



Laboratories for the 21st Century in STEM Higher Education

A compendium of current UK practice
and an insight into future directions for
laboratory-based teaching and learning

Lynda Gibbins & Glynis Perkin

**The Centre for
Engineering and Design Education**

Authors

Dr Lynda Gibbins The Centre for Engineering and Design Education,
Loughborough University email: l.gibbins@lboro.ac.uk

Dr Glynis Perkin The Centre for Engineering and Design Education,
Loughborough University email: g.perkin@lboro.ac.uk

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Centre for Engineering and Design Education
1st Floor Keith Green Building
Loughborough University UK
LE11 3TU

Tel: +44 (0)1509 227191

<http://cede.lboro.ac.uk/>

In Collaboration with:
School of Aeronautical, Automotive,
Chemical and Materials Engineering,
School of Electronic, Electrical and
Systems Engineering and
Wolfson School of Mechanical and
Manufacturing Engineering

Loughborough University
www.lboro.ac.uk/

In Association with:
S-Lab
Professor Peter James
(Director)

Email: s-lab@istonline.org.uk
Tel: +44 (0)1260 290472

[www.goodcampus.org/s-lab/
index.php](http://www.goodcampus.org/s-lab/index.php)

Contents

Acknowledgements	v
Foreword.....	vi
Peter James.....	vi
Melanie King	vii
Executive Summary	ix
Section 1	1
Chapter 1. Introduction.....	3
1.1 What did we aim to discover?.....	4
Chapter 2. Economic challenges and rising student numbers	7
2.1 Economic pressures.....	7
2.2 Rising student numbers	7
Chapter 3. Technology-enabled laboratory-based teaching and learning	9
3.1 History of e-learning.....	9
3.2 Innovative use of technology.....	10
3.3 Online delivery of laboratory activities	11
3.3.1 <i>Virtual laboratories</i>	11
3.3.2 <i>Remote laboratories</i>	12
3.3.3 <i>A blended approach</i>	14
3.3.4 <i>Benefits and evaluation of different models of laboratory delivery</i>	14
3.3.5 <i>Pedagogy</i>	15
Chapter 4. The role of laboratory work in meeting employers' expectations	17
4.1 What is the purpose of laboratories?	17
4.2 Entry-level practical skills	17
4.3 Skills for employment	18
Chapter 5. The student voice	21
5.1 Students' views of laboratory activities.....	21
5.2 Student survey at Loughborough University.....	22

5.3 National Union of Students: Charter on Technology in Higher Education.....	23
5.4 Overview	24
Chapter 6. Rethinking laboratory space and support services	25
6.1 Laboratory spaces are changing.....	25
6.2 Laboratory management.....	26
6.3 Successful laboratory redesign.....	27
6.4 Overcoming difficulties	28
Chapter 7. Evolving academic practice	29
Chapter 8. What does the future look like for laboratory-based teaching and learning?	31
8.1 Increased use of technology.....	31
8.2 Changing physical spaces	31
8.3 Closer collaboration	31
Section 2	33
List of contributing authors.....	33
Examples of current practice – Case Studies	35
Aberystwyth University: Refurbishment of 1960s physics teaching laboratories	
Evans, A.....	35
University of Bradford: Bradford STEM Centre	
Karodia, N., Smith-Harrison, J. and Comerford Boyes, L.....	39
University of Glasgow: Conversion of an obsolete biomedical laboratory into a multi-functional, multi-media teaching facility improves learning and increases utilisation by 280%,	
Bagg, J.	43
Glasgow Caledonian University: Laboratory refurbishment secures chemistry education and research at Glasgow Caledonian University	
Uttamlal, M. and Little, D.	51
University of Liverpool: The Central Teaching Laboratory at Liverpool University: a new combined facility for physical and environmental science teaching	
Reilly, L.M., Rushworth, E. and Vaughan, H.	57
Loughborough University: Maximising equipment use with Kit-Catalogue	
King, M.R.N. and Attenborough, J.....	65
City Academy Norwich: New flexible science teaching spaces enhance learning and showcase sustainability	
Mullis, T.	69
Nottingham Trent University: IT-enabled bioscience and chemistry teaching in Nottingham Trent University's Rosalind Franklin Building	
Kirk, S., Cosgrove, M., Baker, D., Ward, A. and Richards, A.	73
The Open University: Product re-engineering for enhanced end-of-life performance	
Endean, M., Clay, K. and Burnley, S.	79
The Open University: Development of a vendor practice-based distance learning programme	
Moss, N., Seaton, R., Smith, A. and Williams, K.	85

Queen Mary, University of London: The QMUL Virtual Tissue Lab: using 3D interactive games technology to optimise real lab time and improve student learning	
Turner, K., McOwan, P. and Chowdhury, T.	91
University of St Andrews: An integrated chemistry teaching lab at the University of St Andrews	
Aitken, R.A.	97
University of Sunderland: University of Sunderland Sciences Complex refurbishment – a new way of working	
Garfield, I.	101
Synopses of current practice	111
Cardiff University: Empowering learning in electrical machines	
O'Doherty, D.M. and Griffiths, H.....	111
Coventry University: Use of laboratories in postgraduate teaching of Civil Engineers	
Coakley, E.	113
Coventry University: Early introduction to practical activity to advance course assimilation	
Green, P.	115
Coventry University: The use of authentic activity and enculturation in undergraduate aerospace teaching at Coventry University	
Harrison, A. and Jones, C.	117
Loughborough University: The development of a remote laboratory for distance learning at Loughborough University	
Blanchard, R. and Williams, S.....	119
Further reading	121
Providers of remote and virtual online practical activities for STEM subjects	121
Conferences and publications on laboratory-based teaching and learning.....	121
Further reading on higher education.....	121
Further reading on the engineering sector	122
References	123
Appendices.....	127
Appendix 1 – Student questionnaire.....	127
Appendix 2 – Staff questionnaire.....	129

Acknowledgements

“The old model of dedicated laboratories for each discipline seems to be eroding in favour of larger, shared, flexible spaces, which can be used in a variety of ways.”

“The future of UK HE laboratory teaching and learning will continue to be affected by the economic and market-driven pressures under which the higher education sector operates.”

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Dr Lynda Gibbins & Dr Glynis Perkin

Foreword

by **Professor Peter James**

Director of S-Lab. Details of its awards, and presentations and videos from its 2012 and 2013 Conferences (which have featured many of the authors and cases connected with this report) can be obtained from www.effectivelab.org.uk.

As this report demonstrates, this is a challenging period for university teaching laboratories. Lean times require them to be as efficient as possible, whilst rising fees are turning students into discerning customers who demand top-quality learning experiences. Innovation, especially that underpinned by information and communication technologies, promises to square this circle, but some fear that this could undermine educational quality, for example, by replacing physical laboratory experience with ‘softer’ experiential and virtual approaches.

The S-Lab (Safe, Successful, and Sustainable Laboratories) initiative is a response to these challenges – and similar ones in university research – and provides a space for all laboratory stakeholders to share best practice and think strategically about current and future laboratory design, management and operation. In a survey of the academic, technical support and other (mainly HE) practitioners attending the S-Lab 2012 Effective Laboratory Conference, 66% of respondents said that there is great scope – and 30% said there is some scope – to increase significantly the efficiency and effectiveness of laboratories, without compromising their quality of work and safety. A follow-up question asked what would most help to achieve this, and the most popular answers were more pressure from funders of lab work (chosen by 60% of respondents), more focus on the topic by senior staff (57%), and more cross-functional working, e.g. between lab technical staff and facilities (54%).

The implication of this – and the points that are made in the following pages – is that teaching (and research) laboratories can no longer be enclaves, run by and for established academics within a single discipline. They are a learning system which must itself learn from its ‘customer’ students and incorporate the expertise and views of other stakeholders. These include academics in related disciplines who could potentially share facilities and equipment, junior lecturers, teaching assistants and demonstrators working at the ‘coal face’, technical staff who are key to efficient operation and a valuable support for students, AV and learning technologists who can make the most of the digital technologies that

are central to most students’ lives, and estates and facilities staff who can help to achieve optimal and cost-effective performance.

One small example of the benefits of inclusion was provided by a recent S-Lab workshop on new chemical and physical science teaching laboratories. This featured three of the case studies (Liverpool, St Andrews and Sunderland) that are presented in Section 2. After the more visible topics of building features, layouts, equipment, and academic practices had been discussed, a less obvious theme emerged, which was the contribution of changes in technical support (e.g. leaner, less focused on specific cohorts, more integrated) to their success, and the role that technical staff had played in shaping the design. One result of this was ensuring adequate and well-designed storage to enable efficient preparation and changeover and to create a positive image of orderly, clutter-free working. The insight was just in time for one academic attendee involved in a refurbishment at a distant university. “We’ve got to trim the design to be within budget”, he remarked, “and I was suggesting that we cut out some storage space. I can now see that this would be a big mistake so it’s been worth the travel just for that insight.”

Today’s challenges also require a more strategic, cross-disciplinary approach, led by senior managers, to teaching and research laboratories. This can identify commonalities, ensure that the opportunities for rethinking of learning approaches and operational practices which are created by a new build or refurbishment are taken, reconcile the wish-lists of academics with budgetary, space and other constraints more effectively than single-discipline academics, architects or project managers and encourage continuous improvement of current facilities.

The cases, synopses and literature review presented in this report demonstrate that there are already many exciting responses to the challenges of reinventing laboratories which can create benefits for academics, students and university finances. One example is the creation of larger teaching spaces for simultaneous use by different groups. If these exemplars are built upon in the wave of refurbishment or replacement of the 1960s and 1970s teaching spaces that are coming up for renewal, then the UK will have a new generation of world-class science learning facilities to maintain its reputation for world-class science.

Foreword

by **Melanie King**

Head of the Centre for Engineering and Design Education at Loughborough University.

“You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.”

Richard Buckminster Fuller

The transition into the new century has seen a radical change in the provision of education at a higher level in general. Show-stopping technology vies for centre stage, dazzling those educators with a belief in its potential and providing an unwanted distraction for others. However, technological advances have been challenging the pace of education for over a century in a seemingly on-going carousel of progress. What makes the 21st century so different? It is easy to assume that the new generation of learners are at the cutting edge, even bleeding edge of leveraging technology to improve their learning opportunities; a mosaic of tools and devices enabling learners to access a seemingly infinite amount of data. Despite this, surely the business of teaching and learning is fundamentally the same as it was in the last century?

This compendium provides a thorough review of the literature and an insightful glimpse into some of the new and emerging models of teaching and learning for the laboratory-based disciplines (predominantly in science and engineering) in case studies of current practice in Section 2. Chapter 3 describes the burgeoning use of information and communication technologies (ICT), which gives us a clue as to the direction of travel for developments to lab-based teaching and learning. However, to what extent are teaching developments being led by ICT developments – the technological tail wagging the educational dog, so to speak?

Horizon scanning is the buzzword of the contemporary technophile, but how do university planners and educators know exactly which predictions can be relied

upon to provide an accurate picture of what the future really holds? Evangelists of technology’s ‘next big thing’ usually come in the form of corporate Mafiosi or consumer converts with a purchase and upgrade plan for the next five years. These people are keen to attain the accolade of Future Gazer, but how far can they really predict the advances and innovations that pedagogy will undergo in the next 50 years? Are there any visionaries who can provide us with an insight?

Charles Tenney (1962), in his foreword to the book *Education Automation*, describes Richard Buckminster Fuller as, “a nonconformist before nonconformity became a form of conformity”. Buckminster Fuller was an architect, engineer, poet, philosopher, businessman and radical visionary of the 20th century. In April 1961, he was invited to give a talk to the Planning Committee of Southern Illinois University. The Committee was seeking advice from a series of distinguished visitors on their plans for a second major campus, which they had the opportunity to design and build from scratch. Buckminster Fuller’s talk had such a profound effect on those engaged in planning the development of the university that it was issued as a book in the hope that it would stimulate and influence others.

40 years before the birth of the internet, Buckminster Fuller (1973) predicted that, “we are going to get research and development laboratories of education where the faculty will become producers of extraordinary moving-picture documentaries”, and that these will be broadcast to two-way TVs into people’s homes where

The child will be able to call up any kind of information he wants about any subject and get his latest authoritative TV documentary [...] the best information that man has available up to that minute in history. [...] Our educational processes are in fact the upcoming major world industry.

Fuller even posited the invention of the Geoscope, a 200ft geodesic sphere hung 100ft above the centre of campus, controlled by an electric computer where:

All world data would be dynamically viewable and picturable and relayable by radio to all the world, so that common consideration in a most educated manner of all world problems by all world people would become a practical event.

He concluded that “*The universities are going to be wonderful places*”.

In 2013, there is still scepticism, however, over whether the Internet and the currently available learning technologies will in fact bring about a revolutionary change in lab-based teaching and learning. The literature review in this compendium suggests that there is not yet enough evidence to suggest a widespread change in teaching practice. Perhaps technology is being applied with greater effort to resolving issues in efficiency and administrative processes rather than tackling an evolving pedagogy? Chapter 2 highlights the economic challenges of 2013 and that the new mantra of austerity is becoming the main driver for change post-2008 - the challenges facing educators could never be starker. Limited resources result in efficient forms of educational architecture, resulting in the construction of multi-function, multi-user, flexible and efficient machines for learning. However, we must continue to invest in good design for our campuses and try to remember, as Buckminster Fuller (1973) said, that universities are indeed wonderful places.

There is a balance to be met when investing in physical infrastructure and laboratory spaces as well as web-based platforms and technologies (as a digital infrastructure) to support the growing number of potential learners who require anytime, anywhere, educational opportunities (described in more detail in Chapter 5). The new educational masses may even provide a mutually beneficial relationship for time-starved researchers and academics. In the book *Cognitive Surplus*, Clay Shirky (2011) argues that we all have more free time than we used to have centuries ago and that this presents society with a collaborative cognitive surplus that can be harnessed and used for good causes.

The concept of the remote laboratory is described in Chapter 3.3.2, but an example of the power of a global cognitive surplus can be seen in perhaps the greatest remote laboratory in the world - the Galaxy Zoo - founded in 2007. This was potentially the biggest participation project ever conceived, with over 250,000 active amateur astronomers from around the globe. As Tim Adams (2012) points out in his article in the Guardian:

...these volunteer “citizen scientists” have classified images from the world’s most powerful telescopes numbering in the hundreds of millions - in doing so creating a more detailed map of the known universe than once thought possible. Their work has given

rise to more than 30 peer-reviewed science papers, at least one game-changing discovery, countless online friendships and perhaps even a few star-crossed lovers.

What motivates a citizen scientist to participate in projects like Galaxy Zoo is comparable to that of the individual student feeling engaged within a large class cohort. The priority needs to be making the student feel like a valued contributor within their learning community (and discipline community), whether this is working in a multi-purpose laboratory space or participating in a Massive Open Online Course (MOOC). Also prevalent is the idea that a ‘laboratory’ is a phenomenon that is something to be experienced, in the spirit of the scientific method, and that learners should appreciate the intellectual heritage they are building on, whilst they Google for datasets and participate in mass online experiments themselves.

Buckminster Fuller (1973) concluded his speech to the Planning Committee with the idea that the modern laboratory is a transformable environment like a circus:

You can put the right things together very fast, rig them up, get through the experiment, knock it down. It’s one clean space again. You want clean spaces. The circus concept is very important for you.

I could not think of a more apt metaphor to describe not only laboratories but also higher education provision in the 21st century. An institution, if likened to a circus, needs to move continually to where the learners expect it to be and we as educators need to make sure we retain all those damned good ring masters who can effectively orchestrate the show.

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Executive Summary

Recent changes to the way teaching at UK universities is funded, with less money from central government and more from student fees, has focused attention on the costs of providing higher education (HE) programmes, particularly relatively expensive laboratory-based science and engineering programmes. Increasing competition amongst universities for the brightest students has resulted in a drive to update many old laboratory facilities.

Rising student numbers in recent years have led to very large cohorts on some programmes, placing pressure on laboratory capacity. Many HE institutions have implemented larger, more flexible laboratory spaces that can be adapted to accommodate large groups or multiple smaller groups in parallel. Sharing facilities and technical support between disciplines is becoming more common, resulting in efficiencies of space and time.

Advances in technology have brought opportunities and challenges to the way practical subjects are taught. There are many examples described in this report of remote or virtual laboratory activities used to augment or replace some traditional hands-on practical sessions. Opportunities for institutions to share development of, and access to, online resources have led to mutually beneficial collaborations. Laboratories are increasingly ‘digitally connected’, enabling innovative ways of uploading and analysing lab data. The appropriate use of technology can enrich and support the student learning experience.

Science, technology, engineering and mathematics (STEM) skills are in demand by high-technology business sectors, and HE STEM programmes play a critical role in developing appropriate practical skills in their undergraduates. Surveys of employers have highlighted inadequacies in teamwork and problem-solving skills in a significant proportion of recent graduates, which many institutions are seeking to address by means of innovative approaches to practical work.

The views of students themselves are under increased focus in today’s market-driven HE sector. A review of the literature in this area and a small survey of Loughborough University students concur that students

place high value on well-planned and engaging practical activities. They are open to increasing use of remote and virtual online activities, but not at the expense of time spent in the physical laboratory.

The old model of dedicated laboratories for each discipline seems to be eroding in favour of larger, shared, flexible spaces, which can be used in a variety of ways. Specialist equipment can be centralised, creating facilities that offer opportunities for commercialisation as well as ‘state-of-the-art’ centres for teaching and learning. In this compendium we present case studies which highlight the importance of effective stakeholder engagement and developing a clear understanding of the intended use before embarking on either a new laboratory build or a refurbishment.

Many institutions have instigated a review of how they deliver the practical elements of STEM courses. Problem-based learning approaches are popular and many institutions have designed specific facilities to support this approach. Some of our case studies describe the successful introduction of modules completely devoted to practical work. This intensive immersion in practical tasks develops teamwork and promotes understanding. Where shared facilities have been introduced, this can offer opportunities to develop cross-disciplinary modules and projects and also promotes closer working relationships between academic staff.

The future of UK HE laboratory teaching and learning will continue to be affected by the economic and market-driven pressures under which the higher education sector operates. The way practical skills and scientific principles are taught looks certain to be further influenced by technological advances, with increasing development of online resources to augment practical laboratory sessions. The future direction of Massive Open Online Courses (MOOCs) and their impact on mainstream HE STEM provision is as yet uncertain.



Section 1

Chapter 1

Introduction

Laboratories are changing, in ways that could not have been envisaged even 25 years ago. Technological developments have revolutionised laboratory delivery; however, other factors are contributing to the changes. The cost of laboratory provision has led to the introduction of shared laboratories and many dated laboratories are being refurbished and new builds are being commissioned. Universities are showcasing their buildings to prospective students and their parents. There is growing competition between universities for the best students and terminology such as ‘state-of-the-art’ and ‘wow factor’ now feature in university prospectuses. “Education has attracted discussion and controversy whenever decisions regarding its availability, content, delivery or funding have been made” (Perkin, 2007) and it now seems likely that funding cuts will continue and changes to laboratories will accelerate as we progress through the 21st century.

Laboratory-based teaching and learning has been a key part of science education for at least 200 years. In the early 19th century, practical work was introduced to university chemistry courses in Germany, and by the middle of that century it was established at universities in England, Scotland and America (Boud, Dunn and Hegarty-Hazel, 1986). Later in the 19th century the advent of correspondence courses hailed the start of distance learning (Matthews, 1999). The launch of the UK’s Open University (OU) in 1969 changed the perceptions of university education. Distance learning was no longer only paper-based correspondence courses; the advent of technology enabled a mixed-media approach, incorporating videos, broadcast material, telephone and face-to-face meetings.

A step-change in the delivery of teaching and learning material followed the opening up of the Internet and the development of e-learning in the 1990s (Sousa, Alves and Gericota, 2010). New technologies in recent years

have now impacted on laboratory teaching with the development of remote and virtual laboratory activities which may augment, or in some cases replace, practical sessions. Science education, which has traditionally been practically focused, is now becoming more varied.

In parallel to advances in technology, HE has been subjected to a changing economic climate in recent years. Direct central government funding for higher education in the UK has diminished, with a greater proportion of funding coming from student tuition fees, underpinned by student loans. In an increasingly global market, universities find themselves in competition for the brightest students, and up-to-date facilities can be a key factor when potential students make their choice of university. The costs of delivering laboratory-based science, technology, engineering and maths (STEM) programmes are significantly higher than those of non-practical courses. These costs include expensive and energy-intensive services, specialist support staff, large amounts of equipment, health and safety precautions such as fume cupboards and usually much more contact time between staff and students than is usual for other disciplines. Current funding arrangements, while making some allowance for this, do not adequately reflect these higher costs of provision. It is not surprising, therefore, that educational institutions are examining their laboratory provision and seeking efficiencies and maximum return on their investment in these facilities.

The importance of a well-educated and scientifically literate workforce has never been greater, and STEM skills have been highlighted as key requirements for the UK to be competitive in high-technology business sectors (Harrison, 2012). Recent employer surveys, however, have highlighted shortcomings in the level of practical skills in recent school leavers and graduates

(see for example UKCES, 2012). There is a pressing need to review the delivery of practical skills to ensure that graduates leave university with well-developed problem-solving and teamwork skills to meet the evolving needs of employers.

A new phenomenon in university-level education has emerged in the last few years. Massive Open Online Courses (MOOCs) are easy to access via the Internet and enrolment is generally free of charge. A number of key players in this market have emerged, such as Coursera (<https://www.coursera.org/>), edX (<https://www.edx.org/>) and Udacity (<https://www.udacity.com/>). These platforms offer modules of study from a number of HE institutions, including high-profile leading American universities. It is not yet clear what impact this will have on mainstream education, but MOOCs raise the question of what the role of traditional 'bricks and mortar' facilities should be. Will there be a reduction in campus-based students, with much teaching and learning being conducted online? What might be the impact of this on traditional laboratory-based teaching and learning for providers of STEM higher education programmes?

In the light of all of these challenges to the traditional model of HE provision, and particularly laboratory-based education, it is now timely for UK higher education institutions (HEIs) to review their laboratory facilities and consider how advances in technology, best practice in laboratory design and operation, and innovative teaching and learning practices can be harnessed in order to meet the needs of students and employers in the 21st century.

In common with many institutions, Loughborough University has identified a need for a programme of laboratory relocation and refurbishment. To inform this project, the Centre for Engineering and Design Education (CEDE) at Loughborough University was asked to undertake an investigation into good practice in laboratory-based teaching and learning.

Note: Throughout this publication we have used the terms 'laboratory' and 'lab' interchangeably.

1.1 What did we aim to discover?

In conducting this investigation we sought to answer a number of questions which are discussed in subsequent chapters of this report. Firstly in Section 1 we examine the impact of the economic climate and rising student numbers on the provision of practical work in STEM undergraduate programmes (Chapter 2). The impact that technology has had and the opportunities it presents for laboratory-based teaching and learning are covered in Chapter 3. The role of laboratory work in meeting employers' needs by developing practical skills in students is addressed in Chapter 4, while the views of students themselves are examined in Chapter 5. Key recommendations for success when considering a laboratory rebuild or refurbishment are summarised in Chapter 6. Laboratory-based teaching and learning continues to evolve, and examples of innovative practices are presented in Chapter 7. Finally, we look to the future in Chapter 8, and highlight some trends that we believe will continue to influence the delivery of laboratory-based STEM higher education.

To obtain as full a picture as possible, a review of the literature was undertaken, with a particular focus on developments in the delivery of online practical activities for STEM students. This review of the literature relating to laboratories in HE may be considered significant but not exhaustive.

In an attempt to gauge the views of current students on their laboratory activities, a small survey of engineering students at Loughborough University was undertaken and the main themes and concerns that emerged are discussed.

A cornerstone of our investigation includes 13 detailed case studies (see Section 2 of this compendium) authored by staff from 11 UK HE institutions and one school academy. These illustrate a range of different approaches to some of the challenges facing STEM educators today. In addition, five synopses of current practice are also included, focusing on specific initiatives. We are indebted to all of these authors for their willingness to share their experiences. Information was also collected by means of site visits to newly-built or refurbished laboratory facilities, discussions and interviews with key personnel and questionnaires completed by academic staff.

This compendium presents the results of our investigations and highlights areas of innovative practice. It considers the impact that new learning technologies are having on traditional laboratory practice. It is hoped that this will provide insights into possible future directions for laboratory-based teaching and learning within the UK HE sector. This should inform the Loughborough project and also any other institution which is considering how to gain maximum benefit from their investment in laboratory provision.



Chapter 2

Economic challenges and rising student numbers

It is generally recognised that the future prosperity of the UK depends to a great extent on the flow of well-qualified graduates into the workforce and the on-going upskilling of those already working. If the UK is to continue competing and innovating in a range of high-technology business sectors then the demand for STEM graduates seems likely to continue (Harrison, 2012).

2.1 Economic pressures

The Government has, in recent years, reduced the amount of funding available to universities for teaching. In England the funding is distributed by the Higher Education Funding Council for England (HEFCE), and the funding model is felt by many not to reflect adequately the fact that delivery of laboratory-based science and engineering courses is more expensive than classroom-based courses.

A key component of the provision of STEM education is practical work, and most STEM subjects have traditionally involved a significant amount of laboratory-based teaching and learning. The costs of running and equipping laboratories are considerable, and in these times of financial constraints this poses challenges for HE providers. Many institutions have realised that their laboratories are elderly, expensive to run and have outdated equipment in need of replacing.

The financial model for UK HE, with the increased level of student fees (note that there are different fee arrangements for Scottish, Welsh and Northern Irish residents reading for degrees in Scotland, Wales and Northern Ireland), means that prospective students (and in many cases their parents) are increasingly looking at value for money when making their choice of university. Institutions with 'state-of-the-art' laboratories consider that this will be a good selling point in the drive to maintain or increase their student numbers in a competitive market.

The old model of dedicated laboratories for each degree programme or department is under challenge, as many universities seek to implement shared facilities and technical support in order to use space more efficiently and reduce duplication. The high costs of running laboratories (equipment, energy, fume cupboards, specialist support, etc.) are driving initiatives to maximise the usage of labs to justify these costs.

2.2 Rising student numbers

There has been a significant increase in the number of students enrolled on UK HE STEM courses since the early 2000s. For example, enrolments on engineering courses increased by 23% from 2002 to the 2010 intake (Universities UK, 2012). Although more recent figures published by the Royal Academy of Engineering suggest that applications to the Universities and Colleges Admissions Service (UCAS) for all subjects declined by nearly 8% between 2011 and June 2012, the physical sciences and engineering disciplines saw much lower decreases (-1.0% and -2.6% respectively) (Harrison, 2012).

As student numbers have increased over the longer term, pressure has been placed on the existing laboratory facilities at some institutions. Large student numbers in modules lead to space pressures and often result in multiple repeats of each session to accommodate all the students. The resultant difficulties in timetabling may mean that, for some students, the timing of the practical activity becomes separated from the delivery of theory in lectures. Many institutions have implemented shared spaces to allow flexibility of use and to accommodate large groups of students, thereby reducing the number of repeated sessions. The University of Sunderland's MPharm programme has a student cohort of approximately 240. Prior to the refurbishment described in the case study on page

101, up to ten repeats of laboratory sessions had to be scheduled to accommodate all the students. The creation of a large general teaching laboratory with a capacity of 60 allowed the same programme to be delivered with only four repeats. Nottingham Trent University has also undertaken refurbishment of their ex-automotive training centre. This is now being used as a single, multi-purpose teaching laboratory for bioscience and chemistry undergraduates. The case study on page 73 explains how up to 200 students can be taught simultaneously rather than being split into as many as ten classes.



Chapter 3

Technology-enabled laboratory-based teaching and learning

Advances in technology bring both opportunities and challenges. Students increasingly expect to access university systems and applications from their mobile devices at a time and place of their choosing. Technology allows the online delivery not only of lectures but also interactive remote or virtual practical activities. The extent to which it is possible or even desirable to replace hands-on laboratory work with an online equivalent has attracted much debate in recent years. Institutions such as the Open University in the UK, with a long and successful track record of delivering distance learning, are at the forefront of developing online practical activities for STEM subjects.

3.1 History of e-learning

Jay Cross (2004) claims to have coined the term “eLearning” in 1998; however, in a 1997 article Aldo Morri wrote: “The market for corporate interactive distance learning – now known as “e-learning” – has boomed...”

Regardless of who coined the term, in the late 1990s the expectations associated with e-learning were high; however, by the early to mid-2000s uptake was disappointing. One reason, proposed by Zemsky and Massy (2004), for this lack of progress was that it “took off before people really knew how to use it.” They also point out that, despite huge investments in e-learning at US HEIs, the main uses at this time were course management systems such as BlackBoard and PowerPoint lectures. They write that this situation is unlikely to improve until changes in teaching practice take place. However, by 2010 the picture had apparently changed; David Nagel published an article entitled *The Future of E-Learning Is More Growth*. In this article he quotes Ambient Insight’s forecast that growth in the e-learning business in the USA will double between 2009 and 2014.

It was the Internet and the development of e-learning in the 1990s that revolutionised distance learning (Sousa, Alves and Gericota, 2010). Massive Open Online Courses (MOOCs), which are free to sign up to and easily accessible are now growing in popularity. MOOCs enable thousands of students to study a wide variety of courses, not all of which lead to formal qualifications. In the UK, Futurelearn (<http://futurelearn.com>) is a private company which is majority owned by the OU. It is the first UK-led platform for delivery of MOOCs. It will be interesting to view future developments of this initiative and the range of courses that become available.

In the early days of distance education, the teaching of practical skills and laboratory-based activities were still largely conducted face-to-face, the OU residential summer schools being an example. The use of technology was mostly confined to producing non-interactive recorded demonstrations of experiments. As technology has advanced, it is now possible to offer realistic simulations and remote access to real equipment. Online laboratory activities are now delivered by many institutions alongside their physical laboratory sessions and they also form part of many MOOCs, accessed by large numbers of students. The Open University, using a grant from the Wolfson Foundation, is developing an online laboratory for practical science teaching, *The OpenScience Laboratory* (<https://www.open.ac.uk/researchprojects/open-science/>). The content will be integrated into the OU’s undergraduate science programmes and, in addition, students and teachers worldwide will be given free access to some of this material.

It is clear that developments in computing have proved to be beneficial to the progress of laboratories; nevertheless, providing a valuable laboratory experience has been made more difficult due to the increasing costs associated with this provision.

However, as Balamuralithara and Woods (2009) point out, the cost of simulation laboratories is low compared to those associated with hands-on and remote laboratories.

3.2 Innovative use of technology

Advances in technology have made possible a number of innovative approaches to facilitate student learning within laboratories. Techniques can be as simple as providing videoed demonstrations of how to use equipment or by the illustration of certain techniques. This approach can save time in the physical laboratory if students watch the videos as advance preparation. A well-prepared video may also help to avoid the issue of variable quality which may arise when different members of staff demonstrate techniques in real time in the hands-on laboratory.

Laboratories have become much more digitally connected; equipment can be linked directly to an institution's network, allowing experimental data to be stored and backed-up, and then analysed remotely. Following a chemistry laboratory refurbishment at Glasgow Caledonian University (see page 51), microscopy data gathered on the Forensic Microscopy course is uploaded to the network and, by means of an audio-visual facility, can be projected to the whole class for discussion.

A refurbishment at Nottingham Trent University (page 73) created a chemistry and biosciences laboratory facility with an advanced IT infrastructure. Up to eight separate groups can simultaneously use the large, open teaching laboratory, with the capability to connect PCs and visualisers to large screens for live demonstrations. All students are provided with tablet computers to use within the laboratory, allowing remote access to online resources, and the capture and storage of lab data.

Recent undertakings include Cain and Shephard (2011), who report on their initiative to improve undergraduate students' preparation for laboratories by the introduction of compulsory online pre-laboratory quizzes in which students must attain a minimum score of 60%. McClean (2011) describes another initiative introduced at the University of Ulster whereby members of staff give first year bioscience undergraduates working in small groups the opportunity to produce a short reflective video of their experience in chemistry laboratories. These videos are stored on a video sharing website where they become reusable learning objects for future students. Chaudry and Bamford (2011) explain how they use a Personal Response System (PRS) to facilitate laboratory sessions. Observing students and providing feedback on their experimental choices during laboratory sessions is difficult due to time constraints – the PRS system allows lecturers to pose questions with multiple-choice answers and to feed back to the student whether their answer is correct or incorrect.

Dunne and Ryan (2012) describe a project undertaken in Ireland that was designed to improve the laboratory experience for science undergraduate students. The content of two first year laboratory modules was redesigned to include material to develop technical skills, scientific observation and report writing. At the start of each semester, first year students were presented with a laboratory manual that included links to additional instructive material. The students were required to complete a quiz relating to the forthcoming laboratory session. They were also

required to report on a given scientific article, following which they were given feedback on a one-to-one basis. They then produced four small-group reports during the semester. During the third year, students worked in groups to run practical sessions for the rest of their class, which involved prior liaison with the technician. In a follow-on module, groups of students were expected to devise their own experiment.

Bristol ChemLabS (<http://www.chemlabs.bris.ac.uk>), a Higher Education Funding Council for England (HEFCE) funded Centre for Excellence in Teaching and Learning, has developed a Dynamic Laboratory Manual (DLM), which, it is claimed, has transformed teaching and learning in the School of Chemistry at the University of Bristol. Students are required to complete online background work prior to the laboratory session, including multiple choice tests and safety assessments. The DLM shifts the balance of work done outside the lab to before, rather than after the practical session and, according to feedback, students feel better prepared for the laboratory when they arrive. Building on this principle, Dynamic Laboratory Techniques Manuals for first-year undergraduate physics and biological science programmes are under development. A version of the DLM has also been produced to support practical skills development in chemistry at post-16 school level (*LabSkills – Dynamic Laboratory Manuals for Students, Schools and Universities*).

3.3 Online delivery of laboratory activities

For this compendium, literature has been sourced, in particular, on three distinct means of laboratory delivery, namely hands-on, simulated or virtual, and remote. Ma and Nickerson (2006) give clear descriptions of each of these: hands-on laboratories require students to be physically present, virtual labs have simulated experiments that may be viewed on a

computer and remote labs are undertaken by students at a distance from the hands-on laboratory (but students have control of input via their computer).

If considering introducing some online laboratories, it is important to consider how the students will work with the online tools and what the intended learning outcomes are, rather than just to 'virtualise' an existing lab activity. A recent conference workshop (Endean, Goodyear and James, et al., 2012), led by academics from the OU, provided a step-wise approach to reviewing the practical elements of a teaching programme in order to introduce some remote or virtual activities to replace or augment the physical laboratory activities. The approach can be summarised thus:

1. Identify why practical work is included in the programme
2. List the desired learning outcomes for each activity within the context of the particular programme
3. Consider ways in which the same learning outcomes can be developed without students being physically present in the laboratory.

The literature contains many examples of the use of online (remote or virtual) practical activities in STEM education, some of which are highlighted here.

3.3.1 Virtual laboratories

Virtual experiments enable students to experience an activity via images and data presented online. Unlike remote laboratories, there is no actual interaction with real equipment; rather the interaction is simulated and the data is retrieved from a stored database, representing the range of data to be expected from the equivalent physical experiment. Virtual activities can be accessed by large numbers of students simultaneously and can be repeated as required.

The University of Southampton has successfully introduced a number of virtual experiments into undergraduate programmes. For example, a virtual diode experiment in Electrical Power Engineering has improved students' understanding of key concepts. Southampton's Chemistry Department has devised a virtual reaction chamber experiment to avoid difficulties with temperamental 'real' equipment. The Southampton initiative was shortlisted for the 2012 S-Lab Awards under the Teaching and Learning category (S-Lab, 2012).

The OU (with JISC funding) created a virtual microscope activity (<http://www.virtualmicroscope.org/>), giving distance learners the opportunity to examine minerals and rock samples via digitised images held in a large database. Classification and identification skills can be developed without the high costs associated with microscopes.

Another successful introduction of virtual microscopy is described in the University of Glasgow Dental School case study (page 43). An obsolete building was converted to a multi-media teaching facility. Traditional microscopy was replaced by the virtual microscope and a 3D projection system was installed, which allows teaching of aspects of operative dentistry and other anatomical subjects that require complex spatial awareness.

Queen Mary, University of London (QMUL) has introduced a Virtual Tissue Lab which teaches students technical skills via 3D interactive games technology. This experience is described in a case study on page 91. A feedback system has been incorporated into the virtual platform to encourage enquiry-based learning. Students became proficient in using equipment, resulting in a reduction of 'real' lab time from 15 to six hours per week. In addition, students focused more

on analysing results rather than practical techniques, showing greater critical awareness and problem-solving skills. Coursework marks improved considerably.

Outside the UK there are many examples of virtual laboratory offerings, for example in India, which has a large population with relatively low access to costly equipment. The Virtual Labs initiative (<http://www.vlab.co.in/>) supported by the Indian Government is a partnership of educational institutions and offers undergraduate and postgraduate students access to a range of virtual science and engineering experiments. Amrita University has an extensive range of virtual laboratory experiments which are freely available. Additional examples of online virtual laboratories are provided in the *Further reading* section towards the end of this compendium.

3.3.2 Remote laboratories

Cooper and Ferreira (2009) report that it is now over 20 years since the introduction of remote laboratories, the first of which were, in fact, robotics labs (Taylor and Trevelyan, 1995). Remote labs, according to Fabregas, Farias and Dormido-Canto et al. (2011), may be viewed as being somewhere between simulations, which do not have any interaction, and a hands-on laboratory. Remote laboratories avoid some of the constraints that are associated with hands-on labs (such as timetabling, equipment costs and fixed location), whilst still allowing the student to perform experiments and gather data from actual physical equipment. They describe their development of a remote laboratory for engineering students and their subsequent evaluation of the tool. Thirty students were surveyed after using the remote laboratory and, of these, about 69% felt that the experiment had helped them to understand pertinent ideas. However, the authors add that students highly value hands-on laboratories; therefore, remote or

virtual labs should be complementary and not used as replacements for the traditional approach.

Bellmont, Miracle and Arellano et al. (2006) emphasise that:

The overwhelming developments of the Internet technologies are becoming enabling agents of new teaching methods. Among them, the remote laboratories are increasingly being considered as a serious alternative to the classical local laboratories; therefore they are being used by many institutions worldwide.

The laboratory resources that have been developed are wide-ranging and demonstrate the initiative and thought that has gone into their creation. For example, Aktan, Bohus and Crowl et al. (1996) describe the remote control of a robot. Enloe, Pakula and Finney et al. (1999) write about their teleoperation to determine the speed of light. Carusi, Casini and Prattichizzo et al. (2004) discuss delivery of distance learning by remote control of a Lego® mobile robot.

Following the introduction of a distance learning version of an MSc programme *Renewable Energy Systems Technology* at Loughborough University, a number of physical laboratory activities were initially replaced by simulations (Blanchard, Morón-García and Bates, 2006). More recently, a remote laboratory was developed to investigate the energy conversion properties of photovoltaic panels. Students view the equipment via a webcam and can change various parameters such as temperature and irradiance. They then take readings via the remote system and download them for analysis (see page 119).

The benefits of remote access to equipment are obvious for programmes with distance learning students, but collaborations between institutions or with industry can

allow students to conduct experiments on or collect data from large and/or expensive equipment (such as telescopes), which would otherwise be unavailable. For example, students from the University of British Columbia in Canada have used the remote laboratory developed at the University of Leeds, providing an example of successful international collaboration (Levesley, Culmer and Page et al., 2007).

Implementing a remote laboratory at the OU resulted in a number of changes to the activity, even though the intention was to make it the same as the hands-on laboratory; there were aspects of the hands-on lab that were too costly or too difficult to automate. Focus groups undertaken with OU staff showed that they were enthusiastic about their remote laboratories, but one member of staff commented: "The student who wants to work as a chemist needs more hands on than people who need to learn principles" (Scanlon, Colwell and Cooper et al., 2004). The same authors state in their conclusion that, in their experience:

...the process of implementing remote experiments can require changes to the learning and teaching objectives, and it is therefore not necessarily possible to compare a traditional laboratory experiment with its remote equivalent.

Cooper (2005) also discusses issues associated with the widespread implementation of remote laboratories, the benefits being greater accessibility and the possibility for institutions to share expensive resources.

Nafalski, Nedić and Machotka (2011) acknowledge that remote laboratories do not, in general, provide opportunities for students to collaborate. However, their paper reports on collaborative remote laboratories at the University of South Australia that offer students the possibility to work with partners, whether this is

physically sitting with another person or linking to others by computer; up to three students can work on experiments at the same time. Although the system could accommodate more students, the authors conclude that it would not be practical to have more than three people controlling an experiment.

Whilst there has been progress in the development of remote laboratories, there is still room for improvement from a pedagogical perspective; literature relating to rigorous pedagogical research is sparse.

3.3.3 A blended approach

A case study from the UK's Open University (see page 85) describes a collaborative initiative with Cisco Systems to develop distance learning modules in networking for up to 600 students at a time. These modules serve a dual purpose, preparing students for Cisco professional qualifications and also providing the networking element of a number of OU undergraduate programmes. Hands-on use of real equipment is a requirement for the Cisco qualification, so a blended approach was adopted - dedicated day schools for the hands-on practical work, coupled with remote access to Cisco equipment such as routers and switches, and use of a simulation package allowing multiple users to design and simulate network traffic and its routing. Building on this experience at undergraduate level, the OU and Cisco Systems have now introduced a postgraduate programme in advanced networking. The OU experience indicates that, in this example, undergraduate teaching objectives could be met by a mixture of hands-on and simulated activities, but at postgraduate level remote access to physical equipment, in addition to hands-on work, was found to be necessary.

3.3.4 Benefits and evaluation of different models of laboratory delivery

There have been a number of reports which describe or evaluate the relative benefits of remote, virtual and hands-on laboratory activities. Balamuralithara and Woods (2009) discuss the key issues related to simulation (virtual) and remote laboratories as described in the literature and report that, whilst the virtual laboratory often receives criticism for not providing a realistic experience, it does offer an opportunity for students to access it repeatedly at times that are convenient to them and also provides an explanation of theoretical concept. Although the remote laboratory provides students with an opportunity to control equipment and perform experiments remotely, the effectiveness is dependent on the extent of interaction available to the user.

Corter, Nickerson and Esche et al. (2004) have undertaken an evaluation of the effectiveness of remote versus hands-on laboratories, taking into account student test scores, lab scores and preferences. The authors are aware of variables such as abilities and cognitive styles and also types of experiment that may influence the findings. The study participants were 29 mechanical engineering students at an American college of engineering. Six laboratory classes were used for the evaluation; three used remote labs and three used hands-on labs. Comparison between the two formats was made using data on student satisfaction with the remote labs and by looking at examination marks (two exams included two questions specific to the lab content) and laboratory marks. Each student's individual characteristics (such as scores, cognitive style and demographic information) were taken into account. The findings were that over 90% of the participants "rated the effectiveness and impact of the remote labs to be comparable (or better) than the hands-on labs". This was backed up by analysis of

the examination scripts. In agreement with this study are Bellmunt, Miracle and Arellano et al. (2006), who compared the examination results of students enrolled on an Electrical Workshop of Automation course, which is part of the Electrical Engineering degree at the Technical University of Catalonia. The comparison is between 11 students using a local laboratory and 14 students using a remote laboratory; survey feedback from the students is also discussed. When the results and feedback were compared there were not any significant differences between the two groups; none of these students had any prior programmable logic controllers programming knowledge.

Lang, Mengelkamp and Jäger et al. (2007) studied 52 students prior to and after undertaking laboratory experiments; this included one group in a traditional laboratory and another in a remote laboratory. The findings did not show any significant differences in the students' learning outcomes that could be related to the mode of delivery.

It is interesting to note that, although the above studies have not been large-scale, the findings are all in agreement. However, Ma and Nickerson (2006) point out that they did not find any agreement on practices that evaluated the effectiveness of laboratory work and Hanson, Culmer and Gallagher et al. (2008), after reviewing studies that have compared remote and hands-on laboratories, mention that direct comparison between two different mediums may not be appropriate.

Nevertheless, Fabregas, Farias and Dormido-Canto et al. (2011) are of the opinion that if students use a remote laboratory prior to a hands-on lab they will be better prepared for the experience. After implementation of a control engineering remote laboratory, an online poll was made available to 30

randomly selected students so that they could evaluate their experience. The results were generally positive in nature; for example, 69% of respondents felt that the remote laboratory had helped their understanding of relevant concepts. However, 23% of the students did not feel that the remote laboratories had any advantage over hands-on labs, which may demonstrate the importance that students attach to traditional labs. Some students who had used both types of laboratory gained better marks than students in the previous year who had only attended hands-on labs; however, the authors acknowledge that the study size is small and the examination papers were different.

In conclusion, although direct comparison may be problematic or inappropriate, remote or virtual labs can be useful either as preparation for a physical activity or as an opportunity to repeat activities and embed learning.

3.3.5 Pedagogy

As mentioned previously, there are very few publications detailing rigorous pedagogical research relating to different forms of laboratory delivery, although small-scale investigations are numerous and, in general, agree with each other as detailed in section 3.3.4. Indeed, Hanson, Culmer and Gallagher et al. (2008) raise the issue that there is ongoing debate surrounding the effectiveness of hands-on laboratories compared to remote laboratories but add that little research has taken place regarding how remote labs can be designed to underpin learning. However, Abdulwahed and Nagy (2009) implement Kolb's experiential learning theory using a combination of remote, virtual and hands-on laboratory sessions. They also give before and after laboratory tests in order to aid information retention by activating Kolb's learning cycle. The authors propose that a virtual laboratory used for preparation will lead

“... when considering introducing technology-enabled methods, careful thought should be given to the desired learning outcomes in the context of the overall study programme.”

to improvements in understanding. This was backed up in the findings; the virtual laboratory also reduced the cognitive load.

Cooper and Ferreira (2009) give an overview of the lessons they have learned from their involvement with remote laboratories and associated projects over a ten-year period and reiterate the rationale for their use. The authors acknowledge that practical work is a fundamental part of science and engineering education. There are many reasons for higher education institutions to implement remote laboratories but in the main they relate to issues associated with students' access to laboratories. Remote labs are of particular benefit to distance learners and replace the home experiment kits used by students prior to advances in technology. Students with disabilities that prevent them from entering a hands-on laboratory or from operating equipment may also benefit from remote laboratories. One project undertaken by these authors involved evaluation of pedagogical effectiveness; the findings indicated that students do recognise that there are pedagogical benefits associated with remote laboratories.

Adams, in his 2009 publication, cites many instances of enquiry-based learning being incorporated into laboratory teaching, and cases where undergraduate students are involved in research, again in a laboratory setting. After reviewing numerous publications relating to laboratory teaching he concludes that:

...there is a need to restructure traditional laboratory classes to enable students to learn by discovery, interact more effectively with peers and tutors, and begin to appreciate the excitement of performing experiments.

On the other hand Almarshoud, in his 2011 paper, concludes that although there have been advances in the features of remote laboratories there is still debate concerning the advantages and disadvantages of these labs and indeed the impact they may have on learning.

It is clear that there is a considerable body of research into how to harness advances in technology to engage students better in learning practical skills. The literature contains many descriptions of specific remote or virtual laboratory activities. If used appropriately, these innovative tools can enrich the student experience and support learning. However, when considering introducing technology-enabled methods, careful thought should be given to the desired learning outcomes in the context of the overall study programme.

Chapter 4

The role of laboratory work in meeting employers' expectations

Students value the hands-on aspect of traditional laboratories. This is relevant, as the activities provide opportunities for development of some of the practical skills valued by employers. In the past, many students would have well-developed practical skills before embarking on a degree programme, perhaps through school science or by engaging in practical-based leisure activities in their spare time. Changes to the school curriculum in England, Wales and Northern Ireland and the advent of the 'throw-away' rather than repair culture have resulted in some students having less hands-on practical experience prior to entering university.

4.1 What is the purpose of laboratories?

The Engineering Council (2011) lists practical skills amongst the required competences for engineers. The USA Accreditation Board for Engineering and Technology (ABET) lists goals for engineers, from which it is clear that laboratories form an integral part of an engineering degree, for example, the ability to conduct experiments and use modern engineering tools (Engineering Accreditation Commission, 2011). Nevertheless, Reid and Shah (2007) emphasise that laboratory work cannot be viewed as a stand-alone activity; it must relate to material encountered in lectures. Furthermore, laboratories must be used efficiently and effectively as time is at a premium. They also point out that nowadays there is very little explanation given for the inclusion of laboratories, even though they form a significant part of most science courses.

The need for laboratories in HE chemistry has been challenged in a one-page commentary by Hawkes (2004), who says that there is insufficient evidence to claim that they contribute to the achievement of course aims. Jervis (1999) also points out that, despite practical work being a fundamental part of science programmes, there does not appear to be any

"formal pedagogy to inform science educators as to what proportion of practical work in an undergraduate programme contributes to an effective science education". This is in accord with Feisal and Rosa (2005), who write that, whilst most authors are in agreement regarding the necessity of laboratories, there appears to be little published work relating to what it is that laboratories are expected to achieve. Therefore, laboratory work must have appropriately planned learning objectives. They continue by reporting on a colloquy that was held in 2002 at which 13 objectives relating to engineering instructional laboratories were determined. These objectives relate to: instrumentation, models, experiment, data analysis, design, learn from failure, creativity, psychomotor, safety, communication, teamwork, ethics in the laboratory and sensory awareness. Moreover, Hofstein and Mamlok-Naaman (2007) point out that, although research has been undertaken to investigate the effectiveness of practical experimentation, this research has not identified a relationship between the laboratory sessions and student learning.

4.2 Entry-level practical skills

Research has shown that university science staff overwhelmingly feel that most new undergraduates are not equipped with the necessary laboratory skills and that the level of practical skills of school leavers has declined in recent years (The Gatsby Charitable Foundation, 2011a). This research revealed that universities have been forced to adapt their first year courses as a result of this decline. Laboratory courses have been simplified, online pre-laboratory activities have been introduced and more support from staff and demonstrators is required. A parallel survey of STEM employers corroborated these findings, with significant numbers reporting a decline in the practical skills of school leavers over the previous five-year period (The Gatsby Charitable Foundation, 2011b).

“... a decline in the practical skills of school leavers ...”

4.3 Skills for employment

Employers of STEM graduates expect that their new recruits will have gained an understanding of the basic principles of their academic discipline. In addition, employers value the practical skills traditionally acquired via hands-on laboratory experience.

In the first UK-wide employer skills survey (UKCES, 2012) it is reported that up to 82% of employers believe that university leavers are well-prepared for work, which is in accord with earlier reports and surveys such as the UKCES briefing paper (2011) and the Learning and Skills Council (2008). Whilst these figures are gratifying, what is of concern is the significant minority of employers (up to 18%) who view graduates as not well-prepared for the workplace. One of the problems cited was lack of specific skills such as technical or job-specific skills (Learning and Skills Council, 2008). However, the UKCES 2011 briefing paper acknowledges that:

It is not possible for HE institutions to predict and meet the full range of skills that employers may need; they are too numerous and too specialised to be covered in a four-year degree.

Employers' dissatisfaction with the skills level of new graduates is echoed in a recent study undertaken in the US (Fischer, 2013). The main deficiencies identified by employers included poor communication, problem-solving and decision-making skills. Employers are reluctant to invest in graduate training programmes since employees tend to move on frequently, and businesses increasingly expect HE to prepare students for the workplace. This is resisted by some who feel that the role of a university is to provide a broad education rather than narrow job-focused training. The challenge is to strike a balance between those practical skills that it is reasonable to expect an HE programme to embed in its undergraduates and those more job-specific or sector-specific skills that employers should deliver to new recruits by on-the-job training.

A research study, undertaken by the Henley Management College on behalf of the Royal Academy of Engineering, (Spinks, Silburn and Birchall, 2006) investigated the skills that engineering employers required their graduate employees to possess. The study comprised interviews and focus groups with industry practitioners and recent graduates. Communication was a highly valued skill (this is also reiterated in the report *Graduate Employability: What do employers think and want?* produced by the Council for Industry and Higher Education, (Archer and Davison, 2008)) but one area, namely practical work, was cited by employers and recent graduates as not having a prominent enough role at university. Companies identified that a skills gap was evident in problem-solving and the application of theory to real problems. The study also mentions that, over the previous ten years, there has been a reduction in the unit resource for teaching engineering at undergraduate level, which has led to a reduction in the amount of practical work that is included in degree courses.

The Royal Academy of Engineering in a 2007 publication, *Educating Engineers for the 21st Century*, writes that:

universities and industry need to find more effective ways of ensuring that course content reflects the real requirements of industry and enabling students to gain practical experience of industry as part of their education.

In general, industrial employers are satisfied with the ability of incoming undergraduates; however, their ability to apply theoretical knowledge to practical problems, which is a highly desirable attribute, is becoming less apparent. The Confederation of British Industry (CBI), in its 2012 survey, found that the employability skills of graduates are better than those who do not participate in higher education, although there were still inadequacies associated with teamworking, problem-solving skills and work experience.

Hanson and Overton (2010) acknowledge that there have been several reports published that detail the skills required by employers, but add that:

...relatively little has been reported on the knowledge and skills that graduates have found of value when they enter into employment or further study.

In order to gather some evidence to fill this gap, they have undertaken a survey of chemistry graduates from nine universities approximately 2½ years after graduation; there was an overall response rate of 36%. The findings show that many chemistry graduates were satisfied with their programme of study but it was felt that more assignments and report writing at university that replicated the workplace environment would have been useful.

Many institutions have attempted to mimic a modern industrial laboratory setting when upgrading their facilities in order to make the student experience as realistic as possible. For example, following its refurbishment (see page 73), a Nottingham Trent University lecturer noted that the new facility “allows students to gain an insight into what it’s like to work in a professional modern laboratory environment”.

Problem-based learning (PBL) is an educational approach that seeks to enable students to ‘learn to learn’. Practical activities are based on a series of problems designed to mimic those encountered in the real world and the teacher takes the role of facilitator. It is claimed that PBL can result in students developing improved levels of professional and process skills (such as problem-solving, analytical and critical thinking, project management and collaborative skills), all of which are much in demand by employers. This approach has been successfully introduced at many universities (for example Coventry University’s Department of Aerospace, Electrical and Electronic Engineering, see page 117), and some institutions have created specific problem-based learning spaces to facilitate small-group work (for example the University of Sunderland, page 101). A review of the PBL approach and a number of best practice examples has been reported by Teaching and Research in Engineering in Europe. This special interest group is led by Kuru (Kolmos, Kuru and Hansen et al., 2007). The term enquiry-based learning (EBL) is now being used increasingly as an umbrella term, covering problem-based learning, project work and all forms of enquiry-based learning (Barrett and Cashman, 2010).

The Royal Academy of Engineering (<http://www.raeng.org.uk/education/>) has been pro-active in this area with the introduction of their ‘Visiting Professors’ scheme,

“allows students to gain an insight into what it’s like to work in a professional modern laboratory environment”

which is currently focusing on innovation to support “the development of an innovation-driven economy for the UK”. Visiting Professors are based in specific universities and act as a link between undergraduates and industry, focusing on problem-based learning approaches and sharing their knowledge of industrial practice. The scheme was launched in 1989 and has addressed seven distinct areas since its inception.

Amongst the main recommendations of a report in 2008 by the Higher Education Academy Centre for Bioscience, produced as a result of a two-day workshop held at the University of Leeds, is the need to develop communication channels between higher education, employers and funding councils with respect to effective and appropriate laboratory experiences in the biosciences. Moreover, a publication relating to the nature and effectiveness of laboratories should be commissioned and a list compiled of the laboratory skills employers would like their graduates to bring to the workplace.

It is hoped that this compendium addresses some of the points raised by highlighting areas of good practice in laboratory-based teaching and learning.



Chapter 5

The student voice

In an increasingly market-driven HE sector with high student fees there is a growing focus on improving the student experience. The student voice is widely reported in surveys such as the UK's annual National Student Survey (NSS) (<http://www.thestudentsurvey.com/>).

5.1 Students' views of laboratory activities

Russell and Weaver (2008) report on a qualitative, grounded theory study of students' perceptions of the purpose of the laboratory in science education. Semi-structured interviews were conducted with 13 undergraduate chemistry students at a US university. Topics covered included whether or not the students liked attending laboratory classes, what changes would make labs more enjoyable and what was the purpose of the lab class to their course. Three major themes emerged. Students believe that the main requirement is to follow the written lab instructions closely with little thought, they value the visual, kinaesthetic element to learning that laboratory activities provide and there appear to be two distinct viewpoints as to whether or not practical activities are connected to lecture material. Some students see this connection and appreciate it, while others feel that the laboratory does not reinforce lecture content and does not help them to learn material.

Another study undertaken in the USA by Koretsky, Kelly and Gummer (2011) examined student perceptions of a virtual laboratory and two physical laboratories. The students had a hands-on lab, then a virtual lab followed by a hands-on lab. This was during year one of their study and was repeated with a new intake of students the following year with the order of the two hands-on laboratory activities reversed. There were 45 students in year one (82% of students on the course) and 66 (81%) in year two of the study. The survey was undertaken after all three laboratories had taken place.

Student responses showed enhanced awareness of experimental design and greater references to critical thinking and higher order cognition in the virtual laboratory. The physical lab led to greater awareness of laboratory protocol. The authors conclude that:

Our findings support the concept that virtual laboratories can facilitate a broader experience for students and can play an important role in engineering education. Our conclusions are not meant to imply that the differences found are a direct result of the medium of the laboratory, *per se*, but rather the opportunities of instructional experiences that each type of laboratory affords.

Scanlon, Colwell and Cooper et al. (2004) report that students had reservations about replacing all hands-on laboratories with remote labs but were in agreement that remote labs were more effective than simulations. Following the introduction of a remote laboratory at the University of Leeds, feedback was obtained from 39 students. The students were positive about their experience of using the remote lab. In particular, they found that the website was easy to navigate and the experiment was easy to understand (Levesley, Culmer and Page et al., 2007).

In May 2011 a survey was taken of students who had used both remote and hands-on laboratories. The findings showed that the majority of students preferred the remote laboratory; however, they still wanted to have a choice between the two sorts of lab (Nafalski, Nedić and Machotka, 2011).

The student perspective has also been considered by Collis, Gibson and Hughes et al. (2007). First year bioscience undergraduates at nine universities were posed questions relating to their feelings about laboratories. There was a 70% response rate from



the 695 students who participated. Learning new skills, using new equipment and having engaging content were among the best features identified. By contrast, the worst features were perceived to be the repetitive nature, writing up reports and poor organisation. This is in accord with the findings from student questionnaires which have been distributed at Loughborough University, an overview of which is presented in section 5.2.

5.2 Student survey at Loughborough University

As part of a planned laboratory relocation and refurbishment at Loughborough University, it was considered important to obtain the views of students. To inform the method of data collection a small review of research methods was undertaken. Burns (2000) describes two forms of survey: the census, which incorporates 100% of a population, and questionnaires, which are a sample survey and should be representative of the population. Robson (2002) explains that open-ended questions avoid the limitations of closed questions, providing freedom for the respondents to explain and describe situations in their own words and giving the rich detailed information that is characteristic of qualitative data. For small scale research, these questions are particularly enlightening. Questionnaires with open-ended questions were chosen as the medium for data collection; it was felt that a census would be impossible to administer in the time available.

During spring 2013 the paper-based questionnaires were distributed to engineering students. The questionnaire (see Appendix 1) contained five open-ended questions and space for additional comments. The five questions posed were:

- What do you value most about hands-on labs?
- What do you value least about hands-on labs?
- How could labs be enhanced?
- What would be on your laboratory wish-list?
- How do you envisage IT advances impacting on lab design, lab teaching and learning in labs?

Completed questionnaires were received from a total of 50 students; 34 from Materials Engineering and 16 from Aeronautical and Automotive Engineering. These responses ranged from brief comments to those containing large amounts of descriptive data and additional information. Analysis of responses was undertaken by grouping comments thematically. The main points arising from this survey are detailed below.

Most valued aspects of lab work

Two main themes emerged from this question. Some students find that laboratories aid their understanding of the theory from lectures and this was the most-cited reason for enjoying them (mentioned by nearly half the respondents). The hands-on, practical nature of labs leading to learning of skills was also highly rated. Related responses included the visual illustration of theory to see how things work and applying theory to real-life situations. A few typical responses illustrate this:

Putting knowledge into practice, learning how to use different techniques.

See the relevance of textbook theory in practice.

The experience gained (I learn better by doing things).

Least valued aspects of lab work

Writing laboratory reports attracted some negative comments:

Long write-ups; Writing the report; Pressure to compile results.

Feelings of being rushed and not having time to understand fully the theory behind the activity were cited:

Rushed feeling where you don't really understand what's going on.

Short deadlines.

The different level of practical skills between students working together was highlighted:

People who know more than you take the lead and do it all, meaning those who don't have as much practical knowledge/experience don't get much chance to learn the basics.

The importance of a good laboratory leader with effective communication skills was evident in some remarks:

The mentors sometimes not explaining things well. Hard to understand... .

Many students viewed laboratory sessions as too lengthy, with long periods of idle time either watching a demonstration or waiting for equipment or results.

“Technology should be used to enhance teaching and learning but not act as replacement to quality teaching.”

However, other students expressed a wish for longer laboratory periods and additional sessions. Activities were often described as too predictable with little variety.

Suggested enhancements to the laboratory experience

There was support from students for more hands-on work and less watching others or listening to lengthy explanations. Timetabling of laboratories was criticised for sometimes scheduling an activity before the theory had been covered and some students did not see the connection between the lab activity and the theoretical content of modules.

Laboratory wish-list

The students surveyed had many suggestions for additional specific types of equipment or investigations that they would like. Their responses indicate that they value activities and experiences that they see as relevant to an industrial environment.

Student perceptions of the impact of IT advances

Students expressed a range of views about the impact of IT. Some respondents communicated a desire for more simulations and video-recorded demonstrations to aid visual learning of theory. Others were more cautious and felt that increasing use of technology should not be allowed to reduce the practical hands-on element of the laboratory experience. Another view was that more training on software packages would be needed.

5.3 National Union of Students: Charter on Technology in Higher Education

All of the views expressed by the students in our small survey are in accord with the National Union of Students' charter on *Technology in Higher Education*

(accessible from <http://www.nusconnect.org.uk/news/article/6010/2489/>) which states:

Technology should be used to enhance teaching and learning but not act as replacement to quality teaching. Retaining face-to-face contact time between academic staff and student as well as peer-to-peer interaction is fundamental to providing a holistic learning experience.

5.4 Overview

Anecdotal evidence from colleagues at Loughborough University who have interviewed students outside the UK suggests that our findings are echoed elsewhere. Students in general want more practical work, but many find their current laboratory sessions too prescriptive, with little opportunity for initiative, creativity or responsibility. One comment from the Loughborough student survey captures this desire for more challenging activities:

Too structured – give job and ask for plan. Mark plan and allow student to undertake.

It is clear from the literature in this area, and from our own small survey, that students value practical hands-on laboratory activities when the sessions are well-planned and engagingly presented. Students are open to more innovative remote and virtual lab components, but these are most valued when they augment rather than replace a physical laboratory.

“Students in general want more practical work, but many find their current laboratory sessions too prescriptive, with little opportunity for initiative, creativity or responsibility.”

Chapter 6

Rethinking laboratory space and support services

Some institutions have found that their laboratories have become outdated and are not adequate to meet the needs of the 21st century. There are many examples of innovative new builds and refurbishments of laboratory spaces and case studies illustrating some of these are documented within this compendium.

6.1 Laboratory spaces are changing

Goodhew (2010) describes redevelopment at the University of Liverpool's School of Engineering. This included the introduction of an Active Learning Lab (ALL) which adopted the Conceive, Design, Implement and Operate (CDIO) approach. The laboratory enables an annual cohort of approximately 250 students to participate simultaneously in group activities. The author also points out that if you have the opportunity to design a teaching space then it is important to give this careful consideration. For example, if you want your students to be active then you will need space that is flexible. At Liverpool, Goodhew briefed the architects with the following: "nothing is to be bolted to the floor" and "I cannot tell you what the space will be used for because others more imaginative than me will do different things over the probable forty year life of this building". The pros and cons of open versus closed laboratories are discussed by Watch (2012), who points out that an open laboratory engenders communication and teamwork; however, not everyone is comfortable working in one. Furthermore, closed laboratories are still needed for some research areas and certain equipment.

Other features that need to be considered are the addition of break-out rooms, adequate storage for equipment and lockable space for student possessions. Approaches used by other universities include the use of internal glazing to give high visibility of events in other rooms, for example the New Teaching and Research

Centre, Royal Veterinary College, as reported in the S-Lab awards and conference proceedings (S-Lab, 2012).

The 2012 S-Lab conference proceedings (S-Lab, 2012) give details of laboratories and initiatives that were shortlisted for awards or received awards. The Baddiley-Clarke Building at Newcastle University has an external glass wall which allows natural light through an internal glass wall to the science area and there are also excellent views of the laboratory area from a central staircase. The Health Sciences Building at Queen's University Belfast and the J.B. Firth Building at the University of Central Lancashire each benefit from maximised natural lighting through the inclusion of a central atrium. The University of St Andrews has introduced colour coding in its Chemistry Teaching Laboratory whereby, "first year equipment, chemical cupboards and shelves, and demonstrator lab coats are all coded red, while second and third year are green".

The old model of dedicated laboratories for each discipline seems to be eroding. The majority of our case studies, together with anecdotal evidence from other correspondents, show that there is a move towards implementing larger, more flexible spaces with movable equipment and services, where more specialist facilities are centralised when possible. When refurbishing its Sciences Complex, the University of Sunderland co-located all analytical equipment into one specialist laboratory, creating a first-class area for teaching, research and commercial activities (see page 101). The benefits of a flexible, well-equipped teaching space also extend to outreach activities such as those detailed in the University of Bradford case study on page 39 and prove popular with prospective students and their parents at open days.

*“nothing is to be bolted
to the floor”*

*“... larger laboratory spaces
are being designed to be shared
across disciplines ...”*

A refurbishment of two physics teaching laboratories at Aberystwyth University (see page 35) resulted in multi-purpose, multi-disciplinary facilities which are used for hands-on practical teaching of mathematics and physics. Large open areas and movable furniture were incorporated into the design, allowing flexibility of use for seminars, workshops and project discussions. In addition, small Welsh language classes can be run in parallel with mainstream English classes. A dedicated PC suite with centrally controlled specialist software has proved invaluable in teaching statistical techniques, data acquisition and analysis.

Increasingly, larger laboratory spaces are being designed to be shared across disciplines and/or year groups. An unexpected benefit described in the St Andrews' case study (see page 97) is access by students in the laboratory to a wider range of expertise (students from later years and other staff) when there are multiple groups being taught simultaneously.

Larger, more flexible spaces are also of benefit to schools seeking to introduce more engaging ways of teaching science. City Academy Norwich (see page 69) incorporated a Discovery Zone into its new school building. The large double-height studio space can host multi-class presentations, small group clusters and large-scale practical activities as well as traditional lessons. Innovative teaching practices are supported by the flexibility of the space and the integration of IT into the design.

6.2 Laboratory management

Institutions that implement shared laboratory facilities have found that they need to consider how to manage student access to the labs. In some cases a fully timetabled model of access has been retained and students are told when to attend each lab activity, whereas in others, students are able to book 'drop-in' sessions or out of hours access. There are implications for the level and availability of support services if this latter model is implemented.

There are obvious cost savings in reducing duplication of laboratory equipment; further savings may be realised if a single supplier can be used, with the added benefit of a single point of contact for support and maintenance. The Kit-Catalogue® system (see page 65) developed at Loughborough University by the Centre for Engineering and Design Education is an example of the use of technology to catalogue an institution's equipment and facilitate sharing across disciplines. An open-source version has now been taken up by a number of HE institutions. Details of other software packages that help laboratory staff to share, reuse or recycle equipment have been collated by S-Lab (2013). Although moving to a model of shared ownership of laboratories and equipment can be cost effective, this may make finding specific equipment more difficult, since it is no longer associated with a single department. The use of a cataloguing system such as Kit-Catalogue® can help staff and students locate the kit they need.

When common equipment is co-housed rather than duplicated across multiple laboratories there are other associated benefits. For example, the University of St Andrews' new integrated Chemistry Teaching Laboratory now hosts all first, second and third year student laboratory classes in a single lab serviced by two technical staff.

*“...simple, robust, high quality
equipment may be most
appropriate ...”*

A single adjacent instrumentation laboratory and a computer suite reduce queuing times for equipment. The decision to provide a single integrated space has allowed greater flexibility in timetabling different class sizes and the new facility is almost fully utilised throughout the week. Two members of staff at the University of Liverpool were specifically asked if they had experienced any difficulties with changeover of equipment in their shared laboratory; by scheduling a changeover window at the beginning, middle or end of the day, and by using trolleys to move equipment, they manage to set up subsequent sessions with minimal disturbance.

If considering an upgrade of laboratory equipment, it is important to consider what role the equipment should fulfil. There is often a desire to focus on latest design 'wow factor' kit, but in many cases simple, robust, high quality equipment may be most appropriate for illustrating basic science and engineering principles, especially as many students may enter university not having used even basic equipment at school (The Gatsby Charitable Foundation, 2011a). Four members of staff from Northumbria University and the University of Ulster completed a questionnaire on laboratories (see Appendix 2) and all refer to students expecting modern spaces with new equipment.

Informal discussions with colleagues at a recent workshop, *New and Refurbished Labs at Warwick* (S-Lab, 2012a), suggest that many institutions find that implementing a shared technical group with a single point of contact for booking rooms and support is helpful if facilities are to be shared. Opening up technician stations increases visibility and enables closer supervision of students in laboratory classes.

Some universities use their laboratory technicians as teachers, whereas other institutions are opposed to

this. Westwood and Baker (2013) presented at the 2013 S-Lab conference and found that their audience had mixed views about this; however, there was agreement that suitable training for technicians who want to teach is not readily available.

6.3 Successful laboratory redesign

Although each new build or refurbishment is obviously specific to that particular institution, some common key success factors emerge.

Clarity over intended use

Be clear about how the building will be used before embarking on the design. The University of Liverpool case study (page 57) describes some of the factors to consider.

Effective stakeholder engagement

Engage all stakeholders and end-users (academics, technicians, students, etc.) at the outset to ensure all voices are heard. If changes to working practices are envisaged then it is essential to have early buy-in from all parties. The case study from the University of Sunderland (page 101) provides a good example.

Shared spaces

Efficient use of shared space depends on the consistent use of a good timetabling system to allocate rooms, technical support and equipment. Sufficient time must be allowed between sessions for equipment changeover where this is needed. Consider the use of room dividers or soundproofing (as described in the University of Liverpool case study, page 57) to reduce noise disruption if multiple groups will use the space concurrently.

Storage areas

If designing shared flexible spaces, allow sufficient storage space for equipment and ease of access for moving equipment in and out (see, for example, the University of St Andrews case study, page 97).

6.4 Overcoming difficulties

Areas where difficulties can arise were reported to include apportioning costs for shared facilities and equipment between departments; these difficulties were referred to by staff at Northumbria University in their completed questionnaires. Sufficient discussion should be allowed early in the process to identify commonalities across functions where shared facilities are to be implemented. The University of Sunderland case study shows how they approached this by use of a Relationship Diagram (see page 101). Significant delays in a building or refurbishment project can obviously have an impact on teaching schedules but may also have a knock-on effect on the delivery and installation of equipment, as experienced by the University of Liverpool (see page 57).

“... the consistent use of a good timetabling system to allocate rooms, technical support and equipment.”

Chapter 7

Evolving academic practice

A laboratory refurbishment or rebuild project can provide the opportunity to review how practical elements of a course are taught. Many HEIs have taken the opportunity to overhaul how they use laboratories in their teaching, with the aim of improving student learning. For example, at the University of Liverpool the Department of Physics moved to a context and problem-based learning strategy, and the Department of Geography and Planning introduced an extensive set of new practical modules. Both developments were facilitated by the purchase of new equipment and the availability of the new space (see page 57).

Closer integration of academic disciplines in a shared building or laboratory space can lead to increased staff interaction and opportunities for collaborative use of equipment. At the University of Liverpool (see page 57), the purchase by the Department of Physics of bench-top X-ray machines has resulted in plans by the Department of Chemistry and the Department of Archaeology, Classics and Egyptology to utilise the same equipment for their students. Cross-disciplinary dissertations and master's level student projects are also under development.

The experience of refurbishing the Sciences Complex at the University of Sunderland (see page 101) has resulted in increased collaborative working. New teaching modules and programmes have been developed and collaborative research promoted. The introduction of a Problem-Based Learning Room has increased the quality and amount of this style of teaching, with very positive feedback from students. An additional problem-based learning space for non-timetabled activities was subsequently developed and has proved to be very popular.

At Cardiff University's School of Engineering the decision was taken to integrate teaching and research

laboratory space into one room for an Electrical Machines module, following a review of the curriculum and teaching strategy (see page 111). The refurbished room and new equipment allowed undergraduate students to observe current research in power electronics, thus becoming familiar with a laboratory environment more aligned to the industrial scenario. Students completed activities in less time and could, therefore, undertake more practical activities without any overall increase in contact time.

Our case studies and synopses also describe examples of innovative development of practical elements in undergraduate programmes which were not dependent on new facilities. Two examples from Coventry University describe the introduction of modules entirely devoted to practical work. One example is a first year six-week intensive induction module (see page 115) and the other is part of a taught MSc programme (see page 113). This approach allows students to become immersed in carrying out the practical tasks, analysing the data and reporting the results. In the induction module example, students identified at a later date that this approach developed responsibility and valuable planning and information literacy skills.

Another example from Coventry University (see page 117) illustrates the pedagogic approach of Activity Led Learning (ALL) in the stage one *Aircraft Principles and Practice* module. The majority of learning takes place as guided self-discovery activities (including laboratory work), with only a minimum of formally taught sessions. The use of authentic aircraft assets and staff with an industrial background promotes enculturation of the students into the community of aircraft engineering.

The Open University has a long history of providing summer schools for its students who are otherwise distance learners. The case study on page 79 provides

“... a shared building or laboratory space can lead to increased staff interaction ...”

an example of a group activity that was successfully developed for a week-long residential OU engineering module. The activity was a team-based investigation of product design, focusing on improving the end-of-life performance of small items of electrical equipment. An important element of the task was the hands-on dismantling of the items to examine their construction. This plays to the engineer's propensity to take things apart. The activity also involved information gathering and online research, followed by a team presentation of potential improvements to the product design. The intensive nature of the endeavour meant that effective teamworking and communication skills were quickly developed, and the learning outcomes were closely aligned with the UK-SPEC learning outcomes for accredited engineering programmes (Engineering Council, 2011).

Parry, Walsh and Larson et al. (2012) have undertaken a small study to determine whether the introduction of a 'critical incident report' requirement as well as traditional laboratory reports would help students to reflect and result in deeper learning. The study was undertaken with 25 second year students studying a biochemistry and molecular biology laboratory skills module. A template for the critical incident report was provided; this included space for students to reflect on a critical incident that occurred during the practical session and describe how it would affect their behaviour in future laboratory sessions. Post-intervention evaluation showed that there was little difference in the students' engagement with the laboratory sessions; however, the questions relating to reflection showed that students were more likely to read material related to the topic being studied.

In summary, there are many opportunities to introduce innovative approaches to practical work in undergraduate teaching. Many institutions are moving to a more collaborative approach to the design and use of laboratory facilities, which can facilitate the introduction of cross-disciplinary projects and engender a closer working relationship between departments. Restructuring the practical components of a module into more concentrated 'chunks' can be beneficial, allowing the students to become immersed in the tasks.

Chapter 8

What does the future look like for laboratory-based teaching and learning?

It is evident from the literature and from the case studies and synopses by our contributing authors that there are three main areas that will continue to impact the future style of laboratory-based teaching and learning. These are advances in technological developments, the reconfiguration of physical spaces and growing collaboration between departments and institutions.

8.1 Increased use of technology

The increasing use of technology in practical activities is changing the way some laboratories are delivered. Pre-laboratory information such as health and safety training and demonstrations of how to use key equipment are increasingly being delivered online outside normal laboratory sessions, thus freeing up more time to be spent on experiments. Remote and virtual laboratory activities will continue to enhance and augment hands-on practical sessions. Gaming and entertainment technology is already being used to produce realistic interactive content to meet student expectations.

MOOCs, although relatively new, offer a vast range of subjects to study, although at present there is limited practical work included. One could foresee possible collaborations between traditional HEIs, offering the practical elements of STEM courses, and MOOC providers, supplying the majority of learning material online.

8.2 Changing physical spaces

From the case studies and events such as the S-Lab conferences it is apparent that many universities are refurbishing their laboratories or investing in new builds. It appears that refurbishment often proves to be less expensive but more problematic than new build. In addition to the visual aspect of laboratories, the internal space usage is also changing; there is more flexible space and shared facilities are being introduced. This requires a more collaborative approach to technical

support and ownership of equipment but delivers valuable benefits and opportunities.

8.3 Closer collaboration

There is growing collaboration not only between university departments but also between institutions and with industry, as many funding bodies are specifying that funding is available for collaborative bids. Collaboration may also be driven by the need to raise income by hiring out laboratories to industry to obtain a return on investment. For example, Imperial College London hires out laboratories for testing, evaluation and development work <http://www3.imperial.ac.uk/civilengineering/aboutus/departmentallaboratories>.

Outreach events and summer schools provide a means of generating interest in institutions, which may prove to be beneficial as competition for the most able students increases. Hosting summer schools is also beneficial in offsetting some of the costs of laboratories, showcasing facilities and helping to ensure they are used year-round.

Collaboration between institutions is already evident in initiatives to create and share access to high quality online resources. As the opportunities afforded by technology are taken up, further collaboration seems inevitable as the costs of developing online material are high.

In addition to increased use of technology, changing physical spaces and wider collaboration, the external pressures of funding and competition for students look set to continue to impact on higher education generally and the provision of costly, high quality laboratory facilities in particular.

In Section 2 of this compendium we present examples of initiatives that address many of the challenges currently facing laboratory-based teaching and learning.



Section 2

This section comprises case studies and short synopses, highlighting examples of innovative practice in laboratory teaching and learning, authored by those listed below, to whom we are very grateful. Many of the following cases have been derived from applications to the S-Lab Awards and/or presentations at S-Lab events.

List of contributing authors

Aitken, R.A. University of St Andrews

Attenborough, J.D. Loughborough University

Bagg, J. University of Glasgow

Baker, D. Nottingham Trent University

Blanchard, R. Loughborough University

Burnley, S. The Open University

Chowdhury, T. Queen Mary, University of London

Clay, K. The Open University

Coakley, E. Coventry University

Comerford Boyes, L. University of Bradford

Cosgrove, M. Nottingham Trent University

Endean, M. The Open University

Evans, A. Aberystwyth University

Garfield, I. University of Sunderland

Green, P. Coventry University

Griffiths, H. Cardiff University

Harrison, A. Coventry University

Jones, C. Coventry University

Karodia, N. University of Bradford

King, M.R.N. Loughborough University

Kirk, S. Nottingham Trent University

Little, D. Glasgow Caledonian University

McOwan, P. Queen Mary, University of London

Moss, N. The Open University

Mullis, T. City Academy Norwich

O'Doherty, D.M. Cardiff University

Reilly, L.M. University of Liverpool

Richards, A. Nottingham Trent University

Rushworth, E. University of Liverpool

Seaton, R. The Open University

Smith, A. The Open University

Smith-Harrison, J. University of Bradford

Turner, K. Solvexx Solutions Ltd., Hertfordshire

Uttamlal, M. Glasgow Caledonian University

Vaughan, H. University of Liverpool

Ward, A. Nottingham Trent University

Williams, K. The Open University

Williams, S. Loughborough University

Examples of current practice

Case Studies

Refurbishment of 1960s physics teaching laboratories

Aberystwyth University

Andrew Evans (dne@aber.ac.uk)

Abstract

The Institute of Mathematics and Physics (IMAPS) at Aberystwyth University is housed in an architecturally-recognised 1960s building that featured on a postage stamp, but by this millennium the undergraduate teaching laboratories no longer met contemporary requirements. During summer 2011 the two teaching laboratories (with total floor-space of 500m²) were completely refurbished at a cost of £286k to provide multi-purpose, multi-discipline laboratories fit for the 21st century. The laboratories, previously used for traditional physics laboratory teaching, now accommodate hands-on practical teaching in physics and mathematics. State-of-the-art facilities and a relaxed modern laboratory environment are paramount to enhance student learning, experience and employability skills. Satisfaction in resources is reflected in our National Student Survey scores.

The newly refurbished laboratories were formally opened on 7 November 2011. The Tudor Jenkins Laboratories, named in memory of the late Dr Tudor Jenkins who served the department as lecturer, senior lecturer and reader between 1983 and 2009, are a fitting tribute to his tireless contributions to the teaching of physics at all levels.

Background

Student numbers in physics have increased almost threefold over the past ten years, giving rise to a need to make more efficient use of space within the existing building. The teaching laboratories had had very little

refurbishment over the years and were showing their age. The need to comply with modern legislation on accessibility and health and safety meant that the existing laboratories needed extensive modification.

Overview of project

The refurbishment of the IMAPS laboratories was carried out in thorough consultation with physics and mathematics academic, technical and support staff, with student needs being a central factor. Teaching and technical requirements were at the forefront of considerations, as were increasing student numbers, cost and compliance with environmental, safety and accessibility standards. Mathematics and physics at Aberystwyth have recently enjoyed some of the most successful recruitment years in recent times. For accessibility, an extended ramp was required in one of the laboratories and low-level tables included in both. The work culminated for the student intake of September 2011 with transformed large, light, airy rooms with a friendly working environment. Both laboratories are now used every day of the week, accommodating students ranging from our physics foundation year to the final year of MPhys and MMath.

Each laboratory has a large array of westward facing windows forming part of the attractive curved frontage of the building. Both laboratories accommodate benches for traditional laboratory work, enhanced by plentiful electrical sockets, integrated low power supplies, network points and PCs. An open shelving system is used for storage of apparatus for instant



Figure 1. Panorama shot of the refurbished laboratory at Aberystwyth University

recognition of available equipment. Both laboratories also have a large open area with moveable low-level tables and whiteboards. The area allows space for the students to reflect on their experiments and write reports. It is also widely used for group seminars, workshops and project discussions, and has proved very popular with the students for work discussions and revision outside formal teaching. In one laboratory there is also an array of 50 forward-facing dedicated PCs with specialist software that are controlled centrally and are used widely for interactive teaching of statistical techniques, computing and data acquisition and analysis methods. Further new aspects of the refurbishment are audio-visual facilities integral to the laboratories, with data projectors, dimmable lights and radio microphone systems that can be used to address part or the whole laboratory. A network link is available to control roof-top solar and astronomical telescopes from the laboratories with an optical fibre connection to astronomical telescope facilities at the remote Frongoch University site.

Smaller dark-rooms are conveniently located for optical experiments and visualisation facilities are in an adjacent room for specialist project work. Both laboratories have technical and electronics support offices and internet protocol video cameras for additional safety and security. BSc and MPhys final-year projects are also located in the laboratories, with the research-led MPhys projects also benefitting from the IMAPS research laboratories which have received parallel investment.

Impact on academic practice

The new flexibility of the laboratories allows the facilities to be used in innovative ways throughout the teaching week, sometimes for more than one class simultaneously. In addition to traditional laboratory classes, the laboratories are used for workshops on mathematical methods and career planning and skills that are taught in modules common to both mathematics and physics students, as well as for computer-based tests and examinations for both disciplines. The flexibility also provides for smaller group teaching, a particular asset for the Institute to support our rapidly developing Welsh medium teaching in physics and mathematics.

Student-centred learning

The laboratories are very popular with both physics and mathematics students outside formal teaching hours, with the relaxed environment of a modern laboratory encouraging student-centred learning and interdisciplinary discussions. They also provide a base to develop and contribute to outreach activities, which include Technocamp activities and schools' visits. The laboratory provision is reinforced by Wi-Fi access, printing, photocopying and scanning facilities, textbooks and notice boards.

Difficulties encountered

The project had to be timed so that existing classes were not disrupted during the work. This entailed scheduling and completing the project over the summer vacation. The external windows in the laboratory are a structural part of this architecturally important building and therefore could not be modified during the refurbishment.

Benefits

- Multi-discipline use of laboratories. Teaching of physics and mathematics
- Common teaching for both disciplines. Workshops for mathematical physics, career planning and skills. Student numbers on these modules are 161 and 91 respectively for 2012/13
- Accommodating increasing student numbers. Total student numbers in Mathematics and Physics: 2010/11 383; 2011/12 490; 2012/13 590
- Increased usage of laboratory, with technician time maintained level
- Range of teaching and learning methods. Traditional laboratory, open-ended projects, research-led projects, workshop, seminar, smaller group work, PC-based learning, computing, career skills
- In-house computer-based examinations and tests. Diagnostic test, statistics examinations
- New furniture. 16 traditional benches, 32 low-level moveable tables, 60 storage cupboards, 95 PCs, six data projectors, four fixed and four movable whiteboards.
- Experimental equipment investment of £40k in 2009
- Remote network link to roof-top robotic telescopes and fibre optic link to telescope facilities at remote Frongoch University site
- Nearby support rooms, three optics rooms, one visualisation room, one technical support office, one electronics workshop
- Increased provision for student-centred learning. Moveable tables, Wi-Fi, textbooks, photocopying, scanning, printing, notice board facilities
- Open space for outreach activities. Technocamps with Computer Science department introducing design, programming and building robots, schools' visits.

The initiative has provided fit-for-purpose facilities and a significantly improved working environment for our undergraduate students. At the same time it has maximised the usage and sustainability of the room space. Attention is drawn to two factors distinctive to our situation at Aberystwyth.

Interdisciplinary interaction

The Institute of Mathematics and Physics, founded in 2003, provides the administrative umbrella for mathematics and physics but comprises the two distinct disciplines in undergraduate teaching. The structure of the Institute and the increased interaction between staff of the two disciplines provided a foundation for the initiative. Historically, the laboratories were used for traditional physics laboratory work, but under IMAPS there was scope to adapt the facilities to cover contemporary requirements of both disciplines. As added value the laboratories accommodate workshops in certain modules (e.g. Mathematical Physics, Career Planning and Skills) that are taught jointly to the two disciplines. The initiative encourages informal interaction and discussion between physics and mathematics students.

Smaller-group teaching

The versatility of the laboratories has allowed increased smaller-group teaching. In the case of IMAPS, Welsh medium undergraduate teaching is an important aspect of both mathematics and physics. The new structure of the laboratories has allowed us to expand this, enabling Welsh-medium groups and the associated specialist lecturers to be accommodated in parallel with the mainstream English classes. Such versatility could naturally be adapted in the context of other groupings where it is desirable to divide classes according to specific requirements.

“The initiative encourages informal interaction and discussion between physics and mathematics students.”

“... relaxed environment of a modern laboratory encouraging student-centred learning ...”

Advice to others

The investment has improved the student experience, providing a better working environment for students and staff. A particular feature that has been very well-received is the flexible, re-configurable areas of the laboratory.

Future plans

In 2013-14, Mathematics and Physics will join with the Department of Computer Science in a new Institute of Mathematics, Physics and Computer Science. This follows major restructuring at university level where four faculties are replaced by seven new institutes. There are considerable opportunities for joint teaching, with the laboratory ideally equipped for the delivery of common topics such as computation, data analysis, computer-controlled experiments, electronics and engineering.

Bradford STEM Centre University of Bradford

Nazira Karodia (N.Karodia@bradford.ac.uk), Janet Smith-Harrison and Louise Comerford Boyes

Abstract

The iconic STEM Centre at the University of Bradford is a 'state-of-the-art' science, technology, engineering and mathematics-focused laboratory and learning resource centre dedicated to schools' outreach and teachers' continuing professional development. It is a high quality learning environment and flexible space, which offers opportunities for multiple modes of learning and a virtual and remote learning facility to enable distributed learning to take place. The building, which showcases sustainability, was completed in April 2013. This is the first purpose-built facility for delivering activities across all STEM disciplines.

Background

The University of Bradford has a long and successful tradition of providing science and technological courses to prepare students for careers in a variety of sectors, and providing appropriate continuing professional development (CPD). It is also a university that has a strong sense of the communities it serves and it works hard to encourage participation from all communities by offering the best possible learning experience for all students irrespective of their cultural, social, health or financial background.

Science, technology, engineering and mathematics (STEM) take-up and the nature of provision has been at the heart of many educational and economic debates in the UK over the last twenty years. There has been

growing concern about the declining numbers of students studying mathematics and the three sciences in schools. This has led to declining numbers studying STEM-based degrees in universities. There have been many initiatives to try to turn the situation around, including the significant investment in capacity building initiatives in all sectors of education and training. Many government-sponsored and other reports have raised issues relating to the quality of the teaching, the need to excite learners, the absence of specialist facilities and the lack of attraction for students.

To meet this need 'STEM at Bradford', a flagship HEFCE-funded programme, is working in partnership across the district to raise the attainment and aspiration in STEM subjects of students of all abilities and diversity of backgrounds. The project incorporates the new STEM Centre, located within "The Green" (the student village), and a high quality attainment-raising programme. The iconic laboratory facility will enable schools and colleges to experience high quality laboratory and teaching resources on campus, with a programme of activities developed with leading STEM educators to excite and engage students. This is promoting and stimulating interest in STEM-based higher education courses and career opportunities. STEM at Bradford is championing the next generation of scientists and engineers. In terms of our local population, engagement with school and STEM education partners remains a high priority across the university.



Figure 1:
Location of the
STEM Centre

Overview of project

The design

The STEM at Bradford Programme is a £2.9m HEFCE-funded programme which involved the STEM laboratory build (£1.6m) and a programme of activities (STEM at Bradford) (£1.3m). The approach to the design was collaborative; right at the start it involved the university's Estates team, the design team, architects, internal and external STEM education specialists and the student voice. The choice of suppliers was also crucial to the partnership and early procurement processes meant that they were also involved in the design phase. In terms of location, it was important that the Centre was accessible for school groups and staff delivering the activities. The site chosen is in the heart of the campus and it is co-located with the university's re:centre, which is a new and exciting space designed for industrial collaboration.

The university has a track record in sustainability and therefore it was essential that the build was based on a sustainable construction specification which has a 'fabric first' approach and reduces mechanical and electrical intervention. 'Eco-bling', equipment that is energy-efficient but less effective than simpler technology, was deliberately excluded. The economic rationale for this is that the Energy Price Challenge (Callaway, 2011) predicts that utility costs (gas and electricity) will increase by 88% from 2010 to 2021. There is also the security of supply issue and government documents which warn of possible blackouts and brownouts (voltage reduction); the latter is already being experienced by the university.



Figure 2:
Timber frame
construction

“... multifunctional interactive screens for students to engage in group work ...”

“... a new and exciting space designed for industrial collaboration.”

The aim was to concentrate on the construction of a high performance energy efficient building with minimum environmental impact (building engineering physics), sustainable refurbishments, low energy off-grid new build and exploiting new technologies. The design lent itself to an off-site timber construction and the building was completed in seven months; this was on schedule and within budget. The building is also designed to use over 75% less energy than a like-for-like building.

Key information

- Internal area of 400 m²: Laboratories, preparation room, office and toilets
- EPC energy rating A:18 (UK average D)
- Stable environment year-round
- Airtightness 0.6 m³/Hr/m² (Building Regs 10 m³/Hr/m²)
- Super insulated
- Built using only four skips

The building has achieved three standards:

- breeam** (<http://www.breeam.org/>)
- PASSIVHAUS** (<http://www.passivhaus.org.uk/>)
- AECB** (<http://www.aecb.net/>,
<http://www.retrofitforthe future.org/>)

- BREEAM: Outstanding (87.15%)
- Passivhaus
- AECB: Silver Standard

This makes it the world's first for the construction industry with these standards.

Flexible teaching of the STEM subjects is facilitated by the installation of overhead service wings which supply

all water, power, gas and data services as well as local extraction hoods. There are two fixed fume cabinets at the back and a mobile fume cabinet with 360 degree visibility and a camera. The demonstrator bench is also mobile. These facilities are key requirements for delivering high quality practicals.

The AV solution

In designing the Centre we have explored how technology can be used not only to support learning and teaching, but also to extend and augment the interaction between the students and between the teacher/demonstrator and students. The design incorporates technology that the students are familiar with as well as the latest innovations.

The AV solution in the Centre includes:

- multifunctional interactive screens for students to engage in group work, planning, presentations and exercises
- large projection facilities to enable immersive engagement for large groups. A further interactive video wall has been installed where pupils can explore virtual representations of different environments
- capability for recording demonstrations which can be viewed remotely
- multi-touch screen activities have been designed whereby students will develop fluency and learn to engage in STEM discourse to support their development and expertise.

The programme

The STEM programme of activities will allow the students to discover and investigate STEM subjects in a stimulating learning environment. The programme includes dedicated curriculum-based sessions and enrichment activities from primary, secondary and



Figure 3:
Overhead service wings which facilitate a flexible laboratory space

through to employment. The Bradford Science and Engineering Festival, Science and Engineering Week and Café Scientifique are examples of our public engagement strand, which promotes STEM subjects to all sections of the community. Teardown Lab activities, which deliver activities based on the circular economy, have been developed in collaboration with the re:centre.

During the pre-lab programme we have engaged with over 50 secondary schools through a variety of pilot programmes, events and activities. Approximately 5,000 pupils have benefited as a consequence of our approach to curriculum development. The Bradford STEM Centre will continue to use this ‘teacher-led’ approach to understanding attainment gaps to ensure that the programme delivered in the Centre raises the STEM attainment of pupils. By developing the programme in conjunction with teachers we are accurately tailoring our curriculum to meet attainment needs and creating a partnership which supports the ambitions of the students. We have engaged with 30 primary schools, two of which are now working more closely with us to explore how we can support primary science teaching through a ‘quality mark’ approach.

As the HE sector seeks to ensure equality of access and an enhanced student experience, STEM at Bradford is beginning to provide an evidence base to demonstrate the value of STEM as a tool for social upliftment and of the Bradford model as a template for excellence. Our formative evaluation approach provides a steady stream of both quantitative and qualitative data, the most recent of which indicate sizeable increases in the take-up of triple science GCSE at one particular school. This example indicates the emerging impact of STEM at Bradford and is representative of the information we are receiving back from schools. We will continue to monitor impact carefully in order to draw out lessons learned and widen activity in the most effective areas.

Advice to others

The project has worked collaboratively with STEM colleagues across the country to adopt and disseminate best practice. This has led to a new network of universities, facilitated by Imperial College London’s Reachout Lab and STEM at Bradford, which has created a forum for discussions and sustainability.

Future plans

The space is inspiring as you walk through the doors and look across from the balcony, but there is much promise hidden in the overhead service wings. The potential of the lab to raise both attainment and aspiration is immense and we look forward to the next phase of the project – bringing even more pupils onto campus and giving them a STEM experience to remember.

References

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Conversion of an obsolete biomedical laboratory into a multi-functional, multi-media teaching facility improves learning and increases utilisation by 280%

University of Glasgow

Jeremy Bagg (Jeremy.bagg@glasgow.ac.uk)

Abstract

A traditional biomedical teaching laboratory, in a poor state of repair and no longer appropriate for modern teaching methods, has been converted into a multi-functional, multi-media teaching facility, named after a former Professor of Oral Biology, Dorothy Geddes. The old laboratory was stripped to a bare shell and has been fully refurbished, incorporating movable furniture to seat 50, tablet computers, a powerful IT installation supporting virtual microscopy and 3D projection and a room divider to allow single or multiple occupancy. The space is now being used for a wide variety of teaching across the entire curriculum, together with other related activities such as examination and committee activities, with a resultant increase in utilisation of 280%.

Background

Historically, dental students undertook significant amounts of practical experimental work in biomedical sciences, for example microbiology, and received extensive microscopy teaching in subjects such as histology, oral biology and pathology. To facilitate such teaching, a traditional large biomedical teaching laboratory had been opened in 1970, equipped with fixed rows of benches supplied with gas, water and electricity. The laboratory was well-used over much of the intervening period but had remained unchanged since opening and, after more than forty years, was in

a very poor state of repair. Furthermore, it was unable to support the innovative teaching methods being developed in the Dental School.

Overview of project

A completely revised Bachelor of Dental Surgery (BDS) curriculum, which had largely eliminated traditional biomedical practical classes, was introduced in 2004. Furthermore, there was a strategic decision to replace traditional microscopy with 'virtual microscopy' using digitised images viewed on PCs and tablets. These fundamental changes in modern teaching methods underpinned the philosophy of the refurbishment. The increase in the volume of small group teaching in the new curriculum, which puts pressure on available accommodation, was also instrumental in our decision to develop a space that could be divided into smaller functional units when required.

What were the key design criteria?

It was proposed that the laboratory area should be completely stripped out and refurbished as a multi-functional teaching space with:

- movable circular tables and chairs to allow flexibility of seating arrangements and foster small group working
- local power outlets to support use of PCs and tablets at each table



“... support staff have proved essential ...”

- a central movable divider to allow the room to be split into two smaller independent teaching/meeting areas
- a high specification IT installation that would support virtual microscopy as well as other forms of e-learning
- IT capability to run independent teaching at either end of the room when the dividers were closed and sufficiently powerful Wi-Fi provision to support up to 50 users simultaneously
- a 3D projection system
- multiple hand-washing sinks along one wall to support hand hygiene and related infection control teaching.

Funding

The facility was planned, and the funds identified, over a period of three years. The core costs were as follows:

Refurbishment costs:	£130,000
Purchase of 3D multimedia projection equipment:	£30,000
Purchase of 50 tablet computers:	£16,500
Tablet storage and charging cabinet:	£5,000
TOTAL COST:	£181,000

The funding was identified from four main sources:

- University of Glasgow central capital funds
- Dental School Development & Alumni fund-raising
- NHS Greater Glasgow & Clyde
- NHS Education for Scotland.

The costs of providing staff support for the facility were resource-neutral, since we had already appointed both an audio-visual technician to manage the AV activities in all of our teaching facilities (lecture theatres, seminar rooms and pre-clinical skills facility) and a janitor to perform general duties within the School, so the ongoing operating costs are minimal. Both of these support staff have proved essential and interact with academic staff through a carefully constructed and strictly implemented Standard Operating Procedure, held centrally on the Dental School Virtual Learning Environment (MOODLE).

The Dental School is one of three professional schools (Dentistry, Medicine and Nursing & Health Care) within the School of Medicine, which in turn is part of the College of Medical, Veterinary & Life Sciences (MVLS). The Dorothy Geddes Multi-media Facility is available for use by all of the disciplines within the College and the finances needed to purchase the central server capacity required for the virtual microscopy were raised through donations from Dentistry, Medicine, Veterinary Medicine and Life Sciences, since the technology was recognised by all the Schools to be core to modern teaching methods across the MVLS College.

Impact on academic practice

The impact of this facility, since its opening in September 2012, has been extremely positive, eliciting outstandingly positive feedback from staff and students alike. Its breadth of influence has been even greater than envisaged, on account of the flexibility of the space and the available functions. Its utilisation has been revolutionised, from



“... tablet computers and digital imagery allows detailed and highly annotated teaching ...”

a rarely used, depressing backwater of the building to a heavily used, sought after facility for teaching and assessment across the entire breadth of the curriculum. It is allowing us to use innovative teaching methods that would be impossible on site without access to the facility. Its design is one which would be applicable in any health sciences or biomedical sciences higher education institution.

The replacement of traditional microscopes with tablet computers and digital imagery allows detailed and highly annotated teaching of subjects such as cell morphology which students traditionally find very difficult, employing a medium with which present day students, as ‘digital natives’, are very familiar. This cutting edge application of digital technology is applicable to teaching in all biological and biomedical subject areas that require an understanding of cellular, tissue and organ structure and is available to staff and students across the MVLS College of the University of Glasgow.

The inclusion of an ‘active’ 3D projection system is unique within the University of Glasgow and is linked to the ongoing collaboration between the Dental School and the Glasgow School of Art’s Digital Design Studio, which provides ongoing advanced technical support. In addition to the teaching of anatomical and histological subjects, it is of tremendous potential value in teaching aspects of operative dentistry which require complex spatial awareness, and learning packages exploiting this opportunity are being developed by an in-house e-learning technologist.

Difficulties encountered

Inevitably, identifying capital for a project of this type is a challenge. It took three years of campaigning with the University of Glasgow and NHS Greater Glasgow & Clyde

to identify the capital. The highlighting of the very poor state of repair of the original laboratory in a university report, following a two day internal subject review, proved helpful and resulted in strong support from one of the Vice Principals for a university contribution to the refurbishment. Our bid to the university was strengthened by the availability of funds we had already identified from health board sources and through our own fund-raising. The strong support from NHS Education for Scotland was also immensely helpful.

The fact that the university Dental School operates in a dental hospital building that is owned and managed by the NHS frequently results in tensions when significant capital works are underway. This was accentuated for this university project because the timing coincided with a large NHS project to refurbish some of the clinical areas in the building. The timing of the university project was chosen to minimise disruption to the teaching timetable for the BDS students and was therefore critical. Fortunately the architect, university project manager and contractor combined tact and firmness to ensure that the project was not delayed.

We have encountered no difficulties with the facility since its official opening.

Benefits

This teaching space now supports our modern dental curriculum, including delivery of e-learning, with a flexibility that has greatly increased its range of use and, therefore, utilisation. The multifunctional capability of the room has revolutionised our use of the space and has delivered several major benefits, as follows:

Permits virtual microscopy teaching

This technology is utilised in oral biology, histology and pathology teaching. Each student (maximum capacity

Table 1. Utilisation		
Month	Hours of use	
	2010/2011	2011/2012
September	28	50
October	27	56
November	33	195
December	16	49
January	46	75
February	24	105
March	70	110
April	25	80
May	27	100
Total	296	820

50) works on an individual tablet computer. The digitised histology preparations provide all the 'zoom' and 'roam' capabilities of a traditional microscope, with the added advantage that the teacher can annotate the images and set up exercises and assessments, with full control from the central operating console. Qualified dentists and, indeed, the majority of front-line healthcare workers do not need to be able to operate a traditional light microscope. Learning the specialised skills of the latter tends to delay and detract from the main learning objectives of a thorough comprehension of cellular and tissue structure, disease processes and the ability of clinicians to interpret documents such as histopathological reports. Thus, use of virtual microscopy provides massive advantages, particularly when used in the context of clinico-pathological scenarios. A further significant advantage is that students can view the same materials outwith the facility for tutorial preparation, private study and revision, a frequent student request which cannot be satisfied with traditional slides and microscopes.

Availability of 3D projection

The 3D projection system is the only facility of its type in the entire University of Glasgow. It allows us to teach anatomy using a 3D model of the head and neck anatomy produced through a collaboration between the University of Glasgow (Dental School and School of Life Sciences) and the Glasgow School of Art's Digital Design Studio (www.gsa.ac.uk/dd). The 3D model was launched officially by Scotland's First Minister on 24 April 2013. Other 3D e-learning packages produced by the national Scottish Dental Education Online (<http://www.sdeo.ac.uk/>) collaboration, in subject areas such as tooth morphology, are also available for use. The long term investments made by NHS Education for Scotland in developing e-learning within dental education have been of immense value to us and to other institutions across the country.

Flexibility of use

Incorporation of a high quality room divider and movable furniture facilitates and permits:

- small group, reflective, interactive and collaborative learning
- split teaching sessions (e.g. one group of students engaging in virtual microscopy to study histology of muscle and a second group studying gross muscle anatomy through 3D projection, with a switch around of groups during the session)
- utilisation of the space for examination purposes
- utilisation of the space for communication skills teaching – previously undertaken in a Clinical Skills Unit at a distant site (School of Medicine)
- utilisation of the space for teaching hand hygiene
- utilisation of flat floor space, with tables and chairs stacked, to teach life support, resuscitation, and cannulation skills.

The space is air-conditioned and an extremely comfortable environment for all of the teaching activities identified.

Increased utilisation

The increased usability of the space, both in terms of range of function and variable capacity is reflected objectively in the 280% increase in utilisation figures (hours) since the facility opened in September 2012 (Table 1.)

Staff feedback

Whilst the facility has only been available for use since September 2012, we have already sourced some initial feedback and will be doing this more formally as part of the University of Glasgow Annual Course Monitoring process at the end of the academic year. The following provides some initial reaction.

“The facility has really enhanced my teaching.”

“... 280% increase in utilisation figures (hours) ...”

In a poll of 12 academic staff members who had recently used the Dorothy Geddes Multi-media Facility, all were in agreement that it provided a facility that was highly conducive to student learning and that the facility has greatly enhanced the School's learning and teaching spaces. Perhaps the most illuminating staff feedback was available through the open question: *“Please provide details of your experience of the Dorothy Geddes Multi-media Facility.”* The responses were uniformly positive, but the small selection below indicates some of the key advantages, as perceived by staff:

Notable improvement in student interaction and engagement with previously dry and difficult materials. Very conducive to group work within tutorials.

I have used the facility for several diverse situations ranging from mock OSCEs (Objective Structured Clinical Examinations) to staff meetings, lectures to hands-on tutorials, written exams to symposia, and have found it to be a very flexible, state-of-the-art facility.

I have taught approximately four times in the suite. It is an excellent space to give interactive small and large group tutorials. I am delighted each time I see that I have been allocated that teaching environment.

The facility has really enhanced my teaching. Pathology is a highly visual subject to teach. The use of the latest technology to deliver material has really had a positive impact on both delivery and student reception of the subject. The space is designed for easy movement between groups of students and provides an environment in which interaction between students has been greatly facilitated. The presence of the partition is also very useful as this means that the facility has increased the teaching spaces available in the School.

An excellent facility of a high standard. It is now a pleasure to teach there, and the students engage much better. It enhances the students' learning experience by having access to such surroundings.

Student feedback

A similar poll, to which 36 students responded, indicated that 92% believed the environment in the Dorothy Geddes Multi-media Facility is conducive to their learning and 86% that the flexibility in use of the facility has enhanced the School's learning and teaching spaces. Once again, the response to the open question *“Please provide details of your experience of the Dorothy Geddes Multi-media Facility”* provided evidence of the positive impact of the facility from a student perspective. The following selection indicates the general tone of the responses:

Compared to the previous facility, the new multi-media facility is a vast improvement and a welcomed addition to the Dental School. Before, the room was too large and not very versatile. This limited the type of teaching that could be delivered and I feel compromised the learning experience. I feel the room is a comfortable environment to work in and there is now more space to move around. I particularly like that the room can be split into two teaching areas. This is extremely useful especially for tutorials and group work. Interaction is key to an engaging

“An excellent resource and good use of space, if only we had two of them.”

learning experience and I feel that the use of tablets has enhanced this, as it has made key topics more enjoyable and memorable. I thoroughly enjoy using the multi-media facility and it is a resource that will be well used by all years. ”

Use this facility mostly for oral biology and histology. It has been very useful in learning histology – a subject I struggled with. Using the tablets has been enjoyable and beneficial to my learning.

I think the Dorothy Geddes Multi-media Facility is a fantastic asset to Glasgow Dental School and is a very valuable use of space and resources. The room has been transformed from a traditional and old fashioned space to a dynamic and inspiring learning environment.

The dgmmf is a great room for seminars/tutorials/half class exercises. The facilities are equipped for exams and revision sessions too. The multiple tv screens around the room make it easier to follow the lecturer.

I have only had a class in emergency skills in K27 but it was nice to have a modern space to learn in. We used the tablets once in a BLS (Basic Life Support) class but that was only to split into groups with the tutors showing us the powerpoint on the tablet, but this was better than the standard lecture/tutorial format.

An excellent resource and good use of space, if only we had two of them.

It is a very pleasant environment where it is very easy to follow what the lecturer is doing because of multiple screens available, also a great sound system, 3D projector and of course – the tablets.

They help us zoom in and out to see the picture in various ways and therefore widen out understanding of various subjects. It is an amazing facility that I am very happy to have the possibility of using.

The new multi-media room is brilliant. It's spacious and well laid out which makes working in groups easier than before.

We used the tablets for oral histology and tooth morphology, both topics aided immensely by the facilities. There are a large number of easily viewable screens in the room, meaning even if it is full, every student is able to follow the teaching as it progresses.

In addition to general feedback of the type quoted above, we are also collecting information at individual class level to ensure that any improvements that can be made to our utilisation of the technologies (such as the tablet computers) and the flexibility available are maximised.

Advice to others

The operational aspects have required careful consideration in relation to the multiple configurations available and the need for high quality AV support. An online pre-booking system allows users to identify the room configuration and AV functions required for a particular session and the requirements are monitored by a janitor and an AV technician who ensure that the room is set up in the correct configuration. Security is managed through key-pad entry doors and the tablets are kept in a locked cabinet which charges the devices during storage. The Standard Operating Procedures we have developed, which are working well in practice, would be applicable to others using similar facilities.

Establishment of the facility was expensive, but it was recognised at an early stage that the flexibility and breadth of use of the space would make it suitable for a wide variety of users. The presentation of a detailed case to key potential users allowed funds to be identified from a variety of sources both within the university and from external organisations, including the NHS, to achieve the investment required. In times of financial stringency, this approach to raising capital and ensuring subsequent efficient use of high quality teaching space has much to commend it.

Future plans

As evidenced by the utilisation figures and positive feedback from both staff and students, this facility is now widely used for a great variety of purposes. These include tutorials, seminars, examinations and meetings, in addition to the elements of practical and clinical teaching which are so well supported by the advanced IT and AV infrastructure. We will continue to review our operating procedures with a view to streamlining activities such as the handing out of tablet computers and log-in procedures to ensure that the maximum amount of time in classes is devoted to learning. The facility incorporates all the functionality we require for current purposes and we do not envisage any major additions or changes in the near future. We will, however, continue to develop new e-learning materials through our ongoing involvement with both the Scottish Dental Education Online collaboration and the Digital Design Studio at the Glasgow School of Art.

Further information

A website providing detail about the Dorothy Geddes Multi-media Facility is available at:
<http://www.gla.ac.uk/schools/dental/aboutus/facilities/dgml/>.





Refurbished teaching laboratories at Glasgow Caledonian University

Laboratory refurbishment secures chemistry education and research at Glasgow Caledonian University

Mahesh Uttamlal (m.uttamlal@gcu.ac.uk) and Douglas Little

Abstract

This article concerns a Scottish Funding Council (SFC) investment of £0.8M for the entire refurbishment of 970m² of chemistry laboratories in three months at Glasgow Caledonian University (GCU). The investment was used to refurbish teaching and research laboratories and all the utility services. Examples of the impact of the investment on learning and teaching, CPD and research are provided.

Background

Glasgow Caledonian University's "Campus Futures" project is a commitment to the ongoing investment and development of its estate to ensure the campus mirrors the ambition and modernity of the university whilst enhancing the student experience, resources and facilities for staff.

It will allow the university to retain its competitive position against other higher education institutions nationally and internationally as well as supporting student retention and attracting higher numbers from around the world.

The key aims of the project include new facilities and building but also the refurbishment of existing infrastructure.

The chemistry laboratories located on the top floor of one of the original buildings (① in Figure 1) had not seen any investment for over 20 years and many fixtures and fittings dated back to the 1970s (Figure 2).

In 2008 GCU received a grant from the Scottish Funding Council specifically for the development of its science infrastructure. The GCU Executive decision to allocate the entire budget of £0.8M to the chemistry laboratories was welcomed by all in chemistry research and education.

Overview of project

GCU Facilities Management established a project team which included academic and technical staff from chemistry. The brief provided by end-users was to provide modern laboratories for practical chemistry, but also to allow staff to deliver education using modern teaching methods and technologies, i.e. computer-based experimentation and learning. Also, the design had to allow the rooms to host seminars and tutorials, thereby increasing their utilisation.

Advice from other universities was sought as part of the design process. In the end it was decided that our development was going to be based on the award winning Bristol ChemLabS (<http://www.chemlabs.bris.ac.uk/>) project. This was a £4.5M investment by HEFCE to provide the UK's first Centre of Excellence in Teaching and Learning (CETL) in chemistry. A delegation from GCU attended a dissemination meeting held at the University of Bristol in May 2009 and took the opportunity to meet members of the development team to discuss all aspects of the project. It is acknowledged that Bristol ChemLabS is today a state-of-the-art, professional standard facility for the teaching and learning of chemistry's core practical elements.



Figure 1:
Glasgow Caledonian University campus

The aim of the SFC investment into GCU was to achieve parity with Bristol ChemLabS. Many of their ideas were implemented in our design.

Ideas gathered from various places were sketched and provided to the architects. Figure 3 is illustrative of the information going from the end-users to the designers and builders at an early stage in the project.

The building works that were affordable within the budget included:

- new services, including power, lighting, ventilation, extraction, vacuum lines
- all ceramic sinks – we avoided plastic resin based on previous experience
- chemical resistant flooring
- new chemicals store with preparation facilities
- heating panels in ceilings as opposed to the usual wall location
- IT and AV services integrated into the laboratories
- a new chemicals store with improved storage capacity and air extraction
- emergency eyewash stations and showers.

Additional features included:

- TrespaTopLab^{plus} bench tops with drip grooves – the material is the best available, being resistant to solvents, strong acids and bases
- disability access and benches that can be lowered to allow wheel chair users in every laboratory
- no blind spots, so staff can monitor student activity in the whole laboratory
- induction loops for the hard-of-hearing
- metal framework for benches with support crossbars for heavy loads
- all cupboards were to be suspended from the floor to allow easy cleaning in the event of chemical spills. All cupboards can be easily removed for repositioning and access to under-bench services
- no chemical storage in the teaching laboratories.



Figure 2: General teaching laboratory, chemical stores and laboratory corridor pre-refurbishment

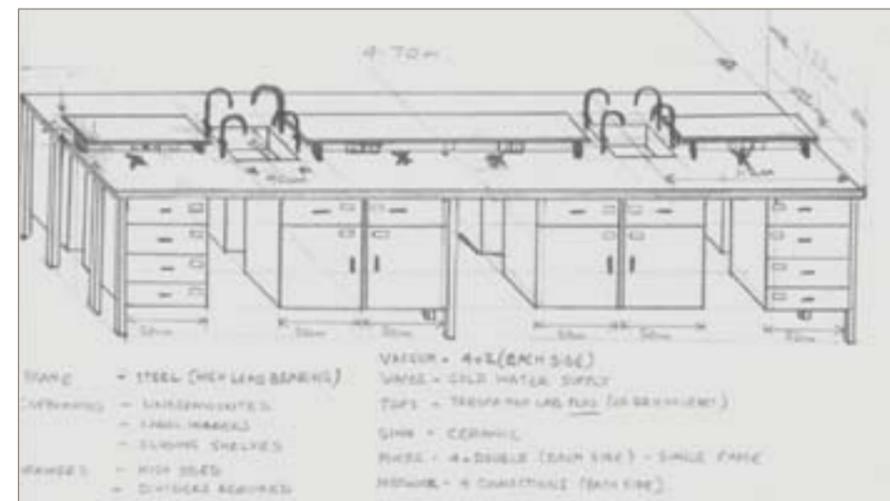


Figure 3:
Sketch of island bench for teaching laboratory

In addition to the above, all the windows to all the laboratories were replaced. The single-glazed metal framed fittings were replaced with double-glazed Scandinavian pine windows. It should be noted that the limited investment did not allow for the replacement of the fume cupboards, although the extraction pumps were replaced. Figure 4 shows photos of the general teaching laboratory refurbishment.

The building project was scheduled to start in June 2009 and be completed in September 2009. The close working relationship between the contractors, architects, GCU Facilities Management and the academic team meant that the project was completed on time. There were no disruptions to our teaching schedule for the 2009/10 session. The final phases of the project were completed after this date and final handover (following the defects liability period) was January 2011.

Impact on academic practice

The new chemistry laboratories have been in use for several academic years and the improved environment has delivered many benefits for staff and students. The learning and teaching benefits include:

- students' experience of working in the laboratories (Figure 5) has been unanimously positive. The 2009/10 National Student Survey showed 91% satisfaction for equipment and facilities, up from 67% in 2006/07
- the clean atmospheric environment, new power and water supply has led to the quality of the experimental data collected during laboratory classes being much more reliable and consistent than pre-refurbishment
- the laboratory development has only led to a marginal increase in the capacity, however, the utilisation has increased. The teaching laboratories are used for tutorial sessions, class tests and IT-based classes. For example, in the Forensic Microscopy course, each microscope is connected to a computer and the computer connected to the GCU network. Students collect images and save their data directly onto the network drive. The data can be accessed remotely for assessment. By using the IT/AV facility in the class we are able to project data directly onto the screen on view to the whole class
- the interactive boards installed in the laboratories are ceramic and resistant to chemical attack. The data on the screen can be saved, e-mailed, printed, etc.



Figure 4: General teaching laboratory refurbishment



Figure 5: Refurbished teaching laboratories – (left) general teaching laboratory

(right) chromatography laboratory

Difficulties encountered

The parameters for this project were set out on day one (i.e. budgets and timeline). We were extremely fortunate that no unforeseen problems arose during the building works, or with suppliers and contractors. There was close co-operation between all parties and the project was delivered on time and on budget.

Benefits

In addition to the academic benefits, the laboratory refurbishment has had an impact on a number of our other activities.

Student recruitment

The main users of the chemistry laboratories are students on the BSc/BSc (Hons) Forensic Investigation programme. The number of applications for the

programme in 2008 was 178 for approximately 40 places. Following refurbishment the number rose to 278 in 2010. The number of applications to our programme has remained strong; for 2013 there were 250. We have increased the entry tariff and rarely use clearing to achieve our target numbers.

Continuing Professional Development (CPD)

It was always intended that the new facilities be used for CPD activities by GCU and other outside organisations for income generation. In 2012 we attracted an International Summer School in Comparative Forensic Sciences to be based at GCU from our partner institution, California State University, Long Beach, USA.

The three-week course gives international students an insight into forensic science practice and the criminal



Figure 6: Forensic summer school laboratory activities

“The total income to date has outstripped the initial investment.”

“We have increased the entry tariff and rarely use clearing to achieve our target numbers.”

justice system of Scotland and the USA. The programme of activity includes a series of lectures from GCU staff (Chemistry and Law), laboratory work (Figure 6), field trips and cultural events. Other contributors include the Scottish Police Services Authority (SPSA) Forensic Services, Scottish Courts, Scottish Prison Service, Scottish Drug Enforcement Agency and Scottish Police. The package also includes cultural trips to various historic sites in and around Glasgow and Edinburgh and a finale dinner.

Without the laboratory investment we would certainly not have attracted the summer school. The 2012 event was a resounding success both educationally and financially for GCU. The summer school will run again in July 2013.

Research, consultancy and Knowledge Transfer Partnership (KTP) benefits

Following refurbishment we have received several major investments for research and KTP, including £150k from Scottish Enterprise/FMC Technologies for subsea sensor development, £200k (2010) and £900k (2013) from the EU for pharmaceutical analysis in clean and waste water and £180k from the EU for impact on air and water from livestock waste.

The total income to date has outstripped the initial investment.

Environmental improvements

In 2008 GCU embarked on an ambitious strategy to reduce total carbon emissions by 20% by 2014 and to deliver potential cumulative financial savings to the organisation of around £300,000. The energy use in all of the campus buildings contributes over 80% of total emissions (calculated at 1.1million kg in 2008).

The integration of the lighting, heating and ventilation of the chemistry laboratories into the GCU Building Management System is helping the university to realise the target. An example of energy saving includes heat loss from the laboratory being reduced by 12% simply by window replacement.

A copy of the GCU Carbon Management Programme can be found online at http://www.gcu.ac.uk/sustainability/documents/finalGCUCMPversion6_000.pdf

Advice to others

The new economy emerging from the recent recession will have a much bigger science base. This is going to require more young people to be attracted into science education. In this project we have succeeded in turning an antiquated facility into one fit for the 21st century economy. This should be the driver for any new project.

In this relatively small laboratory refurbishment project the future of chemistry laboratory-based education and research at Glasgow Caledonian University has been secured. The new facilities have inspired staff and students

“... take advice from others who have undergone similar developments”

by providing a clean and safe working environment. The integration of AV/IT facilities has allowed greater utilisation of the laboratories and attracted CPD programmes and other stakeholders in science to GCU. The subsequent income from CPD, research and consultancy has, since the new laboratories came online, surpassed the original investment.

Our advice to ensure that educational and research requirements are met, the end-users (i.e. the academic team, in our case) must:

- take advice from others who have undergone similar developments
- produce detailed documentation outlining their vision/plans. These should be distributed to everyone involved in the project
- during the build, attend every site meeting with the architects, FM, building contractors, quantity surveyors and site managers to ensure that the laboratories are fit for purpose and to ensure any proposed changes have the consent of the end-users
- respond quickly to any requests made by the architects, FM, building contractors, quantity surveyors and site managers.

Future plans

This article has described the impact that a relatively small amount of money can have on the fortunes of an academic group within a university. At GCU we plan to continue enhancing the student experience by further developing the facilities and teaching and learning practices. Examples include:

- continuing to attract funding for infrastructure and equipment internally and externally
- interfacing all instruments onto the GCU IT network for remote storage and access of data
- allowing private companies to use our laboratories

to provide training courses and CPD. We have demonstrated this in early 2013 in collaboration with Crawford Scientific (<http://www.crawfordscientific.com/index.htm>) for hands-on training on gas chromatography. The course was successful and discussions are on-going to develop other CPD courses in analytical chemistry

- attract other “faculty-led” summer schools from the United States of America and beyond in forensic science and analytical chemistry
- outreach activities to promote young people to engage with chemistry
- chemical inventory to be computerised using commercially available software
- monitoring of equipment utilisation using an online management system.

Project partners

Client:

Glasgow Caledonian University, Glasgow, UK <http://www.gcu.ac.uk>

Architect:

Wylie Shanks Architects, Glasgow UK
<http://home.btconnect.com/WylieShanks/index.html>

Quantity Surveyor:

W. I. Talbot & Partners, Aberdeen, Scotland

Consulting Engineers:

Mech. and Elec.: Davie & McCulloch, Glasgow
<http://www.davie-mcculloch.com/>)

Structural: Struer Consulting Engineers Ltd.
<http://www.struer.co.uk/>

CDM Coordinator: Carr, McLean & Watson, Glasgow

Main Contractor: Morris & Spottiswood, Glasgow
<http://www.morrisandspottiswood.co.uk>

Framework contractor: GENT, Weir & McQuiston, Crowthorne

The Central Teaching Laboratory at Liverpool University: a new combined facility for physical and environmental science teaching

L.M. Reilly (l.reilly@liv.ac.uk), E. Rushworth and H. Vaughan

Abstract

The newly built Central Teaching Laboratory (CTL) at Liverpool University provides teaching space for chemistry, physics, environmental science subjects and archaeology. This combined facility has improved space usage and allowed the purchase of expensive equipment that can be shared by students across subjects. In addition, it is an attractive new building that is an asset when promoting the university.

Background

Liverpool University needed to refurbish a large number of undergraduate teaching labs which had not been renewed in a number of years. It was seen that, instead of refurbishing these labs, building a new combined facility would provide a number of advantages and synergies. As student numbers have increased the old labs were becoming too small and, with an increasing use of computers and electronic equipment, the infrastructure of the older buildings was being strained. Students also expect a higher level of accommodation, with modern audio-visual (AV) equipment. The obvious synergy would be increased usage of the teaching labs. Secondly, the number of technicians is lower as they are now servicing labs in the same building, instead of being spread across campus. Thirdly, equipment in the new labs can be used by more than one subject, avoiding having to buy multiple sets of the same equipment. This final point also allows the purchasing of more expensive equipment, as it becomes cost-effective

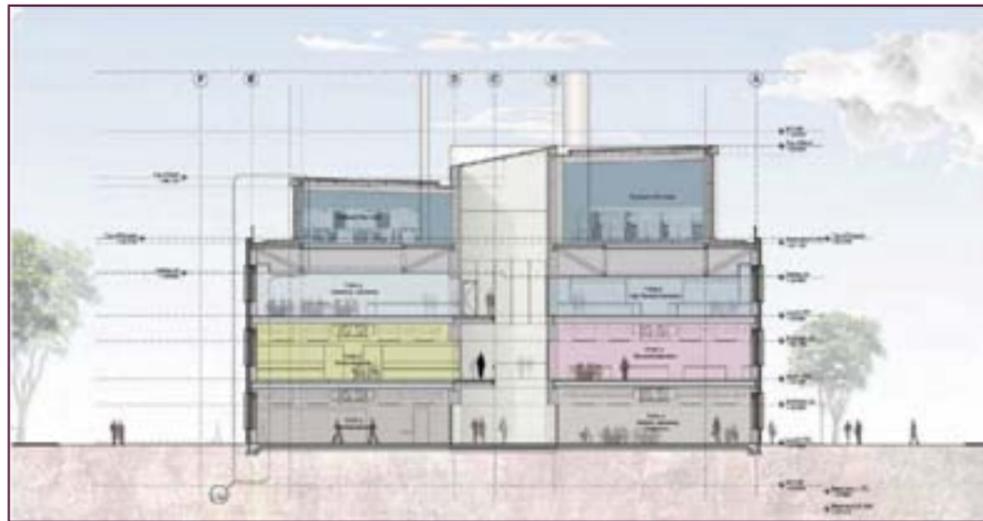
when used by more than one subject group. The combination of these factors meant that a new build would be more cost-effective than refurbishing older labs and would also enhance the student experience.

General layout of the building

The building is based on five levels; three floors are dedicated to teaching and the top floor and basement house plant rooms with storage (see Figure 1). The central section of the building is a large atrium, which divides the building in two along the main axis. This allows light into the centre of the building, giving a bright space which is also filled with furniture and has Wi-Fi access, allowing students to study or socialise. It is also used as breakout space for group work and informal meetings between academic staff and students. The atrium contains a large number of lockers of the returned deposit type. These are built into the wall, helping to retain a feeling of space. There is also a central staircase that connects the teaching levels (see Figure 2). There are a number of wayfinder screens on which notices can be displayed about building information, class times and rooms, and university news. The building is joined to an older building which houses lecture theatres.

The top floor and basement both contain plant rooms and storage areas. The top floor holds the machinery to run the air handling systems and water purification system for deionising water. It also has storage space

Figure 1: A cross section of the Central Teaching Laboratory. The central atrium divides the building in two. The top floor is a plant room, floor two is Chemistry, floor one has a computer teaching room, and an environmental science lab. The ground floor is mainly for physics teaching, and has a large open classroom for innovative teaching. The basement is not shown.



which is used for the chemistry labs on the floor below. It is served by two staircases and a goods lift which connects it to all levels, including the basement. The basement houses the rain water handling system, part of the measures to reduce the environmental impact of the building, and a large storage area.

There are three teaching floors; the top floor has two labs designed for chemistry teaching. One is a synthetic lab containing 67 fume cupboards where students carry out complicated chemical reactions (see Figure 3). The second lab is used for analytical work and has eight fume cupboards. This lab has benches with plenty of power sockets and data points so computers and instruments can be used freely. The lab is used for geology, archaeology and oceanography too. Both labs can be used in a shared mode with two separate classes present. This is facilitated by the technicians having a bay in the middle of both labs. AV includes interactive whiteboards on wheels, allowing presentations to small groups in different parts of the lab. In the atrium there is an instrument room that connects to both labs, allowing equipment to be shared. There is also a computer room containing 24 computers. Finally, both labs have benches designed for people in wheelchairs, and one fume cupboard giving good accessibility to disabled students.

The first floor contains two large rooms; one is an environmental science lab and the second is a large computer classroom with 174 seats and AV equipment for large class teaching. The computer room also has an anteroom that has 20 sit-down computers and ten fast-access computers for checking email. The environmental science lab is the lab with the highest usage in the building, being used by geography, geology, oceanography, physics, ecology

Figure 2: The central atrium and staircase that connects all of the teaching spaces. Note on the far left hand wall the built in lockers which allow students to store bags before entering the lab.



and archaeology students. It has 33 large flat benches, each with a built-in computer and a touch screen monitor at one end of the bench. This design allows the centre of the bench to be used for individual and group work, e.g. laying out large maps, bones, rock samples, etc. (see Figure 4). The desks also have power sockets and data points facilitating the use of computers and equipment in the lab. The use of microscopes, which are heavy, expensive and delicate, plays an important role in this lab. It is important to be able to move these in and out of storage safely, easily and quickly, so the gangways between benches are wide enough for large trolleys to be manoeuvred easily. This room is large, with a capacity of 150 students, and is often used by more than one class at a time (on occasion four separate groups have been taught concurrently in the space). This has been facilitated by good soundproofing, with sound baffles hanging from the ceiling. Also, the AV equipment in the room can be zoned into three separate areas, allowing material to be presented to different groups simultaneously.

The ground floor is mainly given over to physics teaching and contains the following rooms: a darkroom for optical experiments, an electronics lab, a radiation lab with secure storage and a mechanics lab. These have also been used by chemistry and geography students. There are two other teaching rooms. One is the flint knapping room, where archaeology students make stone-age hand tools and cave paintings during actualistic studies. In the future, a multipurpose cave wall is planned, to improve the realism of cave painting and to provide measurable geological structures. The second room is a large open classroom with movable furniture. This final room has been a major success of the building so far. The furniture consists of tables and chairs which can be configured in several ways for group work. Academics who have tried to book it for lectures have been refused, as the room is not furnished for

this type of teaching. Group work teaching has been successful and more lecturers are looking for ways to use it. This space can also be used as a poster room for conferences in the summer or as a breakout space. This room is also used by the university as an exam room, again increasing its usage.

Finally, the grounds around the building have also been designed for use by geology, archaeology and geophysics students, with hidden features that can be found using surveying equipment.

Impact on academic practice

The impact on academic practice has been mixed so far. Some departments, Physics and Geography are examples, have used the new lab as the stimulus to totally renew how they teach the practical elements of their degrees. Physics has moved to a context and problem-based learning strategy. This required the purchase of a large amount of new kit, facilitated by awarding a large contract to a single supplier. This has worked in reducing the cost of equipment and given one point of contact for when there are problems with new instruments. Geography has been able to introduce an extensive new set of practical modules using the new space and new sets of equipment purchased as part of the Central Teaching Laboratory project. These have been awarded the Faculty Teaching and Learning Award for their innovation and improved student experience.

Other departments have been more conservative and are now looking at renewing their teaching. In particular, Archaeology, Ecology, and Geophysics are looking to expand the amount of practical work they do in the lab.

Difficulties encountered

The primary problem with the project was the building overrun, which led to secondary problems. This included

“Mitigating against a lengthy overrun is hard to plan for.”

Figure 3: A photo showing the synthetic chemistry lab. A wide gangway that runs the length of the lab allows easy access for large trolleys; this helps technicians setting up.



Figure 4: A bench in the environmental science Lab. Note the computer screen on a pivot at the end of the bench and the large flat work surface which allows both large maps to be unrolled.



“The majority of teaching spaces are multi-user ...”

malfunctioning equipment that was delivered in time for the original opening and has sat in storage; it has been difficult to return these items as they are over a year old. Organising installation has also been awkward when the original date was over a year in the past. Mitigating against a lengthy overrun is hard to plan for. However, on a new build it is important to have a large time window between handover and the start of proper teaching in the new building to allow for installation and checking of equipment.

Audio visual equipment has been one problem that has been apparent; it has been difficult to design a system for any of the rooms that is as flexible as would be hoped. The majority of teaching spaces are multi-user and, as well as projecting sounds and images at the correct student groups, we also need to consider how to prevent this from disturbing other students.

A practical problem has been the gas handling system. It was decided early on that no large gas cylinders should be used in the building, but instead held in a shed outside the main building and piped in. This has also meant the addition of a computerised gas handling system connected to the fire alarm. A safety feature of the fire alarm system is that if it rings then the gas supply to the building is turned off. This became awkward during fire alarm testing as the labs have had gas cut off. This has been addressed, with the fail safes being turned off for fire alarm tests and the gas pipes for gas chromatography equipment being isolated from the system.

The technical difficulties have mostly been addressed, but a more difficult problem is the attitude of academic staff. The teaching labs have been an intrinsic part of their department and changing working practices is difficult. This has been most acute in the labs where the technical staff have moved over from the departments;

the working relationships have been long established. These practices are not necessarily the ones that are suitable for the new building, where just asking the technician if the room is free (or assuming it is as “there has never been a lab on Friday morning”) can lead to double booking or excessive workloads for technical staff. In reality this has not been a major problem on the Physics and Environmental floor because the technical staff are new. Overall, though, the problems have been minor and most have been fixed with simple solutions.

Benefits

After only one full teaching semester it is too early to see the full benefit of the building, although some benefits are already apparent. As the space is bright, airy and attractive, something which could not be said about the earlier labs, students are keen to be in the building, and subjects that have optional drop-in sessions report that attendance has increased since the switch. Students also choose to use the lab space for group work projects where possible.

There is increased staff interaction and, with the new equipment, teaching staff are now envisaging and developing new experiments. An example is that the physics department purchased eight bench-top X-ray machines that can be used to do powder X-ray diffraction. This is an important technique in solid state chemistry, in which Liverpool University has a strong research presence. A lecturer from the Department of Chemistry is now developing powder X-ray diffraction experiments for chemistry too. Archaeology is also planning to use the same instruments for tomography experiments. Without the new lab and shared equipment this would not have been possible. Cross-disciplinary dissertation and masters student projects are being developed and final year students doing

“... sound proofing was prioritised in the design ...”

project work are already accessing equipment and samples from different disciplines (for example, a physics student looking at rocks for radiation studies). Research grade and high tech specification kit on three floors means more availability for dissertation project students which increases student employability. In addition, there is interest from some industrial sectors in using the high specification kit and developing links with teaching.

Another benefit to the university will be seen in the longer term as the old labs are now being converted to new uses, allowing updated spaces for teaching or research. An example is the Stephenson Institute, which is a University Centre for Energy Research. The old physics undergraduate teaching labs are currently being converted for their use. This is essentially a new building, as only the external walls have been left from the earlier structure. The same thing, on a smaller scale, is happening to all of the old undergraduate teaching labs and within the next two years they will have been converted to new uses.

In terms of promoting the university, the labs are now an important part of both the UCAS open days and the post-application visit days. The labs that were replaced were often not shown to the applicants. The new labs are a central part of the effort to attract new students and have a high impact, resulting in positive feedback from prospective students and parents. Related to this, is that the lab is helping to promote cross-disciplinary outreach events and providing a space for new outreach models. In the summer we are holding an outreach week across the physical and environmental sciences disciplines and pupils will be able to sample a number of different subjects on the same day and in the same building.

Advice to others

When building or refurbishing labs, it is important to consider problems such as access for all users, ease of cleaning of surfaces and ease of building maintenance. These are all issues for the architects at the planning stage. From an end-user's perspective the issue that should be addressed from the start is how the building is going to be used. Issues that have arisen are equipment being bought without a clear idea of where it will fit in the building, instruments like gas chromatographs need pipework fitted and cannot be easily relocated. Also think about how students will move around the labs; it is best if they do not need to move far to do regular procedures such as weighing. Entering and leaving a lab is now a more planned operation; with the wearing of lab coats in communal areas frowned upon by health and safety officers, how do the students enter and exit the lab? Can they store their lab coat in the room during the semester? Where will they leave bags and coats during the session?

If the design has large labs with multiple occupancy, are you going to have room dividers? At Liverpool this was rejected on the basis that other labs that have them either never shut or open them. Instead, sound proofing was prioritised in the design and this has mostly been successful, the odd loud academic excepted.

With increased use of labs, teaching materials and chemicals need to be stored effectively. A large proportion of the space in the CTL has been given over to this purpose and a lot of consideration was given to the type of storage that was bought. In the Environmental Science Lab (the one with the most flexible use of space) the proportion of storage is naturally highest, with the use of movable shelves being used to maximise the use of space (see Figure 5).

As well as storing resources it is also important that it is as simple as possible for the technical staff to change the equipment laid out in the lab. An example is that in all of the labs the gangways have been designed to allow the easy movement of trolleys in and out of the lab. One storage area is a trolley park, with experiments for the semester stored on trolleys in boxes so that they can be wheeled in and out of the lab easily.

Future plans

Future plans for the building are centred on improving the student experience. They include relocating more classes from the environmental science disciplines into the general chemistry lab. In general, appropriate timetabling is vital to make the most effective use of space, equipment and technical support, such as improving timetabling in chemistry to avoid under-occupancy in the labs.

Another priority is developing new experiments, especially shared experiments. The physics and chemistry departments are looking at X-ray practicals and the physics academics are interested in using the rock collection to study natural sources of radiation.

Finally, improving the university's outreach is the major plan for the summer. In the summer a week of physical and environmental sciences activities are planned. Local school pupils will come in for a day and have experience of two or three separate activities across different subjects. This will be a strong advertisement for both the university and science.

Figure 5: The building contains a large amount of storage space, including movable shelves to increase storage capacity.





**Loughborough University's
online catalogue of equipment
facilitating research and teaching**



www.kit-catalogue.com



Maximising equipment use with Kit-Catalogue

Loughborough University

Melanie R.N. King (M.R.N.King@lboro.ac.uk) and Jonathan Attenborough

Abstract

Kit-Catalogue - Loughborough University's open source equipment database system - demonstrates the intelligent use of ICT to make cost and energy savings, allowing transformation towards a more sustainable future. The system is innovative and strategic, maximising the use of kit and enabling new models of equipment-sharing with far-reaching benefits for research, teaching and learning.

Background

In 2008, the Materials Research School and the Engineering Centre for Excellence in Teaching and Learning (engCETL) (a precursor to the Centre for Engineering and Design Education (CEDE)) at Loughborough University created an 'Equipment Database', an online catalogue of laboratory equipment, workshop machines and specialist tools from across the university. This catalogue enabled staff and students to search for a particular item to borrow, book out or hire for research or teaching use.

In March 2011, JISC funded further developments to the equipment database. The project delivered significant enhancements and provided public views of the website (<http://equipment.lboro.ac.uk>) as well as open linked data for other web services to exploit. The project enhanced the cataloguing effort, improved system functionality and integrated it within procurement and policy workflows; embedding and encouraging greater use across the institution.

The enhanced application, Kit-Catalogue, has been available as open source software since December 2011, and can be downloaded from: <http://www.kit-catalogue.com>.

Loughborough University continues to sustain the initiative, making significant investments, including:

- system developments, enhancing descriptive data, browsing and searching capability and links to finance systems
- an increased cataloguing effort promoting publicly viewable items
- advocacy of the benefits of sharing and maximising equipment usage (and therefore research capacity) between departments, research groups, institutions and industry
- the provision of thorough supporting material for a growing external community of adopters.

Since first release, Kit-Catalogue has undergone significant enhancements based on valuable feedback from pilots and from the user group, which now consists of 16 higher education institutions (HEIs) and meets twice a year. The latest version of the Kit-Catalogue software (V.2) was released at the second user group meeting in April 2013.

What exactly is Kit-Catalogue?

Kit-Catalogue is an open source, online system that can help any organisation effectively to catalogue, record and locate their kit. This might be laboratory equipment,

“Reducing duplication of equipment enables more cost-effective use of space, and reductions in energy use”

workshop machines, ICT and specialist tools - in fact any physical asset that requires descriptive information to be recorded, the item located and then used to its full potential. Developed hand-in-hand with laboratory technicians, researchers and academics from a wide range of Loughborough University's departments, Kit-Catalogue provides a user-friendly interface enabling users better to understand, locate and share their equipment both within their institution and with outside organisations.

Kit-Catalogue can contain a wealth of information on each item, including its specification, custodian, location, handbook, access requirements, usage data and photos. The system is a PHP/MySQL application that needs to be downloaded and installed on a web server by IT within an organisation. End-users (i.e. staff and students at the host organisation) can then log-in and view items in the catalogue. With 'admin' or 'custodian' level permissions, certain users can then add items to the catalogue, either manually or automatically via a CSV file (spreadsheet) import.

Items can be added into free-text categories that have been set up by the system administrator for a local installation, or the European standard Common Procurement Vocabulary (CPV) codes that come embedded in the system. Out-of-the-box, Kit-Catalogue provides the facility to browse the catalogue by department, equipment type, access type (who can typically use it) and user-generated tags. Browsing using any extra fields added to the equipment database through local configuration changes can also be enabled. At Loughborough, for example, we also record which 'research school' a piece of equipment is relevant to (custom field), as well as its department (built-in field), so browsing by research school is an option.

With the level of detail provided for each entry, including a full description, specifications and manuals, along with the relevant contact information, location and photograph, both staff and students can easily find the right kit for their job, eliminating the need to contact laboratory staff or manufacturer enquiry lines.

Currently, Kit-Catalogue at Loughborough is populated with 2,055 laboratory items, and this number is growing as the data collection process continues. Levels of use are high – internal statistics for the 2010-11 academic year show that over 350 users viewed a total of 960 items, resulting in a total of over 10,300 item views. It should be noted that of the 350 users, around two-thirds were students.

What are the benefits?

- A single searchable catalogue of equipment potentially reduces the need for and cost of travel to carry out certain research experiments
- Highly detailed item descriptions allow users to identify the best item for each individual laboratory operation
- The inclusion of a full description, specifications, photographs, user manuals, case studies and other application details for each item listing means that students can use Kit™Catalogue as an educational resource, increasing their knowledge of certain items
- By encouraging the sharing of equipment between disciplines, the potential for collaborative research and new areas of research is opened up

- Equipment costs are reduced for each department, resulting from greater collaborative usage. This is particularly significant when considering that the government cut capital budgets to Research Councils by 50%, meaning that Research Councils expect a contribution of up to 50% from universities for equipment purchases over £10,000
- Kit-Catalogue prevents the unnecessary and costly double purchasing of items. At Loughborough, Kit-Catalogue is linked to the procurement process and any potential duplicate purchase request triggers an alert. This approach recently saved over £25,000 by avoiding a duplicate purchase, and also stimulated new collaboration between the researchers involved
- Reducing duplication of equipment enables more cost-effective use of space, and reductions in energy use
- Custodians control the availability and visibility restrictions for each of their items; the introduction of a request form greatly expedites the request process and avoids hindrances to normal teaching schedules and research projects
- Kit-Catalogue provides the option to make any item publicly visible and available for external hire. This may generate funds or facilitate collaboration with external partners.

Difficulties encountered

During the first stages of cataloguing equipment onto the database at Loughborough University, there was some resistance from a few technicians and academics about releasing their equipment information onto a catalogue. Reasons cited included hesitations about allowing anyone else to use their kit for fear of damage, the fact that persistent use from specific groups would not create time for any other use of the kit and a lack of infrastructure to support usage requests. Similar resistance was experienced by a few other members of the Kit-Catalogue user group; however, since those

“Kit-Catalogue is an open source innovation that can be easily and freely adopted by any organisation ...”

resistors have been made aware that they can control whether their equipment listings can be seen internally or publically, and that restrictions pertaining to use and availability can be marked clearly on the listing exactly as they require, a welcoming and supportive buy-in has been achieved at Loughborough and the other institutions facing such difficulties.

Collaborative initiatives

The far-reaching potential of the system can be seen in the formation of the M5 group (<http://www.m5universities.ac.uk/>), a Midlands collaboration of research-intensive universities, established to boost research collaboration and promote sharing of equipment.

Nationally, the Kit-Catalogue team at Loughborough is a partner in the EPSRC-funded collaborative project UNIQIP (<http://www.uniquip.ecs.soton.ac.uk/>) along with the universities of Southampton, Bath and Leeds. These four partners represent regional consortia comprising 22 universities. The project aim is to research and propose national guidelines and technical standards (including harmonised vocabulary and schema) for cataloguing research facilities and equipment. The Kit-Catalogue system will pilot and ultimately implement the national agreed taxonomy and standards for describing and sharing data about equipment and facilities in UK HE.

The potential of many UK HEIs making their equipment more discoverable both internally and externally should lead to cost savings and sustainability benefits for all, as well as raising the profile and maximising exploitation of research assets of UK HEIs internationally. Kit-Catalogue is an open source innovation that can be easily and freely adopted by any organisation, with tangible benefits for UK research and sustainability.

Figure 1: The Faraday space, City Academy Norwich



New flexible science teaching spaces enhance learning and showcase sustainability

City Academy Norwich

Tim Mullis (timothy.mullis@cityacademynorwich.org)

Abstract

City Academy opened in a new building designed by Sheppard Robson in 2012. The construction of a new building allowed the Academy the opportunity to design a facility with the architects which broadened new ways of science teaching, and integrated technology through teaching aids and within the building fabric itself. The Discovery zone within the new Academy was planned around progressive and innovative methods of science teaching, drawing heavily on Project Faraday. Instead of discrete and inflexible spaces they requested that highly-serviced practical areas be minimised and that opportunities for multiple modes of learning should be brought to the fore.

Overview of project

The science teaching spaces are grouped around the large double-height Faraday studio space which can be configured for a variety of learning scenarios – traditional lessons and practical activities as well as larger, multi-class presentations and experiments such as those used for STEM lessons (explained below) and small group clusters such as teaching to 25 teachers who came over from Korea to visit the department.

The Faraday space is used for STEM lessons throughout the week. The STEM programme (science, technology, engineering and mathematics) allows the children to explore, investigate and discover STEM subjects in a stimulating learning environment, away from the constraints of the school timetable or a prescribed curriculum. STEM lessons allow pupils and teachers

to work together and explore many different ideas and activities across four disciplines. STEM has been introduced as a Year 8-based learning programme which, due to its success, will now be extended through to Year 7 as well. It encourages students to develop problem-solving techniques through large-scale exciting activity work and instils confidence in them through effective teamwork, for instance using CAD CAM to build Formula 1 cars, to build and programme a Lego Mars Rover Lander and then use it to carry out kinetic energy and gravitational experiments on a large self-built ramp which filled the 210m² space.

The ICT provision in this space includes interactive whiteboards where pupils can engage with presentations and exercises, as well as large projection facilities allowing immersive engagement for large groups. A further interactive video wall has been installed where pupils can explore virtual representations of different environments.

The Academy was keen that the new building should showcase sustainability, and its innovative construction – solid cross-laminated timber walls and floors, substantially reducing the carbon footprint of its construction compared to more traditional systems – is left widely exposed throughout. Building services are also left visible, with real-time monitors in the science area giving information on the building's energy consumption and a grey-water WC flushing system using harvested rainwater is also left 'on-show' through Perspex windows to encourage interaction with these sustainable technologies.



Figure 2: Sketch of current Faraday Layout

The Discovery zone with all the science teaching areas is deliberately oriented to face a neighbouring mature coppice, with an ecological garden directly outside the building, which is utilised for outdoor learning exercises. The Academy is currently planning an external science lab in the coppice to augment this relationship with the environment and learning even further.

Impact on academic practice

The Faraday space can hold a large class to allow more staffing options. According to STEM teacher Rachael Ackland, “Not only is the space allowing more creativity for lessons, but it is providing ample staff team teaching and naturally progresses to further professional development and training of staff”. The layout is integrated with diverse and innovative teaching practices and is suitable for teaching up to 80 students at any given time.

Flexibility allows learning to take place in a wide variety of locations throughout the Academy and grounds, deriving maximum value from the new facilities (e.g. the atrium bridges have been used for gravity-associated experiments by the students in their science lessons).

The ICT design broadens the learning experience beyond that which can be physically present in the classroom.

Difficulties encountered

It has taken time to learn to use the space to its greatest effect. We have tried models of rotation whereby classes rotate around two or three teachers during a lesson to complete different activities; however, sound crossover makes this challenging. We have found that the most effective solutions revolve



Sketch of future expansion for Faraday Learning

around team-teaching two classes at the same time, with teachers alternating taking the lead. Students need to be trained to use the space effectively, so some investment in planning and developing students’ routines is required.

We would like to increase the amount of services available as the gas and water is restricted to one third of the space, making practical work less accessible at times. We would also like to have the flexibility of an acoustic divider to allow us to bring in a third small group to work in the space.

Benefits

The Faraday space is used for a number of outreach initiatives (e.g. STEMNet ambassadors and local engineering firms) and by the adjacent University of East Anglia’s students who come to science events held there. In March 2013 the Academy ran STEM week in the Faraday space. This included a timetabled week of fun, hands-on science activities using interactive screens and demonstrations in the space. At these events young people, regardless of background, are encouraged to understand the excitement and importance of science, technology, engineering and mathematics in their lives and the career opportunities to which the STEM subjects can lead.

According to a teacher from the Discovery department at City Academy, “The Faraday space has a certain ‘wow’ factor for the students and they very quickly turn their awe into wanting to work and learn in the space.”

The space is designed for the possibilities of changes in the way science will be taught in the future as opposed to what is just appropriate for now.



Figure 3: Plan showing current Faraday Layout



Plan showing future Faraday layout

The Faraday Project at City Academy Norwich represents a well-developed implementation of the harmonisation of teaching space and practice theorised by the Department for Children, Schools and Families and an exceptionally thorough realisation of the instructive value of sustainable design.

Advice to others

Other institutions could draw on the early integration of a sustainability agenda to the provision of a teaching facility and on the two-way dialogue between bringing teachers and educators to new ways of working, and seeking their input in setting out the spaces for this to happen from the outset.

Future plans

Built into the design is adaptability for the Faraday space to extend and easily open up further or in the same realm be subdivided back into the familiar, more traditional lab layouts if required (illustrated in Figures 2 and 3).

The following link to CGI of City Academy includes a walk around the Faraday space and demonstrates the potential future layouts which could be created if the Academy decides to open up the space further in the future:

www.youtube.com/user/CANMediaArchive

IT-enabled bioscience and chemistry teaching in Nottingham Trent University's Rosalind Franklin Building

Sandra Kirk (sandra.kirk@ntu.ac.uk), Mark Cosgrove, Debra Baker, Andrew Ward and Amanda Richards

Abstract

The ex-automotive training centre on the Nottingham Trent University (NTU) Clifton Campus has been transformed into a multidisciplinary chemistry and bioscience laboratory. Effective design has greatly improved the utilisation of teaching areas and has received positive feedback from all users. As a result, the methods and designs adopted for this project are likely to be threaded through to future science building developments.

Background

In 2011/12 NTU was teaching around 850 bioscience and chemistry undergraduates in approximately 1500m² of laboratory space that had not been significantly refurbished since construction in the early 1980s. Hence, the laboratories were unattractive environments for both staff and students and also inefficient because internal layouts required splitting classes into smaller cohorts for many sessions. This meant that the potential for increased recruitment was difficult to realise and also created concerns that the quality of student experience and student employability would fall behind other universities. Therefore, when an on-campus automotive training building became available, the university decided in 2010/11 to refurbish it as a state-of-the art multidisciplinary science teaching facility to house all bioscience and chemistry undergraduate classes. The laboratory is a Containment Level 2 facility. It was named the Rosalind

Franklin Building in recognition of the English X-ray crystallographer and biophysicist whose work was central to the discovery of DNA.

Overview of project

The £5 million Rosalind Franklin Building has a gross floor area of approximately 2,441m² and cost around £1,400 per m² to convert. It comprises:

- a ground floor with a large open space teaching area housing up to 194 students (409 m²), technical/preparation areas (226 m²), an instrument laboratory (122 m²) and X-ray research facility (93 m²)
- a second floor with a chemistry research laboratory (251 m²) and office/IT space (188 m²).

There are also circulation, plant, breakout and storage areas. Student equipment is stored in rackable shelving and in under-bench cupboards.

The two key aims of the new building were to:

- enhance student experience and employability by developing a high quality teaching environment making maximum use of information technology
- enable teaching in larger groups to make better use of staff time and space, but without reducing student interaction with lecturers and technical staff.

A distinctive feature of the building is its use of IT, which is felt to be one of the most advanced infrastructures in a UK science teaching laboratory. This includes:

- enabling simultaneous use of the teaching space by up to eight different groups through three large, and separately controlled, projector screens and earpieces and microphone headsets for all lab users (working on up to 40 separate radio channels to reduce risks of interference between classes). Lecturers are able to connect PCs and visualisers to large screens within the lab, allowing live demonstrations to be screened during the timetabled sessions
- online learning support making use of the NTU Online Workshop (NOW) and Evernote programmes to make available all lecture resources prior to and post the timetabled sessions and to ensure that all data captured (whether it be written or visually recorded via video or photography) can then be accessed remotely from the laboratory environment. Lecturers are advised to record all live demonstrations for this purpose
- a requirement that all students use the Samsung Galaxy 10.1 tablet computers (provided for all users within the teaching space) to access worksheets and learning support materials, make notes, etc. They then access laboratory written material via NOW and Evernote.

The Galaxy 10.1 was chosen after a number of trials of different devices. The Android operating system was seen as a more versatile solution than others which the users were more familiar with. The Galaxy device was also felt to be 'easier to read' and 'more comfortable to hold'. Training workshops in its use are available to all staff and students, with each having an IT-focused person and an experienced individual from both biosciences and chemistry present to ensure that the most effective and relevant assistance is given to attendees.

Figure 1 shows the cycle of events that have been developed and adopted to ensure that the prior, during and post teaching sessions are managed effectively by staff and students within the School of Science and Technology.

Impact on academic practice

Transferring activities from older multiple labs into a single multi-purpose teaching lab has meant that 194-200 students can now be taught simultaneously, giving the opportunity for a variety of teaching arrangements. Larger cohorts of students can now be taught in whole sessions, rather than splits of up to ten classes which previously were experienced. For example, biology cohort BIOL14404 is now split into only two groups, rather than four or more in the previous building. One third year biology student commented that "I think the equipment and general idea of the new lab is excellent".

The presence of different groups within the teaching laboratory, and sharing of equipment, has also increased levels of interaction between students, both within and between their chemistry and bioscience disciplines.

The online system gives staff and students the opportunity to prepare and review materials to be made available to students in the lab setting prior to the timetabled session - effectively this should ensure that contact time is utilised in the most efficient manner, focusing on core teaching content rather than content overviews and aims.

Some modules changed the format of lab sessions to full-day sessions rather than two half-day sessions. For other modules the first year was very much a trial year, with modules running in a similar fashion to how they ran previously. Now that staff and students have had a full academic year in the lab it is likely that module lab sessions may be altered.

Difficulties encountered

In the early operational stages there were some difficulties in operating up to 200 tablets in a single space. Continued communication and collaboration between NTU technical staff, academic staff and suppliers ensured that these were overcome. The timeout time of the tablets was initially very short and students were unhappy with this. As a result, a pilot was run in the second term to extend the timeout on a number of tablets to investigate the effect on the battery life. This proved successful and now all tablets have had the timeout time increased. There were also issues in the early stages with the use of the tablets and the Evernote accounts that were being used for students to store their data. Improvements to Evernote were made and further training and advice was supplied to staff and students to deal with this issue.

The use of electronic lab books proved problematic for chemistry colleagues as their Professional, Statutory and Regulatory Body (PSRB) requirements state the use of paper lab books. Discussions are being held with the Royal Society of Chemistry (RSC) about this and in the meantime the students were given an opportunity to learn skills using paper-based lab books in the facility.

In addition, as expected, students in the second and subsequent years of courses were less inclined to embrace the tablet technology initially, having been used to the previous paper-based regime. Overcoming

“... laboratory time is of a higher quality than previously ...”

this is an on-going task, but relies upon staff being fully competent and 'au fait' with the technology and investigating novel ways of adapting it to the lab setting. Students entering into the first year have not had this initial resistance and readily grasped the new technology. Indeed, in one early lab session when the students were making slides and producing drawings, some of the students used the tablets successfully to take pictures down the microscopes of their slides for inclusion in their work.

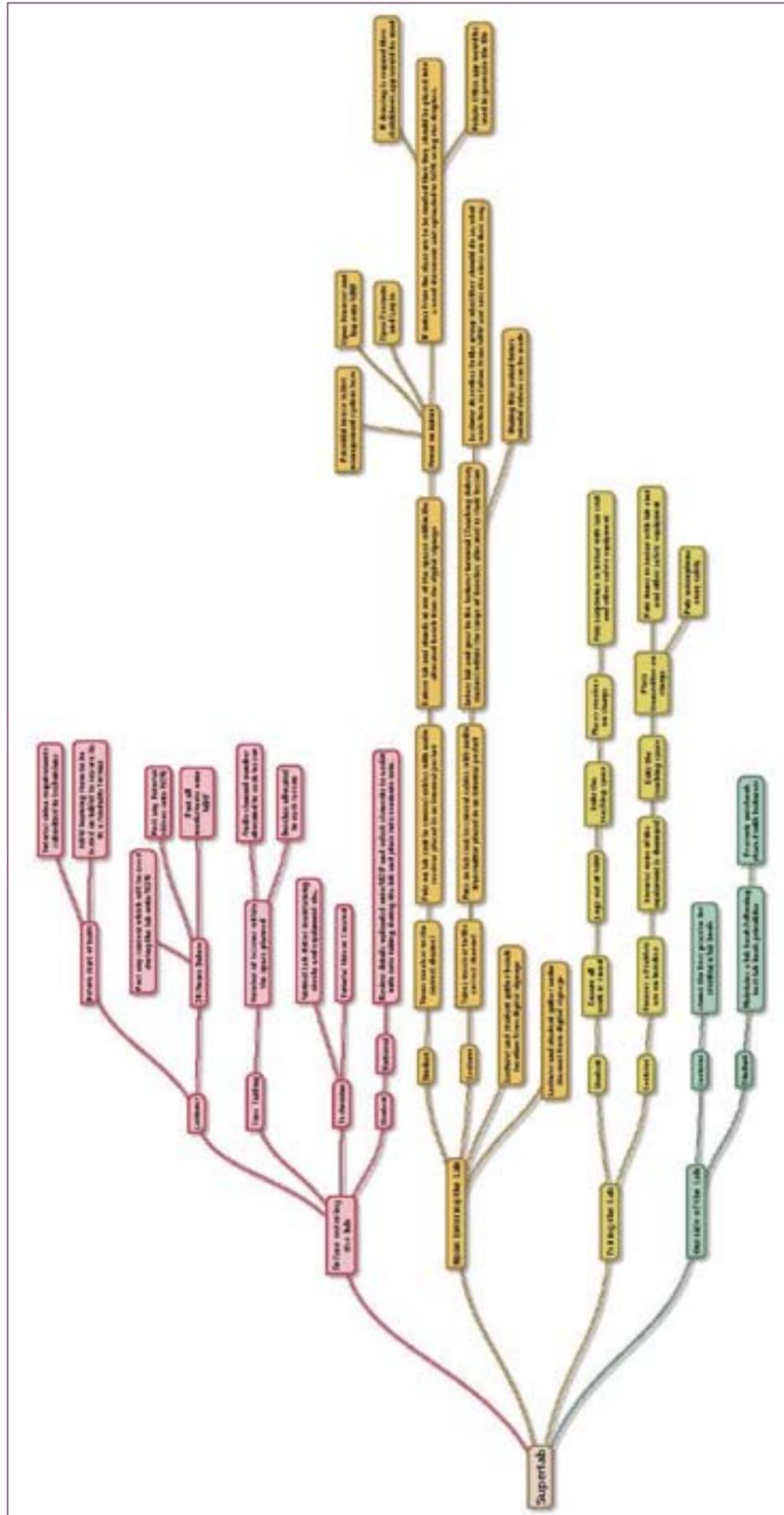
Feedback from the first full operational year of the new facility has shown that students appreciate the ability to be able to take pictures and video clips of experimental procedures but find some difficulties in using the current drawing and graph packages available. NTU has made a set of tablets available for use outside the lab which staff will be using in seminars over the coming year, enhancing familiarity with the devices and enabling students and staff to explore any issues in a smaller group setting.

Benefits

Students are benefiting from the new approaches through an enhanced learning experience. Within the laboratory they have access to a wider range of interaction from both lecturers and other students. They can also access materials immediately afterwards – and in some cases in advance - via the tablets. Outside the laboratory the availability of all content from laboratory sessions via the NOW system and the ability to interact with lecturers and other students provides valuable learning support. Hence, laboratory time is of a higher quality than previously (and has also not been reduced, as has sometimes been the case with other moves to more virtual learning environments).

At open days prospective students and their parents are extremely impressed with the facility, which will be

Figure 1. Flow-chart of activities for consideration in lab design



“... new facility allows students to gain an insight into what it’s like to work in a professional modern laboratory environment.”

“Staff have more time for quality student interaction.”

of benefit in terms of applications. We are unable to carry out outreach activities within the lab due to the containment level but we try to use all opportunities to show around alumni, teachers and others to ensure that word gets out.

The high quality of the space and the equipment, and the advanced IT infrastructure, also help student employability. Bioscience senior lecturer Dr. Rachel Stubbington notes that the new facility “allows students to gain an insight into what it’s like to work in a professional modern laboratory environment”. Comments by students on what they liked best about their modules included “The lab work I found very interesting. Much more enjoyable to learn this way”, “The more hands-on nature of the labs, feel like you have achieved a goal in there”.

Staff benefit from the new system because they spend less time teaching the same material multiple times, or answering routine queries, and can therefore have more time for quality student interaction. When using pre-recorded sessions students benefit from dedicated lecture focus. For example, where previously lecture time may have been used for focusing on carrying out experiments as an example to students, the lecturers now have the ability to simply ‘play’ the recording and focus time directly on individuals where necessary. The fact that they are in larger spaces, with more academic and technical staff present, also increases interaction between them.

The quality of both student and staff work is also enhanced as the tablet computers allow them to supplement the work with photographs of experimental results to provide a visual record of the work undertaken.

Data on staff and student responses and satisfaction is currently being collected, analysed and actioned.

The natural light and airiness of the new building, combined with the non-intrusive but hi-tech ambience, are also appreciated by both current and prospective staff and students and therefore aid satisfaction and recruitment.

Another major benefit is improved space utilisation. Not only has the amount of lab space been halved, it is also used for 90-100% of normal teaching hours, compared to 46% previously. On a 24/7 basis this has created space utilisation of 30%+ in comparison to 8% in previous buildings. This equates to a reduction of 18% per m² per student being achieved.

Finally, the refurbished building has sustainability environmental benefits. It achieved a BRE Environmental Assessment Method (BREEAM) rating of Very Good and has many energy efficiency benefits. The substitution of paper-based materials for virtual ones also reduces resource consumption.

Advice to others

The Rosalind Franklin Building has demonstrated that it is possible to have larger teaching spaces, and groups within them, without compromising the quality of the learning experience.

The design of the building was carried out in a very inclusive way – involving technical staff, academic staff, postgraduate students, Estates and IT, such that the entire design was considered in a very detailed way at each stage. Technical staff have done a fantastic job. It should be noted that they work long hours and are very busy when there are lots of classes going on in the lab.

“... invest in appropriate software at an early stage ...”

To ensure an effective design, it is important to be clear on what the facility is to be used for in the first place and to ensure that any technology being used is fit for purpose and, in the case of a lab, directly replaces the use of pen and paper. This has resulted in a fully fit-for-purpose facility.

It is also important to consider all options and not just follow the market in terms of the IT selected: invest in appropriate software at an early stage (e.g. e-lab books). In this project the decision was made to use android approaches rather than iPads and this has paid off in terms of flexibility.

Future plans

Going forward, NTU will continue to work closely with the users of the building so that the latter's needs are met and to ensure that scientists of the future are prepared for their careers as professionals in a fast-paced environment.

The new teaching and learning practices which are being trialled in the controlled environment of the Rosalind Franklin building are also being extended across the university. More tablet computers are being introduced into other schools and tablet technology is also being introduced into outdoor spaces, turning the rural learning environment into a live laboratory in its own right, with students able to capture and record live results in order to develop top quality reports.

Additional information

http://www.ntu.ac.uk/apps/news/136251-23/New_Developments_Keeping_The_Campus_Green_And_Introducing_New_Teaching_Methods.aspx

Product re-engineering for enhanced end-of-life performance

The Open University

Mark Endean (m.h.endean@open.ac.uk), Kath Clay and Stephen Burnley

Abstract

Starting from the year 2010, students of The Open University who enrol on the Level 5 (Level 9 in Scotland) residential school module *Engineering in Action* have undertaken a team project focused on end-of-life product design. This subject is of key importance in the context of the engineer's role in sustainability, which is now a feature of all engineering programmes. The team aspect of the project also provides an important opportunity for skills development for students who normally work alone and at a distance.

The project is divided into three sessions spread across the residential school week:

- Session 1 acts as a team-forming and icebreaker activity and is centred on dismantling an item of waste electrical or electronic equipment (WEEE) to enable critical analysis of its design and manufacture
- Session 2 is aimed at gathering information on design for manufacture and assembly and design for end-of-life, the waste recovery and recycling industry, and the legislative framework for WEEE. This information is used by the students as a basis for proposals for design improvements to their product to improve its end-of-life performance
- Session 3 culminates in a short poster presentation by the student teams.

Students are provided with preparatory material, which they study before attending the residential week, and

notes and instructions at residential school that cover what they are expected to achieve in the three sessions. There is also additional supporting material provided through a module website, including full access to the Open University online library.

The activity is facilitated by part-time teaching staff (tutors) who are contracted for the duration of the residential week, working to guidance provided by the *Engineering in Action* module team.

The 2010 cohort of students (around 150 in number) were invited to complete evaluation questionnaires and to volunteer for a follow-up telephone interview. Questionnaires were also distributed to the 16 tutors. Further tutor feedback was obtained from direct discussions during the residential school.

The outcome of the evaluation was overwhelmingly supportive of the design and delivery of the new team project. Suggestions for improvements were received but none required significant alteration of the project. Many of these were implemented for the 2011 presentation and a number are being considered for future presentations.

Background

Residential schools have been a feature of Open University provision since its establishment in the early 1970s. From the earliest times, students in all disciplines were expected to attend for one week full-time at the campus of a conventional university during

“... designed to deliver explicit team working and communication skills ...”

most years of their study programme. The timetable for such weeks is organised around the students arriving on site during Saturday, beginning the academic programme on Saturday evening and finishing the programme around midday on Friday. There is generally a half-day break on Tuesday. That provides four full days – Sunday, Monday, Wednesday and Thursday. The remaining sessions are Saturday evening, Tuesday morning and Friday morning.

Engineering in Action was first presented in 2004. The module was an adaptation of the longstanding and successful residential schools from two earlier modules, *Engineering Mechanics: Solids and Materials: Engineering and Science*. Three day-long activities were taken from these two schools to form the majority of the student activity. A fourth was developed from scratch and the four activities were scheduled to take place on the four full days of the timetable. The remaining sessions were linked together into a formal group project for the first time. This was based around an exploratory approach to chocolate and a design activity for a new chocolate-based product which the teams presented at the end of the final session.

At the end of 2009, a Level 4 (Level 7 in Scotland) residential school module formerly administered by a different programme was withdrawn. The resulting gap in the curriculum was taken over by the Engineering Programme with a new residential school, *Engineering: an Active Introduction*. The model adopted for this new school was the one developed in 2004 for *Engineering in Action*. Following extensive discussions, it was decided to transfer the team project activity from the Level 5 school to that at Level 4. This required a new team project to be developed for *Engineering in Action*.

Overview of project

The project was designed to deliver explicit team working and communication skills based on the framework developed earlier. To distinguish the activity from that which had been ‘cascaded’ to Level 4, it was decided to use a different mode of presentation. A poster presentation was adopted as complementary to the Level 4 activity which involved a more formal presentation with overhead projector slides.

The other important development was specific focus on sustainability, a subject which students encounter in their Level 4 studies (although the role of the engineer in contributing to sustainability is not much emphasised there).

A key feature of the activity design was engaging students’ interest by the physical means of dismantling products. Some pundits (Crawley et al., 2007) claim that this kind of physical activity has been lost from engineering education in the recent past, to the detriment of the student experience.

Design of the activity

The following extract from the *Tutor Notes* summarises the new activity.

The idea behind the activity is to explore a small part of a very real problem – how to deal effectively with the waste stream from end-of-life products. It has been quite deliberately designed to resonate with the deep-seated urge felt by many (or even most) engineering students to take things apart. For once, students can be told simply to get stuck in!

What we want our students to do is develop designs that have better eol performance. Taking something apart allows them to find out how the product they choose to work with was assembled and why it was designed to be assembled in that way. They

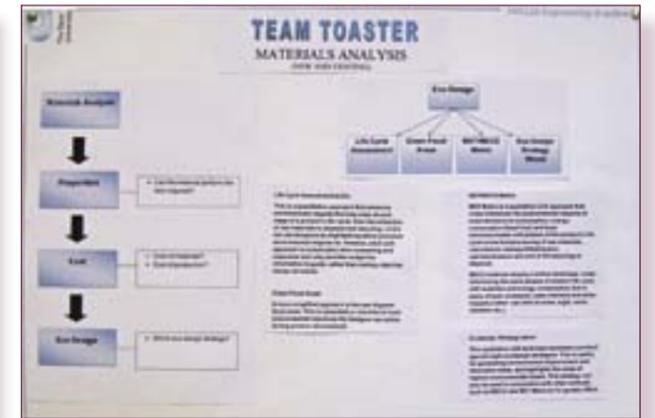
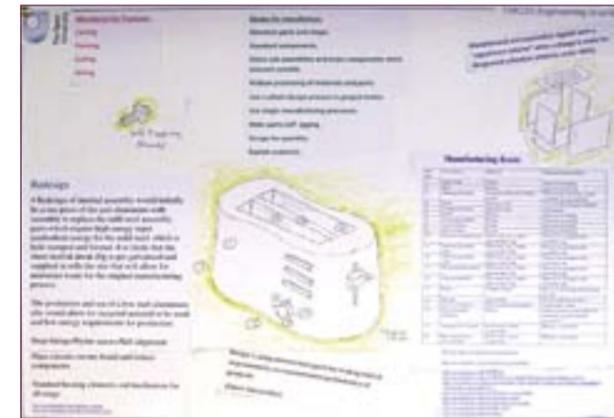


Figure 1. Samples of student posters

can then combine this knowledge with their own experience of dismantling the product to propose design improvements for a product that is easier to dismantle and whose parts can be better reused or recycled.

*Above all, in this activity, we want students to take responsibility for organizing themselves to achieve the goals that have been set for them. [The tutor’s] role is, of course, to support the ‘technical’ work the students need to do but it is even more important to help them organise and undertake their work so that they arrive at a satisfactory outcome having both **had fun and learnt something**.*

Prior to arrival at the residential school each student is provided with activity-specific study material. This contextual material covers waste and resource management, management of WEEE, design and manufacturing, recycling of metals and recycling of plastics. On arrival at residential school the student receives a set of instructions for the activity. These only state the tasks and guidance on the types of activities required to complete them and an outline timetable. (Work scheduling, task allocations and prioritisation are not defined, as these are intended to be a core team organisation task.)

The following extract from the *Student Notes* provides the structure of the activity.

The activity itself is spread over three residential school sessions:

- 1. On Saturday evening you will choose a product and, working in a small team, dismantle it and examine it in a lot more detail. Your team will give a brief presentation about your product to your tutor group.*
- 2. On Tuesday morning your team will investigate further how to extract value from your product*

at the end of its life and balance this against the cost of its recovery and disposal. You will research the various laws governing what happens to such a product once it enters the ‘waste stream’ and you will start to formulate a plan to redesign part of your product to improve the balance of value to cost at end of life (eol).

- 3. On Friday morning you will finalize your proposals and make a short presentation, as a team, to your assembled tutor group.*

The intended learning outcomes for the activity articulate directly with the UK-SPEC learning outcomes for accredited engineering programmes (Engineering Council, 2010). They are the development and demonstration of:

A. a basic knowledge and understanding of:

- the materials used in the construction of typical small domestic appliances
- the methods used to assemble these appliances
- the regulations relating to the disposal of products at the end of their useful lives
- how domestic appliances could be designed and assembled in order to maximise the potential for reusing and recycling the components and materials at the end of the appliance’s life.

B. the ability to:

- work as part of a team to achieve a common goal
- obtain information on how a product is manufactured by dismantling the product
- record this information using qualitative and quantitative methods
- propose design changes to improve the product’s performance in a given respect based on analysis of the information gathered
- plan and deliver a presentation of work in a given format.

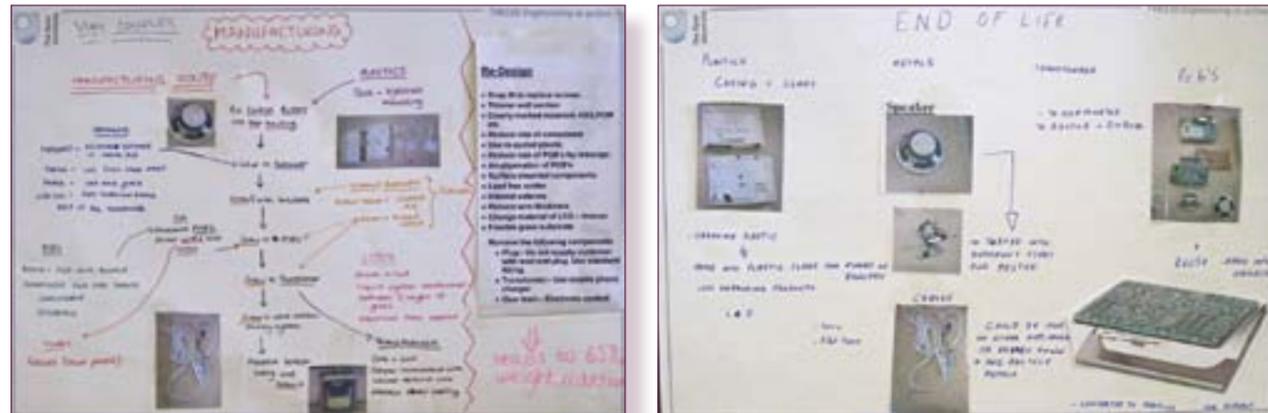


Figure 2. Samples of student posters

Relevant resources are provided during the sessions: tools, product assessment equipment, computers with access to relevant information databases and templates, and drawing equipment for creating presentation posters.

The format chosen for the Session 3 presentations was derived from that of the conference poster. The posters themselves are simple, hand-drawn displays on A2-sized sheets. Each student is instructed to prepare a single sheet, the team's sheets together making up the full team presentation. As the last part of Session 3, each student team in turn must make a ten-minute presentation of their investigation and design proposals.

The role of the tutor

The student body is sub-divided into groups of around 20, each of which is allocated two tutors. The tutors themselves are appointed from full-time Open University staff or are contracted in as part-time staff just for the duration of the residential week. Each tutor is provided with briefing notes outlining their role and providing help and guidance on facilitating the students' work.

The tutor provides a briefing at the start of each session. His or her role is to promote good time-management and provide moderate levels of guidance for the technical tasks such as product dismantling in Session 1 or poster preparation in Session 3. The tutors also monitor the level of engagement of the students in the activity and, at the end of Session 3, complete an assessment sheet for each student.

Difficulties encountered

The limited time available within the activity and outside it but within the week, coupled with the diverse backgrounds of the student cohort, biased us against adopting IT approaches to the group presentation. The default remains hand-drawn posters. However, students generally realise that they can use the computers and colour printers we provide to produce images and text in a way that contributes significantly to the visual appeal of their materials. Examples of this can be seen in the attached illustrations (see Figures 1 and 2).

The one major challenge to providing a rewarding student learning experience will always be securing a supply of appropriate WEEE. For the purposes of Engineering in Action, this amounts in 2013 to over 100 separate items of a suitable design with which students can realistically undertake the activity. We have addressed this through our work infrastructure, encouraging and regularly reminding colleagues across the whole of the university to donate their WEEE to a central collection point on campus in Milton Keynes. This is then sorted and grouped into sets – one per tutor group per week – for delivery to the residential school site.

Benefits

A small project grant was obtained from the UK Centre for Materials Education (UKCME) in 2010/11 to conduct an evaluation of the effectiveness of the project in achieving its objectives from the perspective both of students and tutors. The detailed results of this evaluation have been reported in Endean et al. (2012). Taken together, the evaluative feedback confirmed:

1. The initial premise used in designing the module (engineers are hands-on and wish to get stuck in)
2. The need for the activity to include a mandatory presentation so as to nurture and develop essential professional skills during an engineer's formal education.

Tutor feedback was overwhelmingly positive and tutors were actively engaged both in facilitating the activity and in providing constructive feedback on its design and implementation.

No feedback obtained, either through immediate, informal comments during and after the residential school or through the evaluation conducted as part of this study, suggested a need for any radical change to the activity. Various minor improvements were suggested and discussed and a number of these were implemented for the 2011 presentation.

Advice to others

Sufficient detail of the team project is available on request for it to be implemented in other institutions. This includes tutor notes, student notes, equipment lists and timetables.

Finding suitable WEEE is a matter of experience and context. The OU context favours small electromechanical devices such as toasters, hairdryers and kettles etc., and can extend to simple printers, keyboards and landline telephones. More complex products, such as digital cameras or DVD players, may be suitable where the timetable for dismantling and 'reverse engineering' can be extended. Students are not keen on what they see as 'obsolete' products.

“A key feature of the activity design was engaging students' interest by the physical means of dismantling products.”

The success of the project may well be partly due to contextual factors, such as student demographics, the role of residential schools within the Open University programme and the timescale over which the project is delivered. We hope to learn more from the experience of other educators.

Future plans

The overall framework within which the activity is designed remains sound, as does the activity itself. Although there are no immediate plans for anything more than an annual review by staff of effectiveness, it would be possible to develop new activities within the same framework.

References

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For institutions interested in implementing this activity, detailed information is available on request. The authors are also keen to learn from others with similar experience.

Contact m.h.endean@open.ac.uk

Development of a vendor practice-based distance learning programme

The Open University

Nicky Moss, Richard Seaton, Andrew Smith (andrew.smith@open.ac.uk) and Keith Williams

Abstract

The case study describes the methods used to provide laboratory activities, or their equivalents, to students pursuing Open University (OU) modules delivered by distance learning at undergraduate and postgraduate level in networking. The modules incorporate the study of Cisco Academy materials and prepare students for Cisco professional qualification exams as well as OU assessment for HE credit. Three modes of experimental activity are described:

1. Attendance at physical laboratories
2. Remote online access to equipment
3. Use of online simulation software.

The merits of each mode of operation are presented and discussed.

Background

The Open University [1] has about 240,000 active students at any one time undertaking home-based study, predominantly on a part-time basis. Its core operational model involves the design and development of module curriculum and media content by its academic staff and a module presentation system based on provision of student support through a network of OU employed Associate Lecturers. Students access their learning materials and support services through the OU's Moodle-based VLE. Thus each student currently benefits from online access to high quality teaching media and participation in a student group (~20), enjoying the close support of an Associate

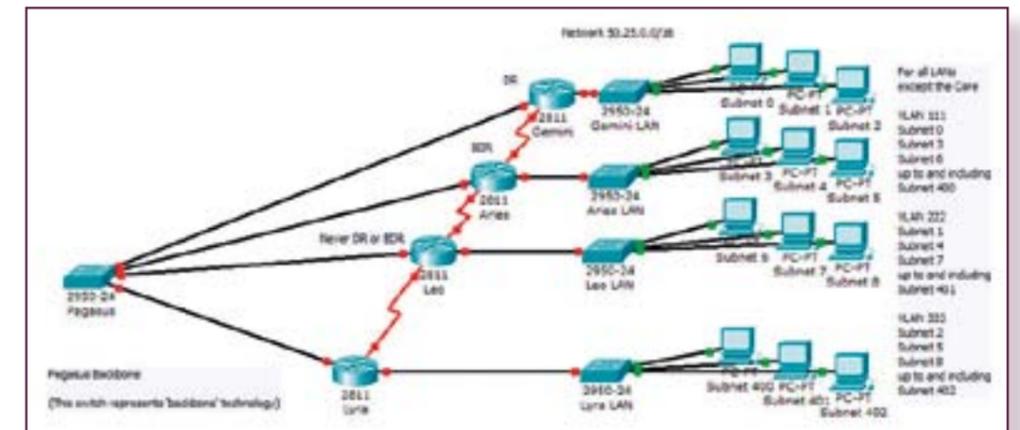
Lecturer who is an expert in both module content and the challenges of study through distance learning. The Open University has from its launch in the early 70s presented a wide programme in STEM subjects, tackling the challenges of provision of laboratory experience through a number of mechanisms:

1. Attendance at residential schools that utilise the laboratory equipment and facilities of face-to-face institutions for intensive laboratory or field study-based teaching and learning
2. The provision of Home Experiment Kits specially designed to enable students to carry out realistic experiments in their home environment
3. Use of media such as DVD and online media to provide materials for observation or simulation of experimental activity.

Patterns of use have changed over the institutional lifetime with changing technologies and financial considerations.

The team responsible for the modules set out to pioneer two significant innovations to the OU standard operational model: firstly to develop a module in which the majority of the teaching material would be derived from an outside source, namely materials available through the Cisco Network Academy system, and secondly to address the challenges of providing distance learning students with access to the equipment and resources needed to provide the practical experience and skills development integral to Cisco programmes.

Figure 1.
An example of a
Packet Tracer network
used in assessment



Overview of project

Open University Module T216 Cisco Networking was planned to fulfil a dual function: to provide a module providing the knowledge and skills required for the networking element of a number of first degree study paths and to provide a route to enable students to secure the Cisco Certified Network Associate (CCNA) qualification [2]. Many other universities provide similar dual purpose modules, but the OU team has been the first to devise mechanisms for effective delivery on a large scale by distance learning with student cohorts of 600 or so. From the outset there are some obvious parallels between the way the CCNA curriculum is delivered through the Cisco Networking Academies [3] and the UKOU's supported open learning model. Looking within the Cisco CCNA programme, for example, these include the use of the universities' internal 'student home' site, an online curriculum, the use of simulation tools such as Packet Tracer and online assessment, both formative and summative. The one obvious difference is that the CCNA is primarily intended for delivery in the classroom.

Teaching the practical skills using real equipment is an essential learning outcome for the CCNA curriculum. The integrity of the final examinations is important for maintaining the credibility of the programme. Maintaining both of these features is therefore critical, even if blended teaching is used. Both of these provided a challenge for the UKOU, where normal practice is for students to take much of their formative assessment at home unsupervised and when the use of residential schools was diminishing as a result of advances in online labs. On the other hand, the ordered structure of the curriculum and the end of chapter tests both fitted naturally with the flexible timetabled teaching used on other courses.

The blended solution, that enabled the UKOU to make full use of its experience in supported open learning and meet Cisco's requirements for hands-on practical and proctored final exams, was achieved with the use of dedicated day schools and the online Netlab+ suite providing access to remote equipment [4][5]. The opportunity for students to develop and practise their skills with configuring networks has also been enhanced by the rapid developments of the Packet Tracer online simulation system. How the UKOU has used each of these elements to deliver the CCNA Exploration curriculum is explained below.

Day schools

Students who wish to study the CCNA Exploration courses with the OU do so as part of an undergraduate degree programme. Currently all four CCNA Exploration courses are offered as a single undergraduate course titled *Cisco Networking* (university code T216). Because this course is part of a degree programme, students are expected to have some prior knowledge of networking computers, their use in the workplace and basic study skills; such students are termed 'experienced learners' in the Cisco Academy. On this understanding of student profile together with recognition that T216 would also include Netlab+, it was agreed with the UK Cisco Networking Academy that four laboratory days would be dedicated to practical skills development. As UKOU students live all over the country, attendance at a single centre is not feasible, especially when it would be better to align one day with each CCNA Exploration course.

Partnerships have been established with 11 Cisco Networking Academies in the UK and one in the Republic of Ireland to deliver the four schools. This co-operation has brought benefits to both students and academies. Students can now attend day schools closer to their homes and they are taught by experienced Cisco qualified instructors in some of the best equipped UK academy labs. The academies have gained extra business on a Saturday, allowing them to use facilities that would normally be dormant, leveraging extra benefit from the investment in networking equipment. Students are able to book each of their day schools from a selection of venues and dates, using an online booking system developed from the normal UKOU residential management system. This system also feeds an attendance mark to each student's assessment record in order to check that the student meets the course requirement for compulsory day schools.

A written handbook is produced for each day school, setting out the learning activities and outcomes, and is supplied to all students and day school centres, ensuring that all students gain a similar learning experience.

Netlab+

The Netlab+ Academy Edition provides remote access to Cisco networking equipment such as routers and switches. It has been specifically designed by Network Development Group (NDG) to host Cisco training equipment on the Internet for student and instructor use and is particularly well suited for blended distance learning [6]. It is important to remember that Netlab+ is not a simulator, but allows students to access the console port of real networking equipment such as routers and switches. All UKOU academy students are given access to Netlab+ for the full duration of their study, normally nine months. Students' accounts

on Netlab+ are organised in tutor groups to enable tutors to monitor students' use and lead sessions as necessary. Some will have accounts on the UKOU's own Netlab+; others will use systems belonging to our partner academies who lease access to the UKOU. Student access is provided 24/7 using the self-booking facility provided by the system. Students can access Netlab+ at any time to undertake labs as specified in the curriculum, or just to practise and develop their configuration skills. All students are required to use Netlab+. Activities specific to Netlab+ are included in the UKOU's assessment to ensure that students complete practical work that can be assessed by their tutor.

Packet Tracer

This is a Cisco developed simulation package that allows single or multiple users to design and simulate network traffic and its routing [7]. With the advent of multiuser functionality in Packet Tracer 5.0 and the development of the Packet Tracer Multiuser Protocol [8], the Packet Tracer application enables students in disparate locations to interact on a common simulated practical activity. This potentially leads to an understanding of the practical and underpinning principles of a complex computer network environment [9]. Figure 1 presents a view of a typical network that can be created on Packet Tracer and used in university assessment.

The mechanics of Packet Tracer

As a simulation environment, Packet Tracer offers router, switch, server, workstation and protocol functionality for students and educators to create diverse and complex routed scenarios, extending the pedagogical and practical experience during participation in the Cisco Academy programme. The Cisco CCNA version 4.x Exploration and Discovery

“Students are able to book each of their day schools from a selection of venues and dates ...”

curriculum contains embedded lab exercises for the students to complete. These are either in class on live technology or remotely via the Netlab+ system. Otherwise labs exist within the online content produced by Cisco Systems; by clicking on an icon within the learning material, the student is able to launch different networking challenges using the Packet Tracer application.

The pedagogic advantage of Packet Tracer

When launched, the Packet Tracer activity is goal-based, giving students milestones and rewards and indicating completion percentage based on the activity scenario. As a simulation tool, the ‘network operating system’ deployed on the included devices is a subset of the real-world equivalent, having the same behaviour, performance and idiosyncrasies within a contained experience. The multiuser functionality allows students and academic centres to create environments that can interact, irrespective of locale and supporting academic environment [10].

Our experience indicates that, at undergraduate level, teaching objectives can now be met through use of online simulation through Packet Tracer. At postgraduate level the use of the Netlab+ system giving access to remote physical equipment is necessary to fulfil programme objectives.

Impact on academic practice

These activities have had impact on two major areas of academic activity relating to programme development and delivery. Use of vendor-originated materials represented a major shift in OU practice as OU staff were previously responsible for the development of all teaching materials. Particular attention has been paid to assessment policies and practice to ensure that learning outcomes address generic aspects of the subject as well as the specifics of the Cisco academy syllabus. The success of T216 and related courses has

been replicated by adoption of Microsoft materials [11] as the basis for other modules, but overall this mode of module development is likely to be restricted to areas in which high quality materials are freely available.

The second area of innovation relates to the provision and organisation of online laboratory access to physical equipment and the constraints relating to reservation systems. Students are driven by assessment deadlines and in courses with high student numbers bunching of bookings occur, which for individual access creates significant availability problems. Hence, it is a challenge to provide sufficient access time. Use of simulation relieves the time constraints arising from shared use of real equipment.

Difficulties encountered

The primary challenge for this project focused on encouraging the understanding of two large organisations, each with successful programmes and cultures of learning, to work together and allow their established cultures of learning to absorb practice from each other.

For the Open University:

- Use of a ‘vendor’ certification within the discipline of networking was a new academic venture, presenting the faculty with the challenge of understanding and evaluating the academic levelling
- Mixing four compulsory practice-based day schools into the delivery model and the costs and logistics this would involve
- Understanding how the costs would move from ‘high production and low presentation’ to ‘very low production and higher presentation’
- Incorporation of an established face-to-face practice into a blended distance learning environment
- Recruitment of the day school partners and ensuring geographic reach as well as quality of delivery.

“Use of simulation relieves the time constraints arising from shared use of real equipment.”

For Cisco Systems:

- Allowing their predominantly (and preferred) model of face-to-face teaching to be delivered in a blended distance learning environment with a reliance on Netlab+ and Packet Tracer
- Understanding the change in scale of delivery from their previously typical encounters of 20-30 students at an academy raised to 600 students at the OU at any given moment.

All of these have been resolved, in part through developing a relationship of trust with Cisco Systems and also through clear evidence of the resulting high standards in delivery.

Benefits

In 2009, a postgraduate programme in advanced networking was created, based on the Cisco Certified Network Professional (CCNP) certification as well as vendor certifications in network security [12]. Per annum there are around 250 students studying at this level. The mode of delivery and remote lab practice was developed based entirely on the experiences acquired from the work accomplished on the undergraduate module.

Additionally, the module team has been involved in the development and documentation of Packet Tracer. This simulation resource now has ‘features’ that have some relationship to the contributions from the OU. NDG (the owner of Netlab+) now has enhanced virtualisation resources. There have also been contributions to Cisco course content and professional development of Cisco instructors worldwide.

There has also been development of modules connected to Microsoft and Linux [13] certification, based on the experiences acquired from working with Cisco Systems.

Advice to others

There is a clear demand for practice-based learning in higher education, using technologies and programmes already established in different vendor education communities. Many HE students want the blend of ‘academic’ practice as well as ‘technological’ experience. The model employed in the development of the Cisco modules at the Open University is a framework for how this may be accomplished in a range of different distance-based educational environments.

Future plans

There is current work on a cyber-security master’s degree which may use some of the experiences gathered with Cisco Systems. Other programmes are currently being reviewed, with a view that the experiences gained from the development of this programme may be incorporated.

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The QMUL Virtual Tissue Lab: using 3D interactive games technology to optimise real lab time and improve student learning

Tina Chowdhury (t.t.chowdhury@qmul.ac.uk) and Peter McOwan, Queen Mary, University of London (QMUL) and Keith Turner, Solvexx Solutions Ltd.

Abstract

The Virtual Tissue Lab (VTL) encourages students to experience real-life lessons in academic practice and transferable skills that are needed for life-long learning. Technical skills are taught with 3D interactive games technology, such that the student can practise lab procedures multiple times and learn from mistakes without incurring additional resources. The VTL utilises the Learnexx 3D virtual lab platform which is custom designed to mimic the facilities and equipment which exist in the real bioengineering world. This has been achieved through collaboration with the life science companies Eppendorf and Ocean Optics. In addition, the VTL facilitates feedback and personalised assessment on user performance by incorporating a self-assessment, peer-review and evaluation process. The VTL is an innovative, cost-effective platform designed to improve learning and help students learn bioengineering effectively in a novel and exciting way.

Background

Since 2008, we delivered the tissue engineering and regenerative medicine module to level 6 and 7 students on the iBSc, MEng and MSc programmes using traditional methods. This led to difficulties with teaching research-led topics to students at different levels and with multi-disciplinary backgrounds. Consequently, both coursework and exam performance varied and some cohorts struggled to cope with understanding new concepts and lost engagement with the course. A new

approach was therefore needed to educate students in tissue engineering technologies and allow discussion of research concepts. Consequently, a novel form of e-learning with instant personalised feedback and peer comment on performance was developed to assess the effectiveness of the approach for further dissemination across college as an element of a wider e-learning strategy.

Overview of project

The VTL is an interactive teaching aid which educates students from multiple disciplines in medicine, medical engineering and biomaterials with state-of-the-art technologies and allows discussion of lab-style problems involving techniques such as cell culture and biochemistry. Technical skills are delivered to students in a single environment by integrating multiple types of media (e.g. wizard exercises, presentations, videos and 3D games technology) through which students perform experiments in a virtual environment. This user-friendly online simulation of real-world activity gives the student an experience that allows testing of genuine understanding and explores whether it is possible to use virtual tools to improve lab effectiveness, both in terms of how much time is spent in the lab and the quality of the learning that goes on during that time.

Furthermore, a feedback system has been incorporated into the platform to encourage enquiry-based learning in a web-based environment. This was developed

“... an enhanced, interactive, virtual environment with personalised feedback on performance ...”

through integration of a peer-assessment exercise with personalised feedback and includes peer comments on performance, enabling peers to assess each others' work and comment formatively online. In addition, an evaluation module gives an opportunity for students to reflect on what they have learnt and communicate what they may do differently next time.

A short video illustrating the key features of the virtual tissue lab can be viewed at: <http://learnexx.com/QMULVirtualTissueLab.aspx>.

This novel form of e-learning, with instant personalised feedback and peer comment on performance, has provided a crucial research platform to assess the effectiveness of the approach for further dissemination across college as an element of a wider e-learning strategy. Consequently, we are in the process of extending the use of the platform to support first year students (level 4) studying medicine, biology/biochemistry and medical engineering/biomaterials (approximately 800 users) in the School of Engineering and Materials Science (SEMS), the School of Medicine and Dentistry (SMD) and the School of Biological and Chemical Sciences (SBCS) with funding from The Westfield Trust (2013-2015). The new platform will be used to teach basic lab knowledge and skills, including lab safety/basic rules and fundamental techniques involving cell culture (e.g. cell counting), microscopy (e.g. how to focus and quantify cells) and biochemistry (e.g. how to prepare serial dilutions or protein quantification with a spectrometer).



Figure 1. Screen shots detailing the methods utilised in the virtual lab. These are sophisticated techniques routinely used in the real bioengineering lab (e.g. bioreactor system for the culture of tissue engineered constructs) and published in several previous studies [1-2]

In summary, this project provides an enhanced, interactive, virtual environment with personalised feedback on performance to help students learn the fundamentals of multi-disciplinary topics in engineering and the biological sciences. To date, no UK institution has created a sophisticated 3D platform to help students learn lab skills at UG/PG level. The virtual tool will benefit the students' learning enormously and support both the teaching and research communities.

Impact on academic practice

For nearly two years, this highly successful initiative has received excellent feedback from student surveys and SEMS module reports. Whilst the early versions in 2009 focused on improving learning using video and a limited 2.5D virtual lab, the 2012 platform integrates wizards, presentations, videos and the latest games technology with the inclusion of a Learnexx 3D virtual lab. Students were given access to the platform following an introductory lecture in week 3 and the module was redesigned to support the online activities during semester A. In addition, guidelines on troubleshooting were sent electronically and a Facebook forum was set up to support discussions between multiple groups. The results have been very encouraging, with a high level of engagement from students, most of whom used the virtual lab extensively. The effect on real lab performance has been marked, with a significant reduction in the time spent in the real lab and emphasis changing from technical issues to critical interpretation of the data prior to coursework submission. Furthermore, both coursework and examination performance have significantly improved, leading to higher marks which were broadly similar across the different cohorts. This has benefited the School, resulting in more time for staff to support

activities which lead to novel e-learning and teaching innovations and provide a cost-effective environment for further research.

Difficulties encountered

The Learnexx 3D virtual lab platform provides a realistic 3D experience where students can make mistakes and are not constrained to follow step-by-step protocols. In general, the platform is liked but some initial reactions were negative (hard, repetitive, tricky), especially for students who found playing games difficult or had no lab experience. However, opinions changed rapidly following real lab sessions and the realisation that the virtual lab mimics the real environment and that performing state-of-the-art techniques actually takes time. In addition, 80% of the students considered the virtual lab to be extremely valuable for learning complex procedures and equipment.

A key factor in student attitude to the VTL is whether the platform is formatively assessed. When students realised the activities in the 3D virtual lab were not assessed and they were allowed to practise and make mistakes, the attitude changed and it became a much more effective tool for students to experiment with and learn what they needed prior to the real lab sessions. In addition, to help guide students during the VTL aspects that were assessed, a "hint" button was made available in the platform. Students were reluctant to ask for help because clicking on the hint button resulted in penalty points which affected the final mark for the self/peer-assessment and evaluation process. Consequently, issues around the VTL were discussed informally by students using a Facebook forum. This encouraged a virtual lab chat room approach for group work.

Other comments include:

Very long procedures which took too long to complete and the method needs to be broken into shorter steps. It is worth noting that the methods are identical to the real lab and, for example, a biochemical assay will indeed take hours to complete in the real lab.

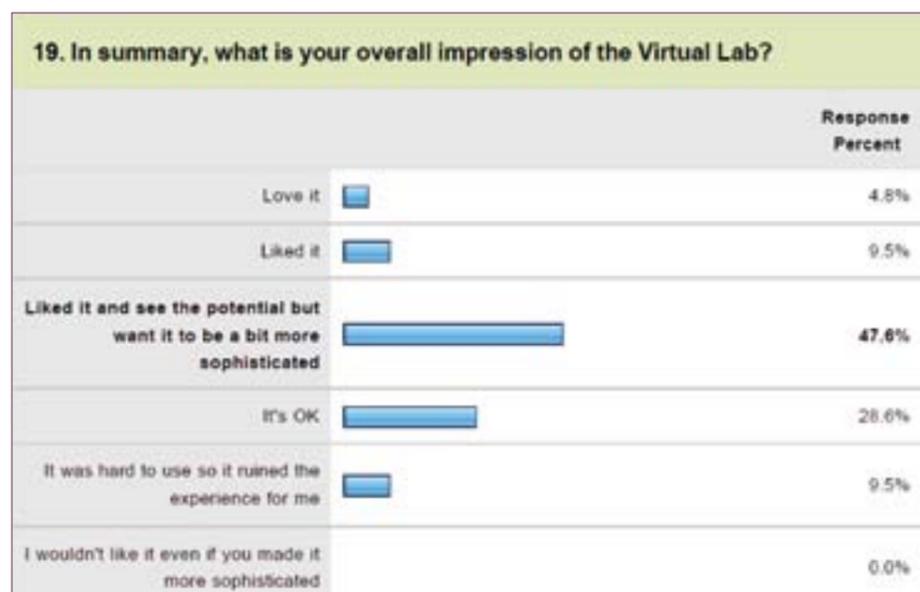
Students want explicit details and granular feedback on why procedure submission failed. At the start of semester, students were given a lecture and a lab handout which described the procedures to be used in both the virtual and real lab. However, some students found it difficult to understand why the virtual methods went wrong but, through practice, mistakes were avoided quickly and not repeated in the real lab. In addition, the procedures are identical to the real lab so virtual and actual mistakes were similar, providing value added benefit.

Some thought the virtual lab was too realistic e.g. knocking tools over or picking them up.

Students would like a lab chat room multiplayer mode for group work.

A video of what the students thought can be viewed at: <http://learnexx.com/Interviews.aspx>.

Figure2. Screen shot summarising overall student view of the virtual lab



“... a reduction in ‘real’ lab time from 15 to six hr/week”

Benefits and key findings

The average time spent by the 63 students in Learnexx 3D Virtual Lab equated to approximately 9.5 hours. Some students practised the procedures repeatedly and all students learnt how to use equipment not easily accessible in the real labs. The virtual equipment is based on real models from manufacturers (e.g. Eppendorf, Ocean Optics), enabling students to familiarise themselves with the tools before they use it in the real lab. This approach gives students the confidence to perform methods independently and helps to reduce both research and teaching costs.

Videos illustrating the virtual lab procedures can be viewed at: <http://learnexx.com/ExampleProcedures.aspx?loc=>

Furthermore, we received good feedback from student surveys and SEMS module reports, resulting in the following key benefits:

Students developed effective transferable and practical skills

- Students were proficient with using equipment and were more in tune with the methods, resulting in a reduction in ‘real’ lab time from 15 to six hr/week
- Few basic questions asked and little reliance on handouts or support from facilitators largely because the students knew what they were doing and were able to self-manage and organise in advance.

Students developed cognitive and intellectual skills

- Students had more time to focus on critically analysing the results and not the technique, resulting in improved data presentation and problem-solving skills
- Students showed critical awareness when analysing the data
- Students recognized alternatives and were able to explain and justify the methods used

- 75% of the students wrote a critical/focused discussion and engaged in balanced structure emphasising argument. This led to a significant increase in coursework marks by approximately 90% across all streams
- Examination performance significantly improved, with marks ranging from 68.2 - 71.2% (2012-13) compared to 46.5 - 67.1 (2010-11) across the different streams.

Whilst the virtual lab will never replace the real facility, our findings demonstrate that students will utilise the time spent in the real lab more effectively, thereby engaging in a more productive learning experience, resulting in better outputs. We will explore this approach college-wide to determine whether lab time saved can be reused for learning new content delivered through additional practical/lecture sessions and the module shared with other programmes.

Advice to others

This approach is an excellent example of a successful initiative which adds to the School’s learning platform and provides an exciting series of student learning enhancements involving simulations in a virtual lab. The platform could be easily broadened to include good teaching practices involved in the life sciences, social sciences and arts, whilst providing greater flexibility and access. The website will increase student interactivity and curiosity supported by the virtual lab and integrates a novel feedback platform. This varied approach to traditional learning platforms encourages students to become independent, deep learners and adopt a critical thinking approach necessary for professional careers. We strongly recommend these themes which provide access to instruction and knowledge world-wide and are in line with the Queen Mary University London (QMUL) Statement of Graduate Attributes [3] and the QMUL Strategic Plan [4].

“This varied approach to traditional learning platforms encourages students to become independent, deep learners ...”

Future plans

Student feedback has been critical in the development of the Learnexx 3D virtual lab platform, with the 2013 version addressing several issues raised during the online questionnaire process. A short video highlighting some of the new features of the 2013 beta version can be viewed at: <http://learnexx.com/newfeatures.aspx>. In addition, the new version will be used in the evolution of the VTL platform with SEMS, SMD and SBCS students, with a novel prototype due to be released in 2014 (approximately 800 users). The platform will be integrated with QM+ (QMUL's virtual learning environment), facilitating user access across College and further dissemination as a key element in the QMUL e-learning Teaching and Learning Strategy.

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An integrated chemistry teaching lab at the University of St Andrews

R. Alan Aitken (raa@st-andrews.ac.uk)

Abstract

Opened for use in September 2010, the new Chemistry Teaching Laboratory within the University of St Andrews' newly-built Medical and Science Building has proved to be an enormous success. All laboratory classes for first, second and third year students within our four-year BSc and five-year MChem programmes are now held in a single integrated lab. This provides an excellent learning environment as well as making for efficient space utilisation, with classes being held morning and afternoon five days a week during the two 12-week semesters. In its first full year of operation the lab was home to 45,000 student hours of classes. The high quality environment created was specifically praised both in the course of the 2010 Internal Subject Review of Chemistry in St Andrews and as part of the Royal Society of Chemistry accreditation process for our MChem degree programmes (2011). Student feedback at all levels has been highly positive. In June 2012 we were the inaugural winner of the S-Labs Award for Laboratory-Based Teaching and Learning Innovation.

Background

The Purdie Building, completed in 1969, was designed with eight separate large teaching laboratories, two for first year students and three (organic, inorganic and physical) for second and third year students. Over the following decades these were steadily whittled away by refurbishment to provide extra research space until only two were left. Their antiquated design meant that, even after sporadic part-refurbishment, fume-cupboard space was inadequate and, after almost 40

years of continuous use, all fabric and fittings were in a dilapidated state. Approval was given in 2007 for the incorporation of new Chemistry Teaching Laboratories within the planned new Medical and Science Building.

Overview of project

As well as using state-of-the art design and materials and employing cutting-edge technology to optimise the efficient use of energy and water, the key decision, taken at an early stage, was to have a **single integrated laboratory space**. This was a definite break with the tradition of having separate labs for each year group or each section of the subject (organic, inorganic, physical). The new integrated lab thus has a main floor area of 455m² with an adjoining instrument room of 72m², preparation room (32m²) and chemical and equipment stores (69m²). There is an associated computer cluster and data-processing area immediately outside the lab. Within this area two or even three different lab classes can be run simultaneously.

For physical chemistry, where fume cupboards are rarely required, extra students can be accommodated, and in fact the instrument room is large enough for the whole first year physical module to be held there while two other classes are in progress in the main lab.

Student equipment sets are accommodated in underbench cupboard units (60 third year, 80 second year, 150 first year) which are on wheels and so can readily be rearranged for varying class sizes. The numbers of students we need to cater for are as follows:

Figure 1. The basic design

Pattern of labs (with class sizes) over the two semesters

First Year – one afternoon a week per module

S1 Inorg/Phys 1 (180)

S2 Org (175); Inorg/Phys 2 (100)

Second Year – two afternoons a week per module

S1 Inorg (90)

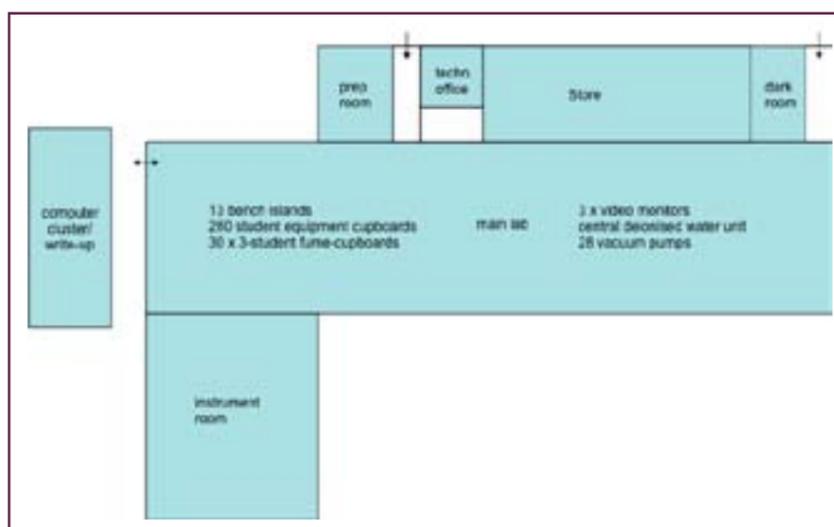
S2 Org (85); Phys (70)

Third Year – five mornings a week per module

S1 Org (70); Phys (75)

S2 Inorg (70); Mini Project (75)

Fourth and Fifth Year – all project work, in research labs



With two and sometimes three separate classes in the lab at any one time, colour coding has proved useful, with first year equipment, chemical cupboard labels and demonstrator lab coats red, while second and third year are green. Separate chemical shelves are located in different areas of the lab for first, second and third year. A common reference book area is centrally located to be used by all students.

Impact on academic practice

The decision to go for a single undivided and consolidated facility makes for maximum flexibility in timetabling and handling different class sizes. This results in a major efficiency saving with the lab being almost fully used throughout the week. It has 29 x three-student fume cupboards (2m working space), thus effectively limiting occupancy to 87 students. However, this can be 60 second year organic students and 27 first year physical students on one afternoon and 60 second year physical and 27 first year organic on another. The specialised requirements of the different labs in terms of equipment are allowed for by a generous preparation room and storage space so that equipment can be brought out to the main lab only when required.

There is a major benefit from the student point of view in terms of continuity, with each student becoming thoroughly familiar with the lab environment and not having to waste time readjusting to new surroundings for each lab class. This is particularly the case in the instrumentation room, where all analytical facilities the student will use in years one to three are gathered together in one room. When we had separate labs, each with their own instrumentation, peaks in demand were common, with students sometimes being sent to another lab to reduce queuing. The new set-up has completely removed this problem. The technical support and infrastructure has also benefited greatly from being consolidated, with two full-time technicians being able to service all classes. The work

Figure 2. The laboratory



environment for the lab technicians has improved enormously. Efficiency savings, in terms of facilities as a result of a single lab, include the following: deionised water is provided to all sinks from a single unit, nitrogen is piped to all fume cupboards from an external generator, vacuum is provided by electrical diaphragm pumps (each serving a whole area and, where possible, cooling is by recirculation/chiller units) and gas (burner for glass melting) is at a single central location for safety reasons. Outwith the undergraduate semester times, the lab provides an excellent facility for various outreach activities for school students of all ages.

Student feedback**Old labs (1969-2010)**

Regular complaints and poor ratings in questionnaires, particularly relating to lack of fume cupboard space, having to reorient each year in moving to a new lab and having to queue up to run spectra.

New integrated lab (2010-)

Actual student comments from questionnaires:

“Labs were really interesting and a highlight of the course”

“Lab sessions are always relaxed and enjoyable”

“Labs were difficult but rewarding”

“Labs were stimulating and helpful”

“Labs were very well organised”

“Labs were brilliant”.

There is also ample opportunity for beneficial contact between students of different years. For example, a first year student who is unsure where something is can soon find out by asking a second year who is also in the lab. The computer and data-processing cluster immediately outside the lab is shared by all students and so also facilitates inter-year contact and advice.



Figure 3. The laboratory

Difficulties encountered

These have been relatively few, but examples could include the installation of bench-top chemical shelving in the design, which was found to disrupt the lines of sight too much and was quickly removed and discarded in the first few weeks of use. The specifications of some lab furnishings have also been found wanting, with shelves inside student equipment cupboards collapsing on occasion. Excess heat production from the under-bench vacuum pumps was solved by cutting ventilation holes in the cupboard doors.

Benefits

There are obvious efficiency savings from the point of view of space and equipment utilisation, but the enhancement to the student learning experience is perhaps more significant. One unexpected benefit is that students have found it useful to be able to get advice on their experiments and results from academic staff members who are there teaching a different lab class. In effect, the range of expertise available in the lab at a given time is greater. The facilities and equipment used in third year are essentially the same as those in the honours research projects of fourth and fifth year, so there is a fairly seamless transition from the experience over the first three years in the integrated lab to the later research projects in individual supervisors' research labs. Within the new facility more advanced techniques can be taught (such as reactions under an inert gas), and staff are developing open-ended experiments involving individual problem-based learning at the third year level to facilitate further the transition to research projects.

Advice to others

We believe that any chemistry department planning new or refurbished labs should consider the benefits

of an integrated lab space suitable for a wide variety of classes rather than a number of separate labs.

Many of the positive developments mentioned in previous sections are simply a result of moving into modern well-designed labs. However, there are a number that are specific to the integrated lab approach which we have adopted:

- Ease of student orientation into a single teaching space for three years' lab classes
- Beneficial interaction with staff and students from other classes
- Optimally efficient use of fume cupboard space and instrumentation with varying class sizes
- Most efficient use of technical staff manpower
- Maximum efficiency in utilisation of available space and resources such as energy and water
- Consolidation of separate stocks of chemicals and equipment leading to reduction in stock levels.

Future plans

Since design in 2007, student numbers have risen by around 50%! This has required some innovative solutions, including the following:

- Portable student equipment boxes
- Out-of-lab activities scheduled for 20% of second year class each day
- Volunteers for Wednesday afternoon labs.

Further increases in student numbers will, at some stage, require provision of additional lab space, but we would plan it also on an integrated multi-use basis.

University of Sunderland Sciences Complex refurbishment – a new way of working

Iain Garfield (iain.garfield@sunderland.ac.uk)

Abstract

The Sciences Complex comprises four buildings connected at first floor level by enclosed bridge structures. The total gross internal area (GIA) is approximately 11,000m² but, due to logistical constraints associated with refurbishing a live building, the refurbishment was undertaken in phases. This paper discusses the undertakings of the first phase which involved the refurbishment of 4000m² in 2010.

Background

The four buildings of the Sciences Complex were constructed between 1979 and 1992 and were designed to be relatively self-contained, subject-specific buildings. Consequently, each building contains laboratories, offices and general purpose teaching rooms.

The academic portfolio, research priorities, and teaching and learning methods within the faculty have changed significantly since the original concept for the complex.

Due to the nature of the accommodation within the complex, subject teams had become insular and isolated from each other. This resulted in a number of issues within the complex.

Firstly, as the laboratory facilities were considered to be 'subject-specific', utilisation was generally quite poor. Due to the changes in academic profile and teaching and learning methodology, the teaching and

research facilities were, in many cases, not suitable for current activities. The offices were generally single-occupancy and were dispersed throughout the four buildings. This created an isolated feel to the academic accommodation and, as there were no casual meeting spaces, there was little opportunity for staff interaction and collaborative working. This also created difficulties for student access to academic staff, particularly for pharmacy students who had a module tutor in most of the subject areas and therefore had to move around the complex to see their various tutors.

Project overview

The project was not a building project. Although building refurbishment was undertaken, it was first and foremost a change project. The faculty was keen to change the culture within the departments, promote collaborative working, improve staff/staff and staff/student interaction, improve the student experience, develop research opportunities and engage with the local community and local, regional and national business and health organisations.

The external engagement activities were an area of special interest and the faculty was about to attract significant Regional Development Agency funding to support the development of this activity.

The physical element of the project, the building refurbishment, was therefore not the primary consideration during the initial consultation with the stakeholders and a more change-focused approach was used.

Figure 1. Hub breakout

Initial discussions with the faculty senior management team were followed by a Value Management Workshop. This is a methodology deployed at Sunderland for all major projects and enables the principal objectives and values of the project to be identified at an early stage. These objectives are prioritised and tabulated in a Value Management Diagram (Appendix 1) and form a clear brief for the project.

As this project focused on change management rather than building refurbishment, a small group of 'Change Champions' was identified within the faculty and the Estates department and these staff made up the project core group for the duration of the project.

This group, steered by the Value Management Diagram, was responsible for developing the brief by identifying current issues, change opportunities, new initiatives and ultimately building refurbishment requirements. The group met regularly and, with the support of the project manager and project architect, articulated the direction of change the faculty required. A major stumbling block, however, was identifying commonalities within the various departments to enable shared resources, mainly laboratory facilities.

Eventually this was overcome with the development of a Relationship Diagram (Appendix 2), which identifies each of the subject areas and their respective use of the facilities within the Sciences Complex and clearly shows the benefits to be gained from shared facilities.

One of the main drivers for the physical element of the project was the development of shared laboratory provision to improve the student experience, standardise facilities and improve teaching and learning environments. There

were a number of issues identified through discussions with the Change Champions and the wider academic teams.

Firstly, all specialist analytical equipment (which was dispersed around the complex in several laboratories) was reviewed and it was agreed that this was creating an issue with utilisation of the space as well as being a missed opportunity. The co-location of all of the analytical equipment into one specialist laboratory would free up lab space for more general teaching activity and also create a first-class analytical suite for teaching, research and commercial services.

The Relationship Diagram identified many different subject areas that could make use of high-quality general purpose labs, both wet and dry. However, to ensure they were suitable for all activities a wide range of services was required in the laboratories. In the wet labs these included gas, water, vacuum, power, data, fume cupboards and high-quality audiovisual equipment.

Finally, to enable the technical staff firstly to store the equipment and consumables and secondly to prepare for the rapid changeover of laboratory activity, the new prep labs needed to be significantly larger than the previous prep labs.

All of these factors were taken into consideration in the laboratory design, resulting in the agreed floor layout shown in Appendix 3. Each of the laboratory facilities on the floor has a dedicated prep area, with the large general teaching lab having prep labs at both ends to enable the lab to be split and serviced from each end as two smaller labs.

As this is a phased development, it was vital to ascertain how best to structure the building and

Figure 2. Close up of laboratory

locate the facilities. Access into the Sciences Complex was poor, with a single entrance at the east end of the complex and link bridges at first floor level. This made circulation around the buildings difficult and also promoted the isolated culture of the various departments. It was therefore decided to develop a building strategy (Appendix 4) that would provide a focus not only for the first phase but also for all subsequent phases.

To facilitate ease of access and circulation and promote the presence of science on campus (one of the key objectives on the Value Management Diagram), it was decided to construct a new entrance in the centre of the complex and create an open plan feel to the interface building.

To promote collaborative working and improve access to academic staff teams, academic hubs would be developed in the interface building. Seminar rooms, IT rooms and problem-based learning rooms would also

“The greatest challenge in this project was the cultural change required ...”

Figure 3. The laboratory



be concentrated in the interface building to free up floor space in the ‘annex’ buildings (Fleming and Darwin) to enable laboratory provision to be co-located in these buildings. This gives each of the buildings identity and greatly reduces the travel/circulation for the students in their daily activities.

This strategy also enabled us to reduce the extent of the expensive laboratory services infrastructure (fume cupboards, gas lines, etc.) from all four buildings to just one building.

Impact on academic practice

As previously mentioned, there has been a significant improvement in collaborative working as a result of this development and consequently the development of new modules and programmes as well as promotion of collaborative research.

The pharmacy (MPharm) programme is the largest programme in the faculty, with cohort sizes of approximately 240. Prior to this refurbishment the

largest laboratory had a capacity of 25, resulting in labs being repeated up to ten times to cope with the cohort size. The new general teaching lab has a capacity of 60; therefore the cohort can be managed with only four labs. This not only greatly improves academic staff workloading but also makes the timetable much more flexible, thus improving the student experience.

The laboratories are also of a much higher quality, with improved audiovisual facilities. This has greatly improved the ability to demonstrate techniques and has transformed teaching and learning techniques within the labs.

Improved storage facilities and the introduction of a barcoded inventory system has greatly improved control of consumables as well as enhancing health and safety management. This has supported the development of the technical support provision within the faculty.

The development of the ‘dry laboratories’, combining the facilities of Physiology and Sports and Exercise

Science, has greatly improved the facilities in these areas as well as developing the approach to teaching and learning, with a greater focus now on human performance, a combination of sports and physiology.

The introduction of the Problem-Based Learning Room has greatly enhanced the delivery of this style of teaching as well as increasing its use. Feedback from the students has been extremely positive, resulting in a new problem-based learning space being developed, not as a timetabled space but as a student-centred resource. This space is extremely popular and consequently extremely well-used.

The introduction of ‘whiteboard walls’ in breakout areas, especially in the academic hubs, has been well received. Often these spaces are turned into impromptu tutorial sessions, with staff and students using the spaces to great effect.

Difficulties encountered

The greatest challenge in this project was the cultural change required to accept new teaching and learning methods, new facilities and new ways of working. This was achieved by extensive stakeholder engagement. The importance of this cannot be stressed enough as the success of this project was down to the engagement and ownership of all those involved. Extensive and structured communication enabled us to involve large groups of staff and students, but the principal success factor was the identification and involvement of the Change Champions.

The pre- and post-occupancy evaluations have been enlightening and are certainly highly recommended as a measure of success of any major project, as well as enabling identification of operation issues.

As expected, the difficulty of a project of this type is undertaking the refurbishment in a ‘live’ academic building. The original programme for this project was 72 weeks; however, working closely with the project managers and main contractor we were able to reduce this to 42 weeks. This obviously greatly reduced the impact of disruption on the teaching facilities as well as providing the facilities a semester earlier than originally planned. However, this foreshortened programme required extensive cooperation from both staff and students. The development areas needed to be vacated and handed over for refurbishment to a tight schedule. To enable this revised programme, the timetable had to be manipulated to concentrate teaching activities in the development areas over much tighter timeframes. Staff and students were willing to undertake these timetable changes and as a result the development was completed 30 weeks earlier than expected, giving staff and students the benefits of the new facilities at the start of the academic year. The project costs were also significantly reduced.

Benefits

The cultural change within the faculty is significant and has greatly improved both the student experience and the collaborative working within the faculty. A building cannot change the culture, only the people can achieve this; however, the building can support and enhance the change and in this particular situation that has certainly been the case.

The improvement in both the staff and student experience, as well as the enhanced profile of science at both an institutional and national level, are key objectives on the value management diagram and have, through positive feedback, clearly been achieved.

The pre- and post-occupancy evaluations have enabled us to assess the success of the project and identify any areas of concern that can be addressed in subsequent phases. Formal and informal feedback from the students suggests that the refurbishment is well-received and their experience has improved as a result.

Advice to others

There is no ‘one size fits all’ solution as all organisations are different; however, one piece of advice that I would give from this project is to say that stakeholder engagement is the foundation of a successful project. The initial brief should be developed in conjunction with the principal stakeholders and Change Champions identified to take ownership of the project and carry it through to completion.

The ownership of this project is not down to one individual or department but to a large stakeholder group led by the Change Champions. As a result a large group of people can rightly say “That was my project”.

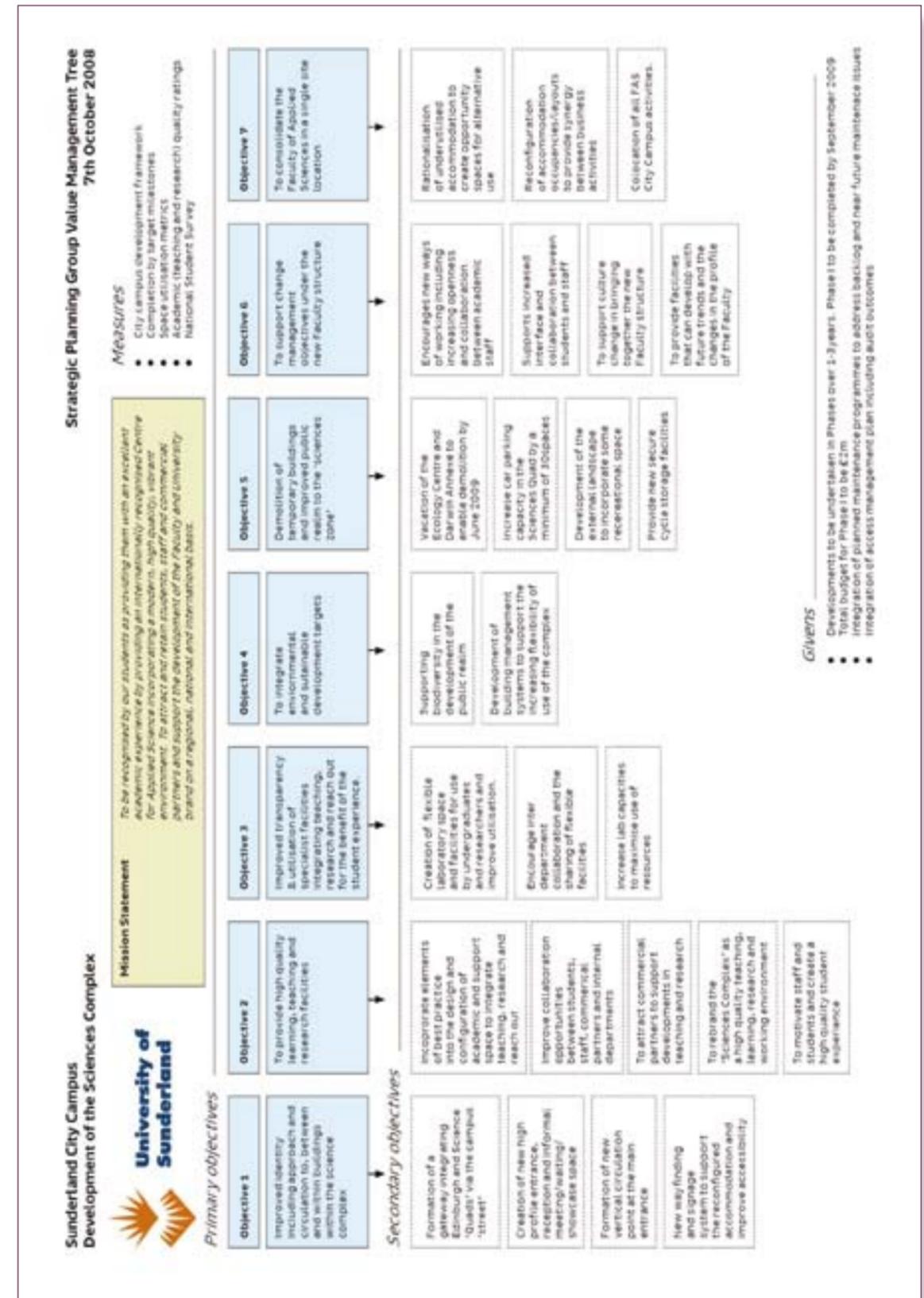
Future plans

As previously mentioned, this project was the first phase of a multi-phased intervention. The next phase is currently being developed and will see the completion of the interface building with the development of the second academic hub and further development of laboratory facilities in the Fleming Building.

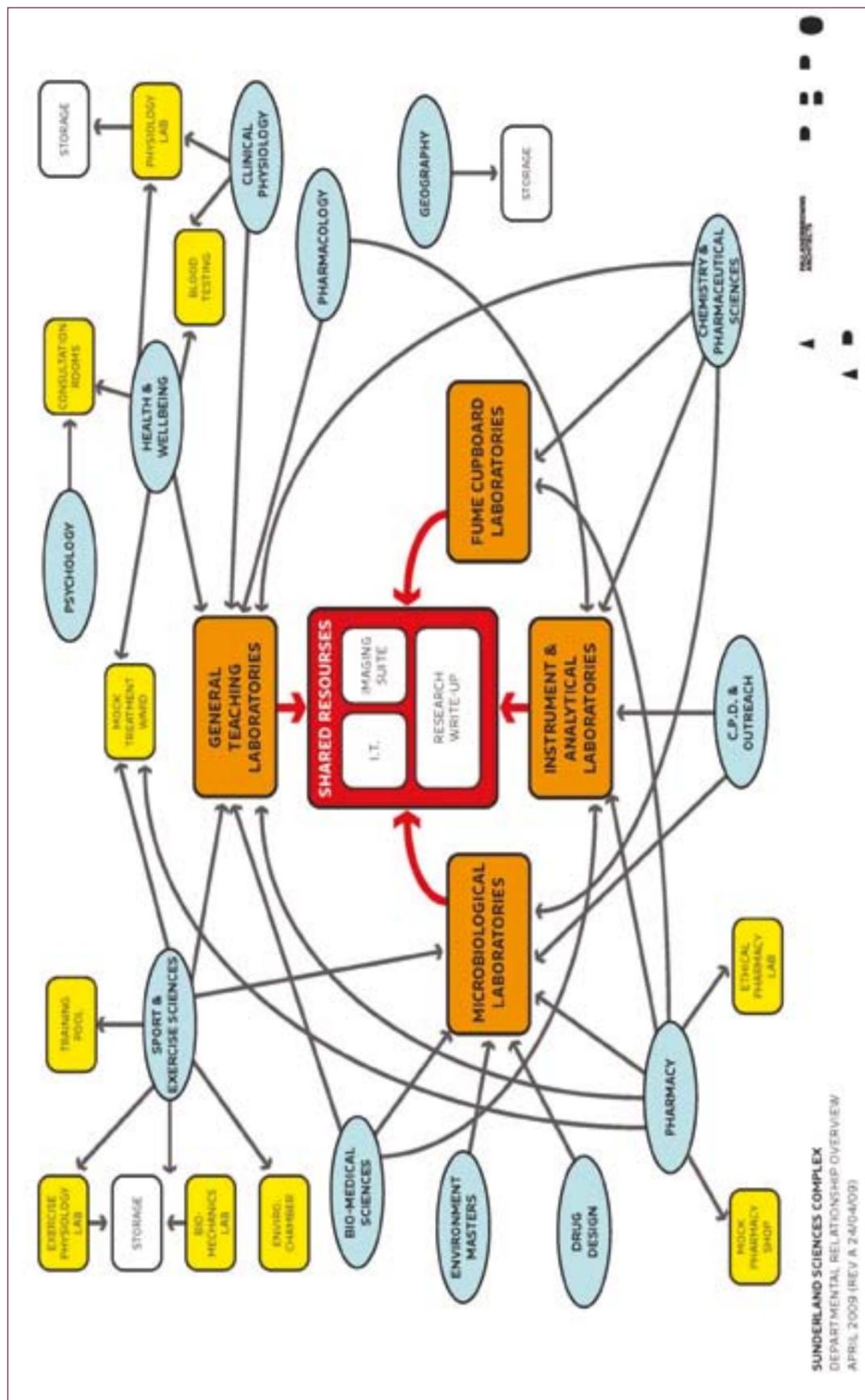


Figure 4. Problem-based learning space

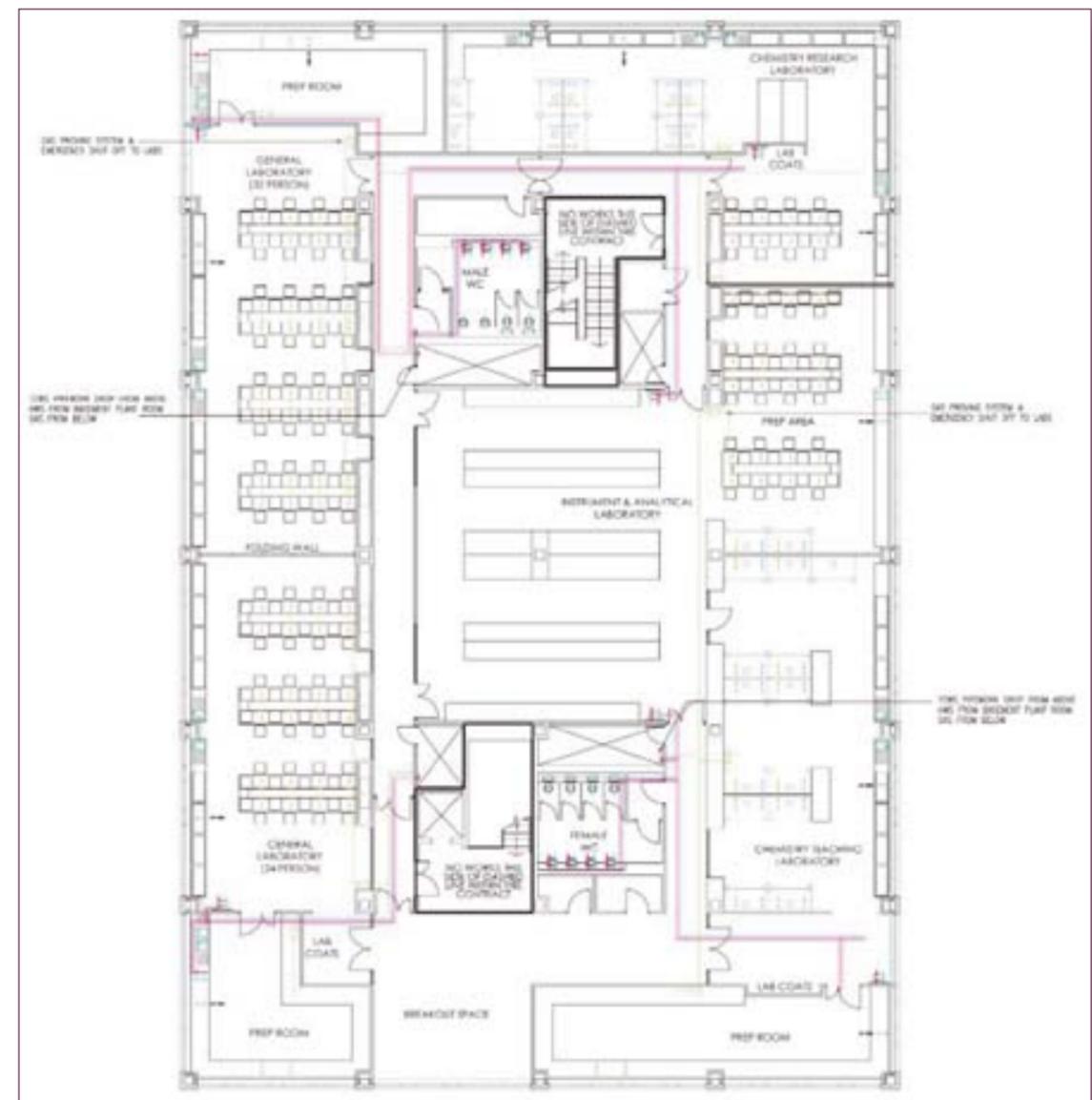
Appendix 1: Value Management diagram



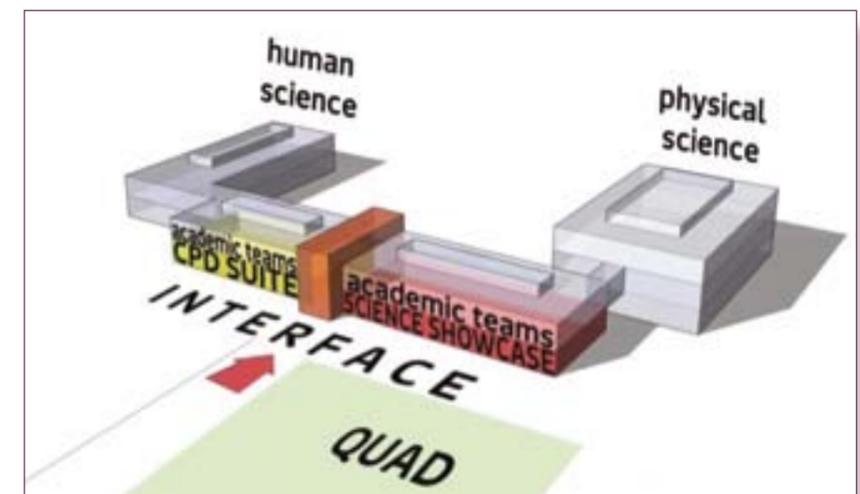
Appendix 2: Relationship diagram



Appendix 3: Floor layout



Appendix 4: Building strategy



Synopses of current practice

Empowering learning in electrical machines

Cardiff University

Daphne M. O'Doherty (odohertydm@cardiff.ac.uk) and Huw Griffiths

Electrical Machines is an integral part of Power Engineering within the Electrical and Electronic Degree programmes. The teaching approach at Cardiff University has an integrated approach to laboratories and as such the labs are part of the taught second year module on Power Engineering 2. In previous years this module has offered five laboratories but, due to time constraints and the antiquated facilities that were available, it was not possible for all the students to undertake all of the activities. This meant that the learning experience for the students varied significantly, with some students only having practical experience of direct current (DC) machines with others only experiencing induction machines.

A review of the curriculum and teaching strategy was undertaken which reinforced the ethos that students should be undertaking labs as part of their learning experience in this module. In addition, it was decided that the students should undertake all of the lab activities in a modern learning environment and should all have experience of DC, synchronous and induction machines. The laboratory space was therefore totally refurbished to provide room for both teaching and research within the room, allowing undergraduate students to observe current research in the field of power electronics. This has the advantage that, in future, students undertaking their final year project will already be familiar with the research facilities in this area. The room has been fully equipped with up-to-date lighting, wiring and audio-visual facilities, as well as new teaching equipment, including modern measurement

systems and a PC on each workbench to allow for data capture and expansion of the curriculum to include the study of dynamic machine effects such as start-up transients.

In particular, new equipment was purchased from Terco. Not only did this allow the possibility of interoperability and the purchase of further modules to enhance the lab at a future date, but significantly the equipment was large scale, with 1-2 kW machines providing a lab environment that was more relevant to the industrial scenario. The new facilities and the combined use of the room for both teaching and research work very well; to such an extent that it has been possible to reduce the time scheduled for each activity and as such allow all students to undertake the same lab activities without increasing the student contact time.

Since this is the first year that students have used the new facilities, it is too early to make an informed judgement on the success of these changes. However, providing the same teaching and learning opportunity for the students is very important and as such these changes should be beneficial to them.

Use of laboratories in postgraduate teaching of Civil Engineers Coventry University

Eoin Coakley (aa7113@coventry.ac.uk)

Here at Coventry University, we believe the importance of laboratory work in the delivery of content for engineering subjects cannot be underestimated and a substantial amount of time within our courses is devoted to laboratory and practical sessions. We consider laboratory work as an ideal means of implementing research-informed learning and this is particularly true at postgraduate level. Developing a research ethos through our courses and teaching students to be more enquiring is seen as vital in preparing them for the demands they will face in their careers.

Our MSc modules in Civil Engineering and Civil and Structural Engineering are taught in week-long blocks (with typically two to three weeks off between modules for coursework and exam preparation). This delivery format does not lend itself to a traditional lab rota so, to include laboratory-based research at MSc level, a module entirely devoted to laboratory work was established. For one week students are immersed in practical lab testing and the module assessment requires the students to write short reports on a number of the experiments carried out.

The intended learning outcomes of the module are as follows:

- Carry out a range of laboratory testing procedures to a high standard of effectiveness

- Demonstrate an understanding of the relevance and theoretical basis of those procedures
- Critically evaluate the capabilities of different types of test apparatus and methodology
- Demonstrate advanced skills in analysis and evaluation of laboratory results
- Produce reports with a high level of clarity presenting the analysis and critical evaluation of laboratory results.

The majority of the contact time for the module is devoted to carrying out the experiments and staff are on hand to offer appropriate advice as necessary. For a given experiment, students are provided with a material sample and asked to determine relevant material properties. They are given advice on how to use the test apparatus etc., but are not given information on what specific measurements they should record. The onus is on the student to research how to establish the relevant properties beforehand.

The module provides the students with an excellent opportunity to gain “hands-on” experience with a large variety of lab apparatus and the experiments typically carried out cover testing on a broad range of civil engineering materials. As part of the experiment write-ups, students are asked to discuss the accuracy of their results and potential sources of error. Students are given guidance on how to assess the accuracy of their results and encouraged to question the reliability of

“The module provides the students with an excellent opportunity to gain “hands-on” experience with a large variety of lab apparatus ...”

each of their individual measurements, citing possible reasons for inaccuracy and how these inaccuracies might be minimised.

Student reports must include a full analysis of results from raw data measured to final material properties and they receive guidance on appropriate presentation of calculations and results. They are asked to compare their findings to those from the literature so that they gain experience in carrying out literature reviews and they must provide a valid justification for any discrepancies observed. They are also asked to put the results into context and discuss the applicability of such results within the construction industry.

The level of analysis and critical thinking expected in the reports is certainly at postgraduate level and the module aims to develop research skills with a view to students potentially continuing their education through research. In fact, quite a few lab-based MSc dissertations have developed from experimental work carried out within this module and the enhanced research skills of these students has been apparent.

Early introduction to practical activity to advance course assimilation Coventry University

Paul Green (cex389@coventry.ac.uk)

Overview of initiative

The Faculty of Engineering and Computing at Coventry University is currently operating a number of curriculum development exercises to improve the student experience. These are primarily targeted at improving student engagement and completion as well as improving employability skills.

Within these initiatives, a new six-week course-based introduction period was timetabled comprising an intensive period of activity led learning. This establishes an activity as the focal point of the learning experience and the tutor acts as a facilitator. This exercise additionally aimed to provide rapid introduction and assimilation to the area of study and across its areas of practical activity.

Following a general induction week, students embarked on the six-week course-based induction period. Within this, 100 students were divided into six groups. Six activity based exercises, mainly extracted from the ‘Engineering Application’ requirements of the course, were set up and undertaken in rotation by the students over the six-week period. The six exercises focused on Design and Build, Metrology, CAD Modelling, Materials Testing, Reverse Engineering and Product Marketing. A 16-strong mixed discipline team of academics, development officers, technicians and interns facilitated and assessed the exercise. Each activity was timetabled for 18 hours across the five-day week and nominally

contained two or three hours of keynote instruction, 14 or 15 hours of supervised activity and one hour of assessment. Students were given their mark and feedback before departing for the weekend.

Following the six-week period, students completed a survey in which 74% indicated that they would like to see more of this type of activity. In a follow-up survey of employability skills in 2012, the student cohort identified the development of responsibility, planning and information literacy as continuing positive outcomes from the six-week exercise.

The use of authentic activity and enculturation in undergraduate aerospace teaching at Coventry University

Alex Harrison (alex.harrison@coventry.ac.uk) and Charlotte Jones (aa8764@coventry.ac.uk)

Overview of initiative

The aim of Activity-Led Learning (ALL) at Coventry University is to improve student engagement and retention and prepare students for the world of work (Wilson-Medhurst et al., 2008). ALL is a pedagogic approach that incorporates problem-based learning into real world applications and has been successfully incorporated within other institutions such as Massachusetts Institute of Technology (MIT, 2012). The problem-based learning approach to educating engineers has also been reviewed in a report by Teaching and Research in Engineering in Europe (TREE, 2007).

In addition to the problem-based learning approach, the Aerospace Department adopts learning design philosophies that are deliberately focused such that students are subjected to an enculturation (Brown et al., 1989) into the environment and community of aircraft engineering.

The stage one aerospace students undertaking the 'Aircraft Principles and Practice' module encounter only a minimum of formally taught theoretical elements, with the majority of the learning taking place as guided, self-discovery learning events, including laboratory activity sessions. The activities are arranged such that the complexity of tasks and the level of required understanding are increased as the students' progress. Activities are undertaken in groups and delivered by staff with extensive industrial experience, which in turn aids the acquisition of new understanding within the formation of communities of practice (Wenger, 1998).

The module revolves mainly around six authentic laboratory activities which are based on realistic scenarios and practices encountered within the industry. Four are undertaken on real aircraft assets and the remainder on the aerospace department's simulator suite. These are used to reinforce theoretical content.

The effectiveness of this initiative has been verified by previous years' module statistics. The pass rates for the past two years have been above the university target of 85% for stage one students and the average module mark has been above 60%. These statistical data reinforce comments and feedback on the module from students, who rate the module highly for staff teaching and comment that the content is stimulating and engaging.

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“Activities are undertaken in groups and delivered by staff with extensive industrial experience ...”

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The development of a remote laboratory for distance learning at Loughborough University

Richard Blanchard (R.E.Blanchard@lboro.ac.uk) and Sheryl Williams

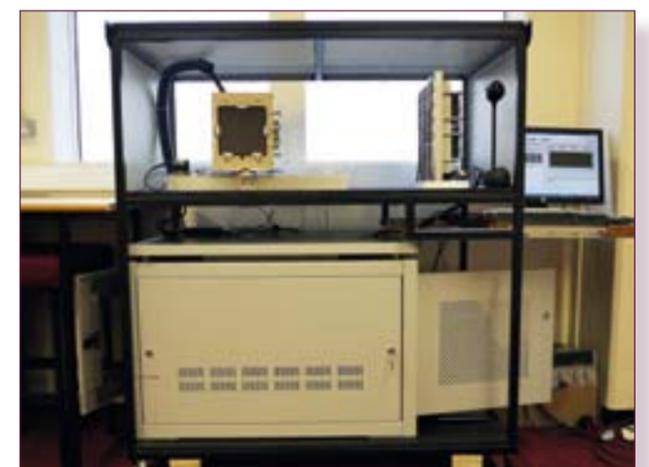
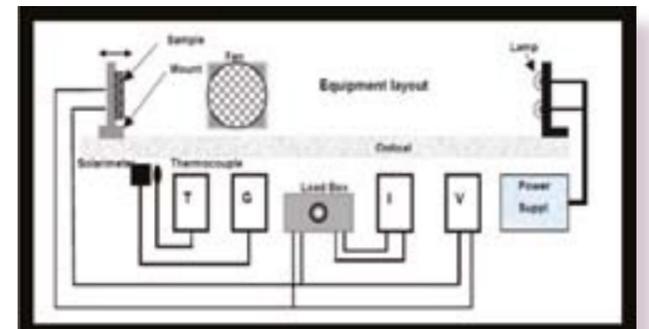
Overview of initiative

In 2002 a distance learning version of the Master of Science in Renewable Energy Systems Technology was developed, based upon the existing full-time version. A number of physical laboratories were converted to computer simulations for the distance learning programme. However, advances in internet communication services allow for the opportunity to control physical apparatus at distance. Therefore, a remote laboratory was developed for distance learning students based upon a physical laboratory used to investigate the energy conversion properties of photovoltaic (PV) panels. The purpose of the experiment is to investigate the effects of temperature and irradiance on PV panels using the characteristic measurement called the IV curve. The schematic shows the physical apparatus.

In developing the remote laboratory hardware, software and system integration was required. Additionally, a booking and login system was developed to facilitate student access. Students log onto the experiment through a virtual instrument developed in LabView. Through a webcam the students can see the experimental rig as shown in the photograph. Students can set and measure irradiance levels from a LED light source, control the temperature of the PV panels, change the PV panels on a turntable, take IV curve readings for the open and closed circuit parameters under investigation and download their results. Further work will be undertaken to evaluate the impact of the remote laboratory on student learning.

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Further reading

Providers of remote and virtual online practical activities for STEM subjects

A number of organisations and collaborative initiatives have created a range of remote and virtual laboratory activities, some of which are freely available and others of which are available to member institutions. A selection of these providers is listed below:

Center of Competence in Online Laboratories and Open Learning (CC(OL)²) <http://ext02.fh-kaernten.at/online-lab/> - conducts research with many other institutions and hosts conferences on online laboratories.

Centre for Research in Advanced Technologies for Education (CREATE) (<http://www2.amrita.edu/centers/create>) - an educational technology initiative pioneered by Amrita University in India.

Global Online Laboratory Consortium (GOLC) <http://online-lab.org/> - a membership organisation which promotes and shares research into remote laboratories for educational use.

International Hellenic University Virtual Lab (VLAB) project <http://rad.ihu.edu.gr/10/> - a number of virtual laboratory experiments on aspects of Information and Communication Technology and Energy Systems which have been released for free use.

Labshare Institute <http://www.labshare.edu.au/> - offers a range of services for the remote laboratory community.

Library of Labs (LiLa) <http://www.lila-project.org/> - an initiative of several universities and commercial enterprises for mutual exchange and access to remote and virtual laboratories.

Massachusetts Institute of Technology OpenCourseWare (OCW) <http://ocw.mit.edu/index.htm> - provides online access to course material.

Virtual Labs <http://www.vlab.co.in/> - an initiative of the Indian National Mission on Education through IT. It provides access to remote or virtual laboratories in science and engineering disciplines.

Conferences and publications on laboratory-based teaching and learning

S-Lab <http://www.goodcampus.org/s-lab/index.php>

International Journal of Online Engineering <http://www.online-journals.org/i-joe/>

Journal of Laboratory Chemical Education <http://www.sapub.org/journal/aimsandscope.aspx?journalid=1139>

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Appendices

Appendix 1

Student questionnaire

<p><i>What is your year of study?</i></p> <p><i>What course are you studying?</i></p>
<p><i>What do you value most about hands-on labs?</i></p>
<p><i>What do you value least about hands-on labs?</i></p>
<p><i>How could labs be enhanced?</i></p>
<p><i>What would be on your laboratory wish list?</i></p>
<p><i>How do you envisage IT advances impacting on lab design, lab teaching and learning in labs?</i></p>
<p><i>Other lab-related comments</i></p>

Appendix 2

Staff questionnaire

CEDE project COLL_B: Effective Laboratory Based Learning and Teaching Practice

Interview question checklist to staff at other HEIs

Name:

HEI/Department:

Background to Loughborough's project

The aim is to refurbish laboratories and integrate Chemistry into engineering buildings at Loughborough University.

Drivers: the need to relocate Chemistry within engineering buildings and the need to update laboratories.

Scope of the project: to ensure innovation in use and equipping of future laboratories for undergraduate teaching, with opportunities to enhance student laboratory experience.

Laboratories at your HEI

Background

- 1) What laboratories do you provide at your HEI/department?
- 2) Have you recently made changes in this provision at your HEI/department?

Developments and practice

- 3) What did you do? For example:
 - Refurbish laboratories?
 - Rebuild?
 - Merge departmental access to laboratories?
- 4) Did you implement or consider shared laboratory facilities?
 - If so, how successful was this?
 - What issues did you face (e.g. timetabling, equipment, budgets, internal politics, technical support)?

- 5) Did you implement or consider the use of virtual laboratories (e.g. computer simulations) to replace or augment practical lab sessions?
- 6) Did you implement or consider the use of remote laboratories?
- 7) Do you utilise online or recorded demonstrations of laboratory classes?
- 8) Do you employ drop-in laboratory sessions where students book a slot to perform a lab investigation or attend a scheduled lab demo etc?
- 9) Did you find that upgrading laboratory equipment and/or facilities led to changes in teaching practice (e.g. redesign of modules or teaching a subject differently)?
- 10) Are your teaching and research laboratories mixed or separate?
- 11. What consideration did you give to flexibility vs. functionality when purchasing new equipment? How did you choose suppliers?

Reflection

- 12) What do you think gives a laboratory the “wow” factor for students? What do you understand by “state of the art” laboratories?
- 13) To what extent did innovative IT developments influence your thinking or planning?
 - Did these considerations lead to changes in teaching practice?
- 14) Looking back, what were the main benefits and difficulties?
 - Were there any unexpected downsides or gains?
 - Do you have any advice for other institutions considering a lab refurbishment or new build project?
- 15) Do you have any future plans to implement changes in how laboratories are used in teaching or to improve facilities further?
- 16) Have you subsequently measured the effectiveness of your changes in relation to the use of laboratories in undergraduate teaching? Are you aware of any methodology for doing this?

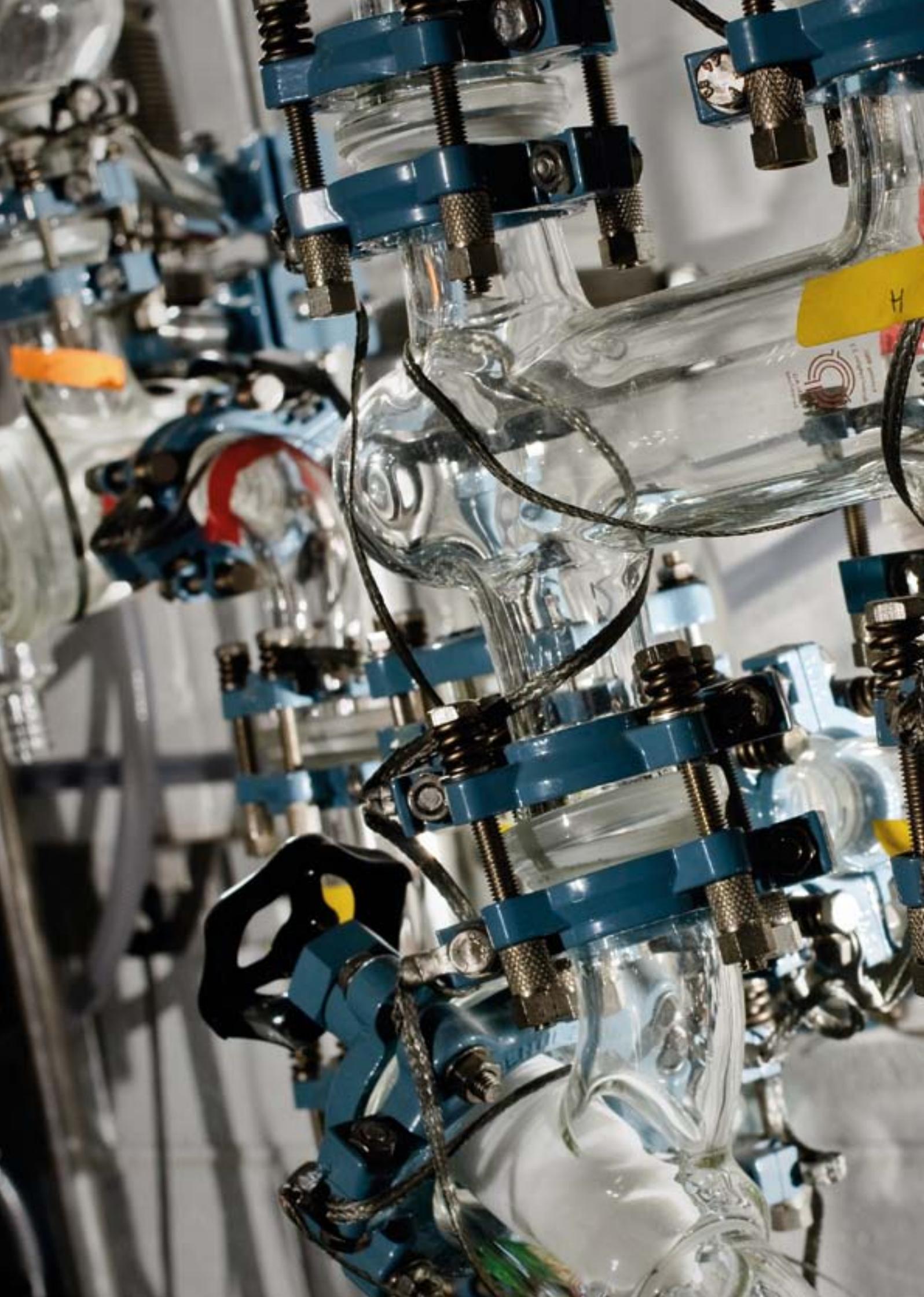
Going forward

- 17) CEDE expects to bid for external funding to produce the Compendium of Current Practice in STEM Labs in a published format, and to work with S-Labs at the University of Bradford on a joint printed publication.
 - Would you be interested in contributing a case study?
[A detailed template is provided and you would be acknowledged as the author, with CEDE as editor/publisher.]
- 18) Would you mind if we contacted you again as the project at CEDE evolves?

Contact details:

.....
.....
.....

Thank you for your time.



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Centre for Engineering and Design Education
1st Floor Keith Green Building
Loughborough University UK
LE11 3TU

Tel: +44 (0)1509 227191

<http://cede.lboro.ac.uk/>

