Remote Laboratories and Reusable Learning Objects in a Distance Learning Context

Abstract

This paper is an investigation into the use of virtualisation techniques and remote laboratory facilitation for networking, systems, forensic and security-based modules with specialist computing lab resources within the Computing and Technology Pathways, allowing students to study elements of those modules in a distance learning context. The research explores the benefits of bringing a cloud computing approach to use of specialist lab resources, where students are able to use virtual machines so that a student's computing resources can be accessed from anywhere and can be considered as truly portable.

Keywords

virtualisation, remote, virtual, laboratory, Web.

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1. Background

Building on the success of work carried out with Peterborough Regional College (PRC) on remotely
delivering Computer Network Principles (EJ23001S) on a distance learning basis, the primary aim of this
research is to develop further the use of virtualisation (as explained below) techniques and remote
laboratory platforms for modules within the Computer Science pathway, allowing students to study
elements of those modules in a distance learning context.

The lessons learnt from the PRC experiment suggest that where properly supported and maintained,
students are not averse to using non-conventional learning methods (especially where students can do
laboratory type work at a time and place of their own choosing). Two of the areas that need to be
researched carefully are the support and reliability issues, which as the experiment with PRC showed
cause the greatest problems.

2. Aims and Objectives

- To research and develop a software solution for one or more modules within the Computing &
Technology portfolio of modules, with significant specialist lab computing requirements to deliver
an alternative distance learning solution.
- To trial a minimum of two differing software solutions in modules (including the solution above)
requiring significant traditional computing laboratory resources to analyse the effectiveness of such
solutions alongside the traditional delivery.

2.1 Longer Term Aims

- Long term goal of developing a part time distance learning BSc Computer Science, as well as
leading a contribution to developing distance learning aspects for master’s and foundation degrees.
- Potential to use this type of technology wherever specialist laboratory computing resources might
alternatively be replaced with a virtualisation solution (see Section 5.3) that students can install on
a reasonable laptop or desktop computer system.

3. Virtualisation

The concept of virtualisation embraces a lot of various areas of IT – virtual machines and server,
application, desktop, data, database and network virtualisation (Fisher & Thacher, 2009). Importantly, what
actually makes this technology so portable is the concept behind it: to create abstract computer resources
which are only virtual software versions of something rather than really existent (Michocka &
Shwartsman, 2008).

To be more specific – ‘virtualization enables one server or computer to act as many’ (Chu, 2008). ‘Instead
of keeping your important programs on separate servers so that if one application or server fails, the other
applications aren’t affected, virtualization software lets you run many applications on the same
server’ (Robb, 2008).

A further explanation is given by J. Borck (2002) in his article ‘Virtual virtuosity’, where he says that
‘virtualization or virtual machine technology is a partitioning technique and introduces a software layer that
effectively enables multiple, independent operating environments to make use of a single set of static
resources’. An important concept to note is that of the virtual machine (VM), where an installed operating
system believes that it is running on actual hardware.

Virtualisation has been successfully used to teach a wide range of IT disciplines, such as:

- Servers and desktop OS’s
- Distributed Application Development
- Databases
- Networks

Fisher & Thacher (2009)
3.1 Virtualisation Models
A traditional computer architecture has an operating system installed on top of a hardware platform (as shown in Figure 1.), with applications installed on top of the operating system. Within a virtualised system, the hardware layer is emulated, and an operating system is built upon that virtual hardware and applications on top of the operating system. In such a way, it is possible for one system to run many different virtual systems, as shown in Figure 2.

![Figure 1. Traditional Computer Model vs Virtualised Architecture (VMWare, 2010)](image1)

![Figure 2. Hardware Emulation and Multiple VM's (VMWare, 2010)](image2)

4. Relevance to the Student Experience and Learning and Teaching Strategy
There are changing demographics in these financially troubled times where more ‘home’-based students will opt to travel to their nearest university (up to 60 miles is not unknown) to be able to embark on a higher education course. For those students undertaking technology-based courses such as engineering or computing, this inevitably means that there is much more of a burden to attend laboratory-based classes in addition to conventional lectures (which all students attend), both in terms of the travel required and the extra carbon footprint/travel costs involved.

From a widening participation standpoint, technology-based courses have not always been candidates for adoption or for delivering in a distance learning context for traditional face-to-face teaching universities. Part-time students, those with additional needs, care commitments or from non-traditional university backgrounds will have greater opportunity to engage at times convenient to themselves whilst being able to maintain their other needs crucial to effectively balancing their lives.

5. What Constitutes a Remote or Virtual Laboratory?
5.1 Remote/Distance Laboratory
According to the *Oxford Dictionary* the definition for a laboratory is ‘a room or building for scientific experiments, research, or teaching, or for the manufacture of drugs or chemicals’. For Computer Science
students, these facilities need equipment like networked computers, routers, switches and specific software applications so that the teaching process can be as productive, fruitful and realistic as possible (Machotka, Nedic & Gol, 2007).

The use of a physical computer lab until recently was the only way to apply in practice the theoretical knowledge gained in the classroom. This, however, causes limitations such as time and space restrictions, supervision, high costs for maintenance and scheduling for the use of the resources (Nedic, Machotka & Nafalski, 2003). All of these can be avoided with the implementation of a distance laboratory solution, which is a system that provides ‘efficient user operations, machine and platform independence, secure operations, graphical user interface capabilities, high processing bandwidth, and low cost maintenance’ (Steidley & Backnak, 2005).

Interestingly, according to Border (2007) there is not a significant difference in the study process between users who learn through onsite experience and those using distance laboratories since ‘the Internet has enabled conducting of real experiments at any time at any location’ (Machotka, Nedi & Gol, 2007). Additional research has revealed that there is ambiguity over what constitutes a remote laboratory. In different studies it has been referred to as a web lab (Ross et al., 1997), virtual lab (Ko, 2000) and distributed learning lab (Winer, 2000). Despite the confusion, after analysing the different types of laboratories, Ma and Nickerson (2006) concluded that the uniting factor between all variations of these systems is that they ‘are characterized by mediated reality’ and ‘experimenters obtain data by controlling geographically detached equipment’.

5.2 Virtual Laboratory

According to Wiseman, Wong, Wolf and Gorinsky (2008), a virtual laboratory is a ‘facility where students can access real laboratory equipment remotely’. However, new technologies have furthered the above statement and have enabled the manipulation not only of real-world equipment but of its virtualised analogies as well, which gives a more specialised meaning of the term ‘virtual lab’. Leitner and Cane (2005) support it by saying that ‘any local computer hosting a simulation’ is considered a virtual lab. They elaborate even further and use the term to describe a computational grid, used for solving computational problems with geographically distant resources.

5.3 Benefits of Using Virtual Labs

<table>
<thead>
<tr>
<th>Laboratory Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real</td>
<td>realistic data, interaction with real equipment, collaborative work</td>
<td>time and place restrictions, expensive supervision required requires scheduling</td>
</tr>
<tr>
<td>Virtual</td>
<td>good for concept explanation, no time and place restrictions, interactive medium, low cost</td>
<td>idealised data, lack of collaboration, no interaction with real equipment</td>
</tr>
<tr>
<td>Remote</td>
<td>interaction with real equipment, calibration</td>
<td>only ‘virtual presence’ in the lab</td>
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</table>

Table 1. Comparative List of Advantages and Disadvantages of Real, Virtual, Remote Laboratories (Nedic, Machotka & Nafalski, 2003)
From Table 1, the comparison of advantages and disadvantages of different types of laboratories by Nedic, Machotka and Nafalski (2003), it can be determined that the virtual laboratory is a worthwhile solution because of its interactivity and high availability. Previous research at the Rochester Institute of Technology (Lawson & Stackpole, 2006), using student satisfaction surveys on virtual labs, found that where students were using a virtual lab solution, they achieved 8% better scores on average than those students learning the traditional way.

5.4 Selection of Research Platforms

From the broad investigations carried out, the remote virtual lab can teach students to use a wide range of operating systems and applications to observe/monitor network traffic and to configure various computing scenarios without necessarily being on campus. However, as any developing technology, there are many obstacles that need to be solved, such as high cost, standardisation and implementation effort, but as every service worth having they would be overcome because of the high demand and advancement of virtualisation.

A summary of the solutions investigated is shown in Table 2 and two solutions were selected for use with the study. Netlab was selected, as it was already in use and could easily be expanded for certain modules and deployment for students. Compared to the other five solutions, Virtual Computing Laboratory (VCL) was selected in terms of flexibility, scalability and the broad range of uses it can be put into. It is designed to run on a large number of platforms, from blade-servers to lab computers, and to make use of almost all virtualisation technologies available, which makes it unique compared to the other five. In addition, it is the only one which has been put into such an extensive employment.

<table>
<thead>
<tr>
<th>Virtual Remote Laboratory</th>
<th>Flexibility and Scalability</th>
<th>Price</th>
<th>Implementation Effort</th>
<th>Student Satisfaction and Achievements</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLabNet (Powell, 2007)</td>
<td>Flexible and scalable</td>
<td>Relatively cheap</td>
<td>Significant difficulties</td>
<td>High satisfaction and practical experience in particular subject</td>
</tr>
<tr>
<td>RLES (Border, 2007)</td>
<td>Flexible and scalable</td>
<td>Affordable</td>
<td>Manageable</td>
<td>Satisfaction and practical experience in particular subject</td>
</tr>
<tr>
<td>NetLab</td>
<td>Depends on funds</td>
<td>Expensive</td>
<td>Easy (external implementers)</td>
<td>High satisfaction and practical achievements in particular subject</td>
</tr>
<tr>
<td>Wisconsin-Whitewater (Villanueva &amp; Cook, 2005)</td>
<td>Flexible and scalable</td>
<td>Cheap</td>
<td>Easy</td>
<td>Satisfaction and practical achievements in particular subject</td>
</tr>
<tr>
<td>Techlabs (Correia &amp; Watson, 2007)</td>
<td>Flexible and scalable</td>
<td>Affordable cost</td>
<td>Difficult</td>
<td>High satisfaction and invaluable recourse</td>
</tr>
<tr>
<td>VCL (Vouk, 2009)</td>
<td>Extremely flexible and scalable</td>
<td>Varies from expensive to really affordable</td>
<td>Manageable (experimental)</td>
<td>High satisfaction and broad scope of users</td>
</tr>
</tbody>
</table>

Table 2. Comparison between VCL and Other Similar Solutions
5.4.1 NetLab
This is a commercial product used widely as an educational tool for Cisco-related courses. NetLab allows lecturers and students alike to interact with real lab equipment (see Figure 3) located elsewhere through the Internet over a Graphical User Interface (GUI) written in Java (See Figure 4). Virtualisation is used to provide the equivalent of lab PCs to interact with the lab equipment. One of the real powers of Netlab is the scheduling ability of booking lab equipment 24/7 (as shown in Figure 5).

Figure 3. Netlab Architecture (Netlab, 2010)  Figure 4. NetLab Academy GUI (Winckles, 2010)

Figure 5. User Session Booking (Winckles, 2010)

5.4.2 Virtual Computing Lab
One of the major virtual lab solutions which has become more than just an 'in house' project is VCL – Virtual Computing Lab. Adopted by Apache as an incubator project and used extensively by its developers at North Carolina State University (NCSU), more than 60,000 virtual machine allocations per semester are utilised (Vouk, 2009). What makes VCL appealing is explained by Vouk (2009) in his paper devoted to the usage of VCL technology, where it is described as follows:

“Virtual Computing Laboratory (VCL) is an award-winning open source implementation of a secure production-level on-demand services-oriented technology for wide-area access to solutions based on real and virtualized resources, including computational, storage, networking and software resources.”

A further explanation of the concept of VCL can be found on the official VCL website, which says that:
“One of the primary goals of VCL is to deliver a dedicated computer environment to a user for a limited time through a web interface. This computer environment can range from something as simple as a virtual machine running productivity software to a machine room blade running high end software (i.e. a CAD, GIS, statistical package or an Enterprise level application) to a cluster of interconnected physical (bare metal) computer nodes.”

(Apache VCL, 2010)

Figure 6. Concept of VCL (Apache VCL, 2010)

As seen in Figure 6, VCL is a highly scalable open-source system that covers a wide range of technologies, which makes it easy for customisation for any particular needs.

6. Research Methodologies

To take the project forwards a number of different threads of research were to be undertaken:

- Prototyping Typical Virtual Lab Environment – customised to Anglia’s requirements
- Experimentation using Remote Lab solutions offering standard lab activities and assignments solutions
- Experimentation using virtualisation to offer diverging solutions to remote access issues
- Quantitative and qualitative analysis of three independent cohorts’ use of such technologies and their experiences.

These involved both established modules, external partners and research project students in several different categories.

- Three module cohorts to utilise Netlab and virtualisation
- EJ230001D – Computer Network Principles
- EJ330009S – Network Technologies
- EJ315013S – Network Management
- Prototype project to implement typical Virtual Lab Solution – VCL
- External cohort trialling Netlab for Cisco Certified Network Associate (CCNA) curriculum

Computer Network Principles and Network Technologies were used to road test the principle of the remote laboratory with active cohorts. Network Management was used to test the use of virtualisation techniques in both assignments and lab sessions.

7. Module Delivery Utilising Virtual Machines

There were several different approaches modelled in the EJ314008S Network Management module:

- Stand alone
- Networked VM's
- Hybrid VM and Real Equipment

For the stand alone solution, each student is allocated a sample template for a virtual machine to use (this could be a minimal Windows 7 or Windows XP installation or a blank template to install a dedicated operating system image). Generally, all that is required is the digital file (an ISO file format), which is used to ‘burn’ a CD/DVD. This could be a good starting point for modules like Computer Systems, where at present students learn to install operating systems direct onto an empty hard drive in a physical computer.

For Network Management and similar modules such as Computer Systems, Network Computer Systems, Databases Design and Administration and Web Server Engineering, where the interactions between computing components need to be explored (client server relationships, for example, such as a web client to a web server), it is possible using VM technology to have two independent installed virtual machine appliances running on a host computer (so there is no need to dedicate two physical hardware devices to demonstrate the concept). By using internal virtualisation technologies, such as network bridging/switching technology, two or more virtual machines can be networked together so that these interactions could be carried out as a scenario on a remote virtualisation server and accessed with some form of graphical user interface. Or by ‘bridging’ the virtual appliances together they could be used on a student’s own workstation/laptop (see Figure 7).

![Figure 7. ‘Bridging’ VM Connectivity (Winckles, 2010)](image-url)
Within technical modules like EJ315013S Network Management, additional scenarios might require the virtualising of complex integrated systems managing dedicated hardware (which in some cases might only be one system). A scenario for this might be to install these VM's on some form of remote access server, which can then give access to dedicated hardware (ref VCL vs Netlab and Figure 8).

Figure 8. External VM Connectivity (Winckles, 2010)

Another scenario is to try and use virtual appliances to remove all hardware restrictions whatsoever. For example, with networking hardware some Cisco Router software can be run on an open source virtualisation solution but this can have license implications (there is still a need to purchase operating system licenses) or use alternative open source appliances such as Vyatta to demonstrate the same sort of functionality.

8. Cohort Questionnaire Results

A total of 45 students were involved in the research, resulting in over 780 hours of online activity between them. A total of 20 students responded to the survey, with some very positive results (registering 84% and above in almost all responses) with some very useful feedback in some key areas to guide future development.
<table>
<thead>
<tr>
<th>Question</th>
<th>Positive</th>
</tr>
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<tbody>
<tr>
<td>Was Netlab and its associated equipment easy to use?</td>
<td>76.9%</td>
</tr>
<tr>
<td>Was the level of interaction with laboratory components adequate?</td>
<td>89.4%</td>
</tr>
<tr>
<td>How was the response time of the laboratory components?</td>
<td>84.2%</td>
</tr>
<tr>
<td>Could the routers, switches and the ‘virtual’ PCs be remotely accessed once a valid username/password had been supplied and an appropriate time slot booked?</td>
<td>84.2%</td>
</tr>
<tr>
<td>Was the operation of the front end graphical user interface (GUI) for Netlab reliable?</td>
<td>84.2%</td>
</tr>
<tr>
<td>Was the operation of the remote ‘lab’ equipment reliable?</td>
<td>84.2%</td>
</tr>
<tr>
<td>Did the interactivity with ‘real’ networking equipment on a remote basis help you to better understand networking and systems concepts and theories?</td>
<td>89.5%</td>
</tr>
<tr>
<td>Was the support and feedback you received from the laboratory instructor and support staff useful?</td>
<td>89.5%</td>
</tr>
<tr>
<td>Were the online instructions and paper documentation useful in supporting your use of Netlab?</td>
<td>94.7%</td>
</tr>
<tr>
<td>Was the online lab exercise information useful when compared to the printed lab exercises given to students at the start of the semester? In particular, was the lab design accurate and relevant?</td>
<td>84.2%</td>
</tr>
<tr>
<td>Was there a ‘hands on’ feeling experienced when configuring/troubleshooting the various lab configurations?</td>
<td>84.2%</td>
</tr>
<tr>
<td>Was the equipment used in Netlab similar to equipment used in a real world, networking environment? Is it ‘state of the art’?</td>
<td>94.7%</td>
</tr>
<tr>
<td>How satisfied were you with the laboratory experience gained in this virtual laboratory?</td>
<td>89.4%</td>
</tr>
</tbody>
</table>

8.1 Table 3. Post Study Questionnaire (Closed Rating Questions)
9. Conclusion

From the promising survey results, it is clear that students are ready and willing to engage with virtual laboratory resources for a wide variety of benefits that can be achieved. However, they want such resources to be available alongside conventional learning so they can mix and match to their requirements.

The biggest barrier to successful deployment of virtual lab resources is the support that must be available. If the system is not available for the students when they want to use it and no support is available in a meaningful timeframe, students might be turned off from using the facilities.

The theoretical and practical approaches in the evaluation of virtual laboratories have resulted in reaching the conclusion that VCL would be an invaluable asset in combination with other specific teaching tools, such as Netlab, when some resources cannot be wholly virtualised (e.g. like the routers in Netlab). Whilst investigating the concept of VCL and contrasting it to other similar virtual remote laboratories, it turned out that the scalability and flexibility of VCL make it a more advanced solution in terms of its broad scope of utilisation. Additionally, its open source scripts can be used in different combinations of equipment and virtualised software, which means that it can be customised to fit any cost, availability or usability requirements the department might have. The prototype system has successfully demonstrated provisioning over the Internet utilising both Windows XP and Linux environments but still requires supervision.

Several issues caused some concerns for future deployment. For a prototype system, deploying all the services on one hardware platform was fine, but for a future production deployment, dedicated systems for both the user front end provisioning system and another for the VM hosting would be required. Another
area of concern is the security infrastructure necessary for students to utilise remote labs can be too restrictive and not dynamic enough to manage the incoming connections

9.1 Key Recommendations
- Make virtualisation technology a core delivery in the Computing and Technology programs; adding the technology to all applicable modules makes the delivery of core Computing modules at partner institutions much easier, as the software image can be ‘portable’.
- Develop model for delivering ‘portable’ student assignments and lab work, which can be delivered locally or remotely using virtualisation technology.
- For dedicated VM delivery (dedicated VM per student), supported hardware and managed ‘front end’ on dedicated systems are required (for managing user sessions).
- By making more resources available generically using virtual machines, computer labs could in theory be used to offer functionality only seen previously in specialist labs. (However, the need for specialist labs still needs to underpin student learning, as noted by student survey responses.)

9.2 Future Work
- The VCL platform prototype has showed much future potential but needs to be customised to deliver a stable provisioning front end so that students/lecturers can allocate and access virtual resources as required.
- Evaluate how support might be offered to students in the future for a successful 24/7 operation.
- Expand the ‘portability’ aspect of using virtualised lab facilities within all computing modules.

10. References


