Improving learning outcomes and sustainability through new laboratory infrastructure

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Abstract: *A set of advanced networking laboratory rooms have been designed and built as part of Swinburne University of Technology's new Advanced Technology Centre (ATC) to facilitate the learning of both fundamental and advanced networking concepts and to ensure that students attain conceptual, design, professional and social skills. The main aim is to give students a more realistic network experience, which is achieved through increased access to equipment, and increased flexibility in how equipment can be utilised. This facility allows students to dynamically connect various computers within the room to different physical networking devices through the use of virtual networks. Multiple devices can be interconnected, both within and between enclosures. Overall power consumption is reduced through the use of managed power cycling and end-host virtualization. This paper outlines the physical, logical and teaching rationale behind the design and construction of the laboratory environment. We discuss the use of virtualisation to establish multiple hosts per kit of equipment and its implications on sustainability.*

Introduction

It is generally accepted by the engineering community that practical/laboratory work is an essential component of engineering education. The value of the practical component lies in connecting theory with the real world, as well as developing skills that are necessary in the engineering profession. The importance of laboratory work has also been highlighted by recommendation 3 in King's report to the Australian Council of Engineering Deans (King, October 2008).

> ***Recommendation 3: implement best-practice engineering education***
> *Proposed Actions: "increase the authenticity of laboratory work and integrating more industry on-site experiences into courses"*
> And
> *"the general quality of engineering laboratories also gives considerable cause for concern: many have outdated and unreliable equipment, and declining numbers of technical staff to maintain them to safe standards."*

In addressing these points, Swinburne University of Technology has designed and commissioned two advanced networking laboratories in the new Advanced Technology Centre and this paper describes the process and rationale. The first section provides background information on the advantages and disadvantages of different laboratory types and their effectiveness; followed by a description of the features of the advanced networking laboratories which take into account the outcomes of the first section; the laboratory innovations introduced in the laboratories, such as improved sustainability, are outlined; this is then followed by a summary of the student and staff experiences and conclusions.

Laboratory Types

In the engineering teaching discipline three broad categories of laboratories are typically deployed. These are the traditional real laboratory, simulated laboratory and remote laboratory. The real laboratory is a physical room where both the user and equipment interact in the same time and space. In simulated laboratories, real equipment is replaced by computers running specific software, thus avoiding the need for dedicated equipment, and possibly saving laboratory space by using a multi-purpose computer room. Remote laboratories are characterized by 'mediated reality', where the students are not physically present in the same space as the physical equipment.

Laboratory Type Effectiveness

As educators, we are interested in the debate around the educational effectiveness of the different types of laboratories as well as the sustainability of implementing each type of laboratory. Anecdotally, there seems to be an increased trend in the use of simulated and remote laboratories as opposed to the real laboratory which is under pressure from factors such as staffing, funding, cost, and timetable management (Magin & Kanapathillai, 2000) and (Klimovski, Cricenti, & Jones, 2010).

Ma and Nickerson (2006) addressed the educational effectiveness debate in 2006 by reviewing the literature and drawing a number of conclusions. They found that much of the literature concentrated on engineering laboratories, which they attribute to factors such as *"engineering is an applied science, and the labs are a place to practice the application of scientific concepts"* and that *"educators in the engineering disciplines may be more likely to have the technical skills needed to create technology-enriched labs"*. These findings confirm that scholarship around the engineering field identifies laboratories as an invaluable tool in teaching engineering. Ma and Nickerson (2006) also observed that the advocates and detractors for each laboratory type may not use the same educational objectives when measuring the effectiveness of the different laboratory types, this must be kept in mind when considering laboratory alternatives.

An important argument raised by advocates of the real laboratory is that students are confronted with the need to explain possible mismatches between theory and experimental results. This implies that there is value in equipment malfunction and student mistakes, as the students develop skills that are not just related to the concepts which are the subject of the experiment. It is argued that without these 'unexpected clashes' students are more likely to believe that engineering knowledge is not gained through experimentation (Magin & Kanapathillai, 2000). We believe that learning through mistakes is a vital part of developing student skills and that the real laboratory facilitates this experience.

Advocates of simulated laboratories claim that the time taken to learn is reduced, and that simulation is at least as effective as the traditional laboratory (Shin, Yoon, Lee, & Lee, 2002). Another advantage of simulated laboratories is that *"students using a simulator are able to 'stop the world' and 'step outside' of the simulated process to review and understand it better"* (Parush, Hamm, & Shtub, 2002). In contrast, Magin and Kanapathillai (2000) claim that excessive exposure to simulation can result in students not being able to differentiate between the real and virtual worlds. We believe that simulated laboratories should augment or complement real laboratories, as there are specific circumstances in which real laboratory experiments are impractical due to their scale or hazardous nature. In addition simulated laboratories are flexible in terms of the experiments that can be conducted.

The main advantage of remote laboratories is the provision of convenient access for students who are studying in distance mode or part-time, or students who feel the need to perform experiments outside of class time. This type of laboratory may save physical space, increase timetabling flexibility, and also provide a better return on infrastructure investment as its use is not restricted to class time.

Simulated laboratories are arguably the most sustainable. Some of the advantages over real laboratories are: they require few consumable resources; no dedicated space; no waste products; lower power consumption due to the absence of the real equipment, and potentially lower lighting and heating/cooling needs. Remote laboratories also have the advantage of requiring less physical space. Both simulated and remote laboratories may save on travel as physical presence at University is not required. A major advantage of these laboratory types is that they can be shared across different educational institutions (Labshare, 2011). Some of the disadvantages are: license fees, administration and maintenance costs and the training costs of staff using the software.

Ma and Nickerson (2006) develop and present a 'four-dimensional goal' model for laboratory education based on the educational goals proposed by the Accreditation Board for Engineering and

Technology (ABET) (see figure 1). This model is used to evaluate competing laboratory types against the differing objectives used in terms of delivering the four key criteria. These results show that advocates of real laboratories believe that alternative laboratory types are not as effective in teaching design skills.

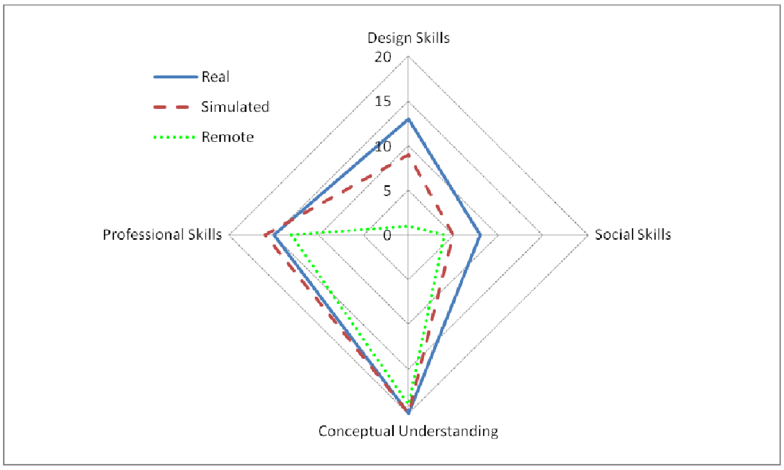

Figure 1 Educational Goals. From Ma & Nickerson (2006)

Laboratory of the Future

If we accept the argument that traditional laboratories maximize outcomes in teaching design skills, then resource allocation permitting, the real laboratory cannot be dispensed with. Whilst remote and simulated laboratories can alleviate some of the pressures on real laboratories, we believe they cannot replace them totally. We have observed that physical contact with the laboratory equipment improves skills such as troubleshooting, connecting components and familiarity with the real equipment.

Sustainability can be viewed from many angles with regards to engineering laboratories, the most obvious of which is power consumption. Other perspectives include maximising usage both in terms of student numbers and equipment availability, and minimising costs and resource usage. Virtualisation of ancillary equipment that does not play a key role in the experiment can improve both the sustainability and costs of real laboratories, with minimal impact on the educational benefits.

Given that there is still ongoing debate regarding the educational benefits of all three laboratory types, it is wise to accept the notion of a laboratory that encompasses flexibility in what can be designed, is able to be remotely accessed, and that encourages interactions between students and instructors, whilst keeping sustainability and low costs in mind.

Swinburne Advanced Networking Laboratories

Two advanced networking laboratories have been designed and commissioned as part of Swinburne University's new Advanced Technology Centre to facilitate the learning of both fundamental and advanced networking concepts. Each laboratory is fitted out with five enclosures which house the networking equipment. This saves time in the setup and tear down of laboratory exercises, as well as allowing remote access to equipment. The learning environment was further enhanced by having at least one wall of whiteboards where students can interact and discuss concepts/designs.

Enclosures and Equipment

For each laboratory, networking equipment is secured within five separate colour coded enclosures. Each desktop computer is associated with two enclosures as highlighted in figure 2. This allows for redundancy and flexibility in network design. Each enclosure (figure 3a) contains:

- Five kits of equipment, each containing four routers and four switches. Each kit is colour coded with different coloured cabling to allow for easy identification (see figure 3b).
- A console server which provides connection to the console port of each device.
- Smart powerboards which are used to automatically power the devices on and off.

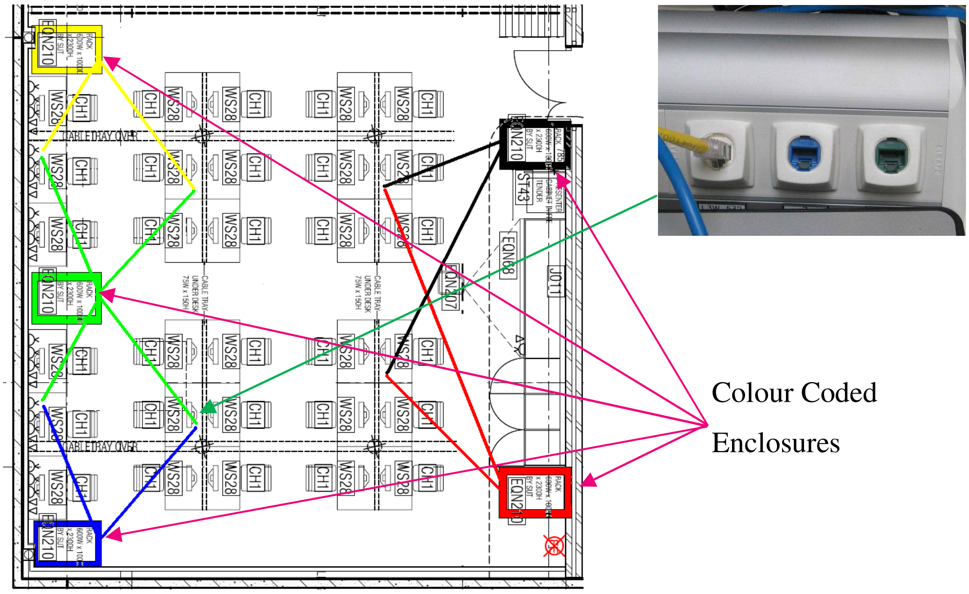

Figure 2 Laboratory Floor Plan and associated desktop connectors

- A patch panel which allows connection from the desktop computer's Ethernet port to the kit.
- An Ethernet switch which connects each device to a different Virtual Local Area Network (VLAN) connection. The VLANs are trunked to the PC-based server for further distribution over a Virtual Area Network (VAN) to individual end hosts.
- A PC-based server (see figure 3b) that manages access to the devices via the console server, and also controls the smart powerboards.

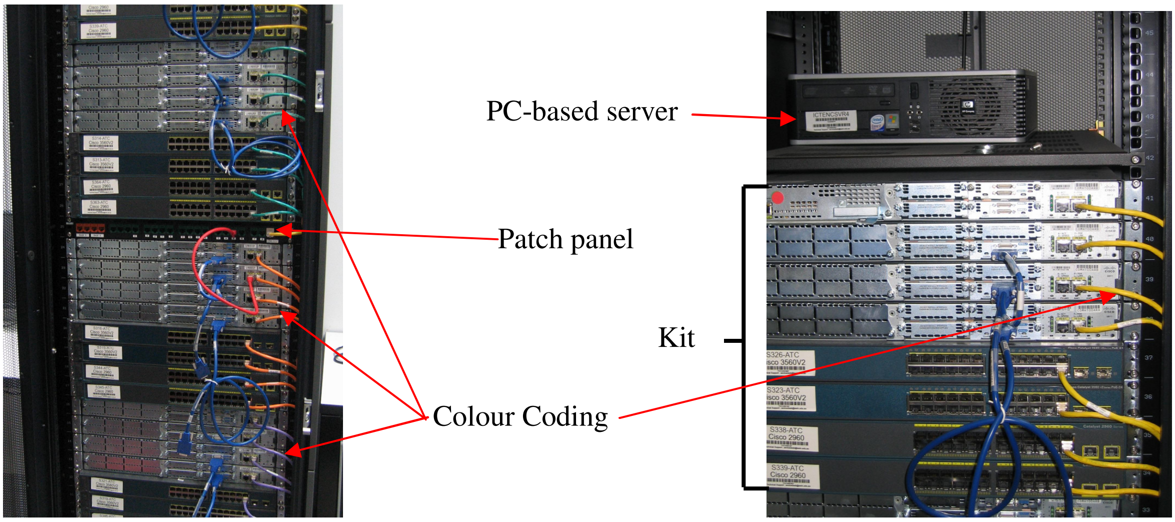

Figure 3a Enclosure **Figure 3b A kit & PC-based server**

Each enclosure is connected to the other enclosures in a daisy chain fashion, which increases access to the number of devices (100 routers and 100 switches) and allows for the construction of larger networks. Multiple devices can be interconnected, both within and between enclosures. All aspects of the equipment management become remotely accessible such that students can access, configure, and power the devices on and off from within the University or remotely.

Laboratory Innovations

In order to realise increased flexibility and sustainability in the new laboratory environment, we have developed a number of innovative techniques. These include extensive use of virtual computing, secure access, and a unique virtual area network that allows for virtual connections between various networked devices. These innovations are discussed in more detail below.

Secure Access

In order to communicate with each device, access to the console port is required. Traditionally students would patch cables from these console ports to the serial port on their desktop computer. This approach causes a number of real and potential problems. Real problems arise where students connect/configure the wrong device, particularly if this device is being used by another person. Potential problems arise if a student wants to display all console connections at the same time due to the limitation of the number of serial port connections on the desktop. These problems are alleviated by the use of a PC-based server in conjunction with a console server.

Access to the console ports of the routers and switches is now achieved via a ***ssh*** connection to the server controlling the enclosure, thus allowing a student to concurrently configure multiple devices in separate sessions. A unique username is assigned to each device, and a random password is generated for each reserved session by an individual student. This information is available via the website managing the laboratory room, so students are not required to enter either the username or password to access console ports. The server will forward all input/output from the ***ssh*** session to the corresponding device via the attached console server, therefore students can't "accidentally" connect to another students device. Access to device console ports is automatically terminated once a reserved session is complete, which is particularly useful under exam conditions.

Virtual Area Network (VAN)

With an aim to increase flexibility, sustainability and to make better use of the Virtual Computing infrastructure, we have developed a technique which we call the VAN. This involves building a series of virtual shared Ethernet networks over the top of the existing networking infrastructure, and then virtually connecting different network devices and virtual computers (VCs) to these VANs.

One Ethernet port on each router and switch is connected to a separate VLAN on a switch contained within each enclosure, all of these VLANs are then trunked to the PC-based server managing that enclosure. This server can access the corresponding Ethernet ports on these devices and is responsible for bridging real Ethernet packets over the VAN environment to the VCs on the desktop computers.

The VAN itself is implemented using IP Multicast with a unique Multicast session allocated to each VAN. The corresponding packets are multicast over the existing network infrastructure which has been deployed to provide Internet access. Any computer in the laboratory can join a particular Multicast session to communicate with other computers connected to the same VAN. The Ethernet frames are de-encapsulated from the Multicast packets and passed to the corresponding desktop's VC.

The PC-based server knows which devices have been allocated to which students; it also knows which VANs should be accessible to those students. We have developed separate software which queries the server to provide a list of the available VANs, allowing students to connect virtually to the nominated Ethernet port on a selected device to which they currently have access. This selection is dynamic, and students can move their connection to a different VAN in real-time, essentially simulating the real environment whereby an Ethernet cable can be moved between devices at any time. We can bridge multiple VAN networks to the same computer, allowing for multiple concurrent VCs to be launched on the same computer, thus reducing the need for additional physical computers.

Virtual Computing

The use of Virtual Computing has increased with the introduction of more powerful computers. Before the VAN, we could run multiple VCs on each desktop by adding more network cards to the physical computer. However, we can now deploy computers with two network cards and run multiple VCs whereby one VC is connected via the physical Ethernet media while one or more VCs are connected via the VAN using Multicast packets over the primary network connection.

In a simple deployment (one VC using Ethernet and one VC using the VAN), we have effectively doubled the number of computers available to students with minimal increases in both power, space and physical infrastructure costs. In this new environment students have more opportunity to build larger and more complex networks, using more end devices than previously possible in a similar sized laboratory environment, thereby improving sustainability.

Student and Staff Experiences

The new laboratory has been operational for a little over 5 months and as yet we have not had the opportunity to fully evaluate its impact on student performance. Staff have observed that in the new laboratory the students waste less time setting up the weekly exercises, individually spend more time configuring and troubleshooting, and that their social interactions with each other and staff are more frequent and at a higher professional level. This is in contrast to the previous laboratory where sharing of equipment often resulted in some students monopolising equipment and others not participating.

Unsolicited feedback from the students using the new facilities as to the benefits they see are:

- *"reduced set up time enables me to do more in the labs and try new things"*
- *"having multiple windows so that I can see my connection to each device has helped me to understand the difference between the console cable and the data cable"*
- *"the flexibility to come in out of class times has allowed me to consolidate knowledge"*
- *“its great that the equipment isn’t locked up and we can use it all the time”*
- *"having a set of equipment to myself allows me to learn at my own pace and how to configure the whole network and not just bits of it"*
- *"I like to learn through my mistakes and having a kit lets me to do that without affecting others"*

From these - and similar - comments, we infer that students have recognised the greater value in the increased “hands-on” time, the increased flexibility and availability of the equipment in the new laboratory, and the enhanced opportunity for self-paced learning.

Conclusion

A set of advanced networking laboratories have been built to ensure that students attain conceptual, design, professional and social skills by enabling the laboratory to encompass flexibility in what can be designed, is remotely accessible, and encourages interactions between students and instructors, whilst keeping sustainability and costs in mind. Implementation of innovative techniques has allowed for increased flexibility without a significant increase in resource consumption or a reduction of educational outcomes.

A major outcome of these new laboratories is that students have a more realistic experience by allocating a kit of equipment to each student. In this new environment students have a greater opportunity to build larger, more complex networks, using more virtual end devices than previously possible in a similar laboratory environment. By maintaining laboratory class sizes, and investing heavily in equipment and infrastructure we have increased the opportunity for student learning.

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