Taking environmental engineering out of the laboratory.

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Abstract

Environmental engineering is a core component of most construction and surveying undergraduate courses. It is generally accepted that students on these courses should have an understanding of thermal comfort, heat transfer, condensation, lighting, noise transmission and acoustics. Experiments are essential in developing students' awareness and understanding of the underlying physical concepts which drive environmental engineering solutions. Traditionally these experiments have been conducted by students working in small groups in laboratories. However, increasing student numbers and, in particular, the growth in part time study, have placed significant additional demands on limited laboratory resources.

The availability of reasonably priced, simple, hand-held equipment has made it possible for students to conduct experiments outside the confines of the laboratory. Furthermore, various professional software packages (some of which are freely available online) enable the resultant data to be further developed and analysed in conjunction with the conventional textbook approach.

This paper examines these alternative approaches to the traditional laboratory experiment. An assessment is provided of the types of experiment which are both possible and appropriate, and the efficacy of these approaches is considered.

Keywords:

Environmental engineering

Construction and surveying

Laboratory experiments

Hand-held equipment

Introduction

Overview

Most undergraduate courses in construction-related areas include coverage of environmental engineering. The teaching and learning approach for environmental engineering typically involves formal lectures, tutorials and laboratory sessions. The laboratory sessions have traditionally been seen as an integral component of teaching and learning by providing a 'hands-on' experience for students, thus stimulating their interest, consolidating theoretical knowledge, and providing opportunities for them to undertake investigative and experimental work. However, in the UK, significant increases in student numbers coupled with reductions in *per capita* funding, and a changing student profile have resulted in pressures on laboratory resources. As a result it has become more difficult to ensure that students derive optimum benefit from the laboratory experience.

At the University of Westminster, since 2004, alternative approaches to the traditional laboratory session have been introduced to students on the Undergraduate Construction Studies Programme. Typically these approaches have involved students in conducting experiments outside the confines of the laboratory using simple, hand-held equipment. In addition, professional software packages have been utilised to help students to analyse the resultant data.

This paper first examines the background to the use of laboratories in construction-related courses and sets out the challenges of maintaining traditional laboratory sessions in modern courses. Examples of the new approaches adopted at the University of Westminster are then described and their efficacy is considered. Finally, the scope for further development of the approach is explored.

Context

The term 'environmental engineering' refers broadly to the application of science to the modification of the human and natural environment. In the context of this paper the term specifically refers to a subject area studied by undergraduate students on courses leading to a degree qualification in a construction-related discipline. The subject area is best summarised by McMullan (2007) as "the science, technology and services that relate to the comfort of humans and the environmental performance of buildings".

In the UK, construction-related honours degree courses typically include environmental engineering during the first two levels. The arrangement at the University of Westminster is not untypical. Westminster's Construction Studies Programme is a suite of eight honours degree courses, including construction management, quantity surveying, building surveying and several other pathways. Students on all pathways study environmental engineering based modules at the first and second levels. The courses are offered in both full time and part time study modes, with the relative percentages on each study mode being approximately 60/40 in favour of part time students. The majority of students pursue careers in the construction-related professions upon graduation.

The Role of Laboratories

Historical role in science and engineering courses

The arguments in favour of laboratory teaching are well rehearsed in academia. There is an expectation that any undergraduate course in the field of science or engineering will incorporate a significant element of laboratory experience. Brown & Atkins (1990) indicate that in Britain the use of laboratories in undergraduate teaching dates back to the mid-nineteenth century. Initially, they suggest, laboratories were used simply for demonstration purposes, but as teaching and learning techniques became more sophisticated, laboratories came to be viewed as "a training ground for scientific enquiry" (ibid).

Benefits of laboratories

Nowadays it is generally accepted that the benefits which students derive from laboratory experiences extend well beyond those directly associated with formal scientific enquiry. An analysis of various sources (Hughes, 2000; Nedic et al, 2003; Brown & Atkins, 1990) suggests that laboratory sessions are used to promote a variety of learning objectives and to provide students with a wide range of opportunities. The following list summarises the key points:

- Stimulation of students' interest by active participation in practical work and interaction with technical equipment.
- Development of students' understanding of methods of scientific enquiry and the discovery of knowledge by experiment.
- Development of students' manual and observational skills relevant to the subject.
- Application of conceptual / theoretical knowledge in a practical context.
- Experience of acquiring, handling and analysing experimental data.
- Development of students' problem-solving skills and the ability to learn by trial and error.
- Experience of working collaboratively in a group in a practical, task-oriented situation.
- Appreciation of the importance of methodical procedures and accuracy.
- Appreciation of the need to be self-critical and open-minded.

Environmental Engineering in Construction-related Degree Courses

What do construction graduates need to know?

It is highly unlikely that students on construction-related degree courses will become environmental engineers / building services engineers when they graduate. It is much more likely that they will pursue careers as construction managers, quantity surveyors, building surveyors or in other mainstream construction roles. As such it is important that graduates from construction courses have a broad understanding of environmental engineering in order to be able to communicate in an informed manner with other members of the design and construction team, and that they appreciate the critical relationship between building services and sustainable development.

Incorporating environmental engineering into construction courses

Construction students need to understand the relationship between occupants and their environment. This requires them to study thermal, visual and aural comfort, along with the building services solutions utilised to achieve those outcomes. The lectures, supported by reading and electronic resources, provide a framework for students to understand the basic theories associated with thermal comfort, heat transfer, air quality, humidity, condensation, properties of light and the principles of sound. These underlying concepts lead to typical environmental engineering solutions, including central heating, ventilation, air conditioning, artificial lighting design, electrical installations, acoustics and noise control, together with hot and cold water supply, sanitation and drainage.

Whilst lectures provide the underlying knowledge base, laboratory sessions may be used to physically 'prove' the theoretical basis of engineering, and to enable students to apply the theory in a practical way. Experimental work also plays a vital role in stimulating students' interest in a subject. As Ahmet (2003) points out, a significant proportion of built environment students have a perception that science based subjects are not directly relevant to their main area of interest. Experiments can help to motivate students by enabling them to see the link between theory and practice. Laboratory sessions help students to visualise complex concepts, consolidate theory and develop practical skills for data acquisition, as well as offering many other benefits, as identified earlier.

Practical Aspects of Laboratory Teaching

Traditional approaches to laboratories in construction courses

The modern framework for construction education has its roots in the 1960s, when there was a major expansion in technical education. This period saw the introduction of many new technician courses, diplomas and degrees at technical colleges, colleges of advanced technology, polytechnics and universities (Burke, 2003). It is interesting to note that many of the new courses emerged from departments with a background in engineering and consequently had a strong scientific and technological flavour. Indeed most of the teaching for science based subjects would have been provided by academic staff who had been formally educated as scientists. Understandably, scientific rigour provided the basis for all science teaching, and this certainly extended to the conduct of laboratories.

Evidence of this formal scientific approach can be found in publications from the period which describe how laboratory work for construction students should be conducted. One such publication (Blunt & Cleveland, 1967) sets out formal procedures for 119 different building science experiments. The majority of these experiments require an extensive range of materials and equipment, and are clearly designed as traditional 'bench work'. They are obviously intended to be carried out by students working in small groups under close supervision, not least because of the health and safety risks associated with some of the experiments, involving boiling water, steam, mercury, and electricity supplies in close proximity to water. For example, one procedure, to "test the luminous efficiency of a metal-filament lamp", involves submerging a 'live' lamp into a beaker of water.

Challenges of laboratory teaching in the current higher education environment

There is considerable evidence to support the view that it has become increasingly difficult, if not impossible, to deliver laboratory teaching to students in the same way as was traditionally expected. For example, Hughes (2000) refers to a "variety of pressures" impacting upon laboratory-based practical work, whilst Nickerson et al (2007) describe how the constraints that universities face have "spurred the creation of new systems for delivering engineering laboratories in education".

In the context of construction courses various factors can be identified as particularly relevant. Firstly, the evolution of mass higher education in the UK since the late 1980s has resulted in huge increases in the numbers of students on university courses. Although admissions to construction courses declined during the 1990s and early 2000s, there have been significant increases since 2004 in response to a buoyant construction market, and the evidence suggests that the demand for graduates from construction courses will remain high for the foreseeable future (ConstructionSkills, 2007). Alongside the growth in numbers there have been ever increasing demands for universities to deliver their courses in a cost-effective manner. This has resulted in increased commonality across several course pathways so that, for example, students on courses in construction management, quantity surveying and building surveying will all be taught together. The combination of increased admissions to construction courses and greater commonality has resulted in much larger student cohorts. Anecdotal evidence from long-serving academic staff on construction courses suggests that typical course cohorts in the 1980s were in the region of 25-30 students, compared with typical cohorts currently between 100 and 150.

The second major factor to consider is the pressure on university resources. Laboratories are expensive in terms of the floor space they require, the specialist equipment which they contain, and the technician support which is essential to maintain them. As student numbers have increased it would not be unreasonable to expect that laboratory facilities would be expanded, but this has not generally occurred. In many cases environmental engineering laboratories are having to cope with a four- or five-fold increase in student numbers without any significant increase in resources. This phenomenon is not unique to environmental engineering, as indicated by Hughes (2000) who describes similar pressures experienced with pharmacology laboratories.

The difficulties associated with resources are exacerbated by the changing student profile on many construction courses. Most laboratory facilities were created for courses which catered predominantly for full time students. However, since the 1990s there has been a significant trend away from the full time mode and towards part time education (Lees & Ashworth, 2005). In many universities the number of part time students on construction courses now exceeds the number of full time students on the same courses. Most part time students attend University on a day-release basis so, unlike full time students, their laboratory sessions cannot be spread out across the week. If part time students are to benefit from laboratory sessions then they all have to be accommodated within a single day.

Alongside all these resourcing issues a further basic problem remains: the need to ensure that experimental and practical work is relevant to the needs of students. To reiterate

Ahmet's point (2003), science based subjects are viewed by many construction students as being remote from their core area. Furthermore, research conducted by Whitelegg & Edwards (2001) points to the difficulties faced by physics students in being able to transfer their learning from one context to another. In other words, the key challenge is to ensure that learning which takes place in the laboratory is not 'context-bound' and that students are able to transfer their knowledge to the real world.

Alternative approaches at the University of Westminster

Underlying approach

Since 2004, academic staff at the University of Westminster have been developing alternative approaches to traditional laboratories to address the challenges outlined above. The primary objective has been to ensure that students studying environmental engineering should continue to be provided with opportunities to undertake practical experimental work which is both stimulating and relevant to their needs. An important consideration has been that the learning outcomes achieved through any new approach should be equivalent (though not necessarily identical) to those of the traditional laboratories. Furthermore, it has been imperative that the health and safety of students should not be adversely affected.

A review of the aims and objectives of the environmental engineering modules led staff to recognise that graduates from construction-related degree courses need the knowledge and skills to evaluate environmental conditions and measure the performance of building services and environmental systems. Traditional 'bench work' in laboratories is not the only method of providing this, nor indeed is it necessarily the best way. Teaching rooms and offices on the campus, or living rooms at home, can provide a 'real world' environment in which environmental parameters can be identified and systems evaluated. The increasing availability of reasonably priced, hand-held equipment means that environmental investigations can easily be conducted by students outside the laboratory.

Procedures

At the first level of the course four 'experiments' are undertaken by students, each relating to a different environmental variable. The basic procedure is the same for each experiment. The students must be thoroughly briefed, and they then work in small groups of no more than four. They must select a suitable room, note the prevailing conditions and carry out measurements of the particular variable. Analysis of results is first carried out in the traditional way by reference to standard text books and reference sources. The analysis may then be reinforced using suitable software and computer modelling. The procedures will now be described individually in more detail:

Condensation risk analysis

This experiment enables students to experience the steps involved in analysing the risk of condensation occurring in a building. Students identify a suitable room and, using a whirling hygrometer, wet and dry bulb temperatures are taken to determine the relative humidity both internally and externally. These values are plotted on a psychrometric chart, and air 'state points' are identified for inside and outside the building. The resultant data is then used in conjunction with construction data derived from worked examples, like those contained in standard text books such as McMullan (2007). Temperature and dew point gradients are then plotted to determine whether surface or interstitial condensation is likely to occur in the given conditions. The analysis can be reinforced using specialist software such as Cymap QuickSlab (www.cymap.com) which facilitates U-value and condensation prediction, or BuildDesk U (www.builddesk.co.uk)which includes a condensation risk tool and is freely downloadable .

Thermal comfort analysis

This experiment requires students to carry out a detailed thermal comfort study of a suitable room, taking into account environmental and personal variables. Students initially undertake a group assessment of thermal comfort to establish a predicted mean vote (PMV) on the seven point index. The students then use black globe and digital thermometers, hygrometers and anemometers to establish radiant and air temperature, relative humidity and air velocity By reference to BS EN ISO 7730:2002 (BSI, 2002), values are estimated for the metabolic rates of activities taking place in the room and the insulation value of clothing worn by occupants. All the variables measured or estimated are then taken into account to arrive at a statistical PMV and predicted level of thermal discomfort as given by the Predicted Percentage Dissatisfied (PPD). Finally, students make use of freely available web-based tools to further analyse and compare their results, as well as investigating adaptive models. Examples include the PMV Tool available on the Square One Environmental Design website (www.squ1.com) and the Thermal Comfort Index Calculator developed by Dr Richard de Dear of Macquarie University, Australia (http://atmos.es.mq.edu.au/~rdedear/pmv/)

Analysis of light levels

This experiment takes students through the basic steps involved in analysing levels of daylight and artificial light in a room. Students select a room with windows on one wall only and working blinds. The dimensions of the room are accurately measured and the total room surface area is calculated. Using a digital illuminance meter the lux level is measured outside and inside in order to establish the light transmittance of the glazing. By reference to Good Practice Guide 245 (BRECSU, 1998), the Average Daylight Factor is calculated.

A grid is then laid out in the room. At grid intersections the lux levels are measured at working height, firstly with the blinds open and then again with the blinds shut and the lights on. The daylight and artificial light measurements are then tabulated and compared with design guidance. Further analysis is carried out using Relux (www.relux.biz), a freely downloadable commercial lighting design software package.

Acoustic analysis

This experiment involves students in modelling the effect of various surface treatments on the acoustic properties of noise breakout from a room. Simple acoustic box kits have been constructed in medium-density fibreboard (MDF) together with appropriately sized sections of foam to provide acoustic linings. Students are issued with a box kit, together with a digital sound level meter and an electronic buzzer. Students take the box to a suitable room and firstly measure the background noise level in the room. The electronic buzzer is then placed on a table and sounded whilst noise levels are measured. A series of further noise level measurements are then taken under differing conditions using the acoustic box kit to simulate various different surface treatments and levels of isolation, insulation and absorption. A modification of this experiment allows students to model noise reduction within a room by inserting the microphone of the meter through a hole in the box. The box alone provides a highly reverberant response which can be attenuated with isolation, absorption and a barrier. Students are also able to assess attenuation by octave band frequency analysis, and to plot noise rating (NR) curves for the various treatments. Further analysis and modelling can be carried out using specialist software such as Ecotect's reverberation time facility (www.squ1.com/ecotect). Students may also attempt to model the effects of acoustic ceilings and barriers using COPE-Calc (http://irc.nrc-cnrc.gc.ca/ie/cope/07_e.html).

Have the new approaches been successful?

Since 2004 the new approaches have increasingly replaced traditional laboratory work. Clearly, it is not possible to make a direct comparison between the new approaches and the traditional approaches in terms of the achievement of desired learning outcomes. Comparison of the two approaches can only be anecdotal evidence from the module team and from students' perceptions.

A superficial analysis of module assessment data over a four year period suggests that the module pass rates have slightly improved. However, there is no direct evidence to suggest that this is a result of the new approaches. It would appear that coursework grades (some of which are based on the experimental work) have shown an improvement, whilst end-of-module examination results have remained fairly consistent. It could be that students found the new approaches more engaging, and were therefore more enthusiastic, but without more detailed investigation this remains conjectural. Evidence from module feedback questionnaires and student comments suggests that students were generally very positive about the module, particularly the practical work. The questionnaires include a standard section in which students give their views on the aspects of the module which they found most interesting. The following examples are illustrative of comments received:

"Enjoyed the practical sessions and experiments"

"Experiments – being taught to look at things more critically and ask why"

"Theory applied to practical situations"

"Relating theory to real world examples"

One interesting by-product which appears to have emerged as a result of the introduction of the new approach is that students seem to be more willing to undertake experimental work in their final year dissertations. Prior to 2007 it was extremely rare for any student to base their dissertation on scientific investigations, and there was a strong tendency towards qualitative research. The dissertations submitted in 2007 showed a marked increase in the number of dissertations based on 'hard' data gathering and analysis. Again, without formal investigations the link between this increase and the introduction of the new approaches remains conjectural.

From an organisational point of view the new approaches have undoubtedly been successful. Conducting the experiments away from the laboratory has enabled significantly larger numbers of students to be accommodated in a single day. There have clearly been some resource implications, but the hand-held equipment used in the experiments does not represent a major expense when considered in the context of the overall laboratory budget. Provided the students are thoroughly briefed, and suitable controls are in place for the issue and return of equipment, the administration of the practical work is fairly straightforward.

Finally, the use of hand held equipment effectively creates a portable laboratory. This enables students on parallel courses which do not include environmental laboratory sessions (such as, for example, Architecture) to have the opportunity to measure, often for the first time, real environmental variables during lectures on environmental design.

Possible future developments

The success of these new approaches has prompted consideration of how the project can be further developed. It is very likely that further experiments will be added to the existing set, thus offering students more choice. Development is currently taking place on a new experiment which will assess ventilation efficacy by measuring carbon dioxide concentrations before and after room occupation. The intention is that students will relate the results to natural and mechanical ventilation systems. Tests are also under way with simple plug-in digital electrical energy meters to measure energy use from domestic appliances which will contribute an ever greater ratio of emissions as we move towards zero emission buildings.

In the longer term it is intended to further investigate the use of computerised simulations alongside the practical experiments. Initial research suggests that there are mixed views amongst educators as to the value of simulations, as indicated by Hughes (2000). Some argue that simulations can provide much more complete and reliable data sets for analysis, whilst others feel strongly that the 'hands-on' approach of real practical work promotes deeper learning. It is envisaged that simulations could have a greater role to play in the environmental engineering practical work, reflecting the importance of computer modelling and simulations in industry. The issue is whether the software is 'user-friendly' enough for students to have sufficient time to learn and apply it.

Summary

Students undoubtedly benefit from undertaking practical experiments when studying a subject like environmental engineering. In the current climate of increasing student numbers, increasing pressure on resources and a changing student profile, universities have little choice but to seek alternatives to the traditional laboratories. The examples outlined above have demonstrated that it is still possible to provide students with opportunities to carry out practical work without being constrained by the laboratory resources available. Indeed it could be argued that the approaches described are actually preferable to traditional laboratories because they relate more closely to the real-life situations which students will face in their professional careers.

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