and data table.

The intention of the embedded activities, prompts and of the simulation is to enable students:

- to become familiar with the laboratory techniques used for monitoring an anaerobic digester,
- to have the necessary practical knowledge to enable them to interpret a set of data (taken from an anaerobic digester undergoing conditions of fluctuating organic loading),
- to prepare a laboratory report on the effects of fluctuating organic loading on the performance of an anaerobic digester.

The resulting virtual laboratories actually provided what could be considered an enhanced experience for the distance mode students. We were concerned to ensure we were not disadvantaging either cohort of students therefore marks and module results obtained by the different cohorts attempting this laboratory are compared in the following section.

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4. Student Results and Experiences

The virtual laboratory showcased in this paper has only been available for three years: academic years 2003/04, 2004/05 and 2005/06. During that time a total of forty-seven students have used the software to complete the module. One way in which to judge the effect of its use is to compare the results of students on different modes [9]. The average results presented in **Table 2** show little difference between those carrying out virtual (distance) or physical (face-to-face) laboratories. Indeed the students undertaking virtual laboratories appear to perform slightly better. However we must be careful in over generalising from these results as the numbers, in the first two virtual cohorts, are small and we have not taken into consideration any other factors such as the availability of online support that may impact on these results. The intention is to use the marks as indicative, not absolute.

Table 2: Average coursework results for physical (P) and virtual (V) biomass laboratories.

Cohort	Mode	Number of students	Average laboratory mark	Module average mark
2003/04 Full-time	P	53	65.8%	61.6%
2003/04 Distance learners	V	13	66.1%	62.7%
2004/05 Full-time	P	35	64.6%	64.1%
2004/05 Distance learners	V	9	66.1%	68.7%
2005/06 Full-time	P	33	63.1%	60.8%
2005/06 Distance learners	V	25	64.5%	60.1%

The average module mark is also included in **Table 2** for reference, if the average coursework mark is higher than the module average students will have performed better in the coursework than the exam, for example both 2003/04 cohorts. Conversely the 2004/05 distance learners performed better in the exam than the coursework.

A small number of standard parametric statistical tests were performed on the student results. Firstly, to examine the level of variance within the data an F-Test was performed on each of the years cohorts. This was to ascertain whether the data had significant variance so that the correct T-Test could be performed. The F-Test results indicated that there was unequal variance within the samples. The unequal variance T-Test was performed to investigate whether there was a significant difference between the average results of the students who took the physical and virtual laboratories in each of the academic years being investigated. **Table 3** shows the results of the T-Test.

Table 3: T-Test results for each academic cohort comparing means of physical (P) and virtual (V) laboratories in the Biomass 1 module

Cohort	Ave	T-Test	Critical T
2003/04 P	65.8%		
2003/04 V	66.1%	1.69	2.04
2004/05 P	64.6%		
2004/05 V	66.1%	1.72	2.07
2005/06 P	63.1%		
2005/06 V	64.5%	1.67	2.01

Table 3 indicates that for each of the year groups, the average results between students who took the physical laboratory and students that took the virtual laboratory exhibited no significant difference in performance. This is shown be the T-Test value being lower than the Critical T value. This in itself is a very positive result for the success of the virtual laboratory as a learning tool to substitute the experience gained in the physical laboratory. However, we do not know if the learning experience was comparable and this is a potential area for future work.

What we do have is additional data from the student feedback questionnaire. This data was analysed and found to be generally positive:

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"The module … gives a good understanding of what is going on, from growing energy crops to producing useful energy for heat, electricity and transport."

And in particular with respect to the virtual laboratory:

"The idea of V-lab work is great, I liked it!!"

The average feedback marks were all greater than or equal to 2.5, students were presented with a range of statements about the clarity of the module aims and objectives, the suitability and organisation of the materials covered, the highest mark possible was 5. Critical comments made were in relation to the organisation and structure of the module and reflect the iterative nature of course development, indicating areas for future improvement.

5. Conclusions

We have explained why we decided to convert a face-to-face course to distance mode and how we overcame the problem of providing a laboratory experience for the distance students. We have described the creation of a virtual laboratory simulation software package and shown that on the face of it students do not appear to have been disadvantaged with reference to the module marks obtained or with respect to their perception of their experiences. They were able, through data interpretation, to meet the learning outcomes at a comparable level to the full-time students who took the physical laboratory. We feel that the software package provides an enhanced experience for our distance students. However there is still scope for further research, for example, to explore why student results are not even better given that the virtual laboratory does indeed provide an enhanced experience. There is also scope to compare the effect of the use of the virtual laboratory by face-to-face and distance students.

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