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Virtualization for computer networking skills development in a distance learning environment

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Abstract

Virtualization is a core technology for teaching networking and operating system skills. In a distance learning, or e-learning, environment, the use of virtualization presents different challenges—both technical and pedagogical. In the initiative presented here, distance learning students studying a module on computer networking and server technologies were required to install virtual machines on their own computers in order to carry out practical labs originally designed for a classroom environment. This research explores and evaluates the strategies developed to support students via a survey of students completing the module. The findings show that the majority of students found it a valuable learning experience and developed practical skills relevant to computer networking careers. Recommendations are made to inform the future development of courses considering the use of virtual machines installed on students' machines to enable practical labs to be undertaken at a distance.

KEYWORDS

distance learning, networking and server technologies, practical skills, virtual machines

1 | INTRODUCTION

Incorporating practical skills development into technically focused, computer networking courses continues to present challenges, and attract new initiatives, in distance learning or e-learning environments [13,16]. Computer networking courses usually have some practical learning outcomes and require students to work with hardware. They can also be based upon, or incorporate, industry certifications which place a high emphasis on practical skills development. It is therefore crucial students develop these skills through some form of hands on experience.

There are several options that can enable students to gain practical experience when studying such a course at a distance. Simulation packages are software programs that are designed to behave like network components. In this scenario students are not actually working with physical equipment

and this can greatly reduce the costs [5]. Another approach, that does enable interaction with actual equipment, is through face-to-face day or residential schools, where students have immediate access to computer networking laboratories and expert tuition [4]. Alternatively, students can be given remote access to physical equipment and this can be managed through students booking time slots. Another approach is to use virtualization [2,11,12,14,15,17]. This means the use of virtual machines (VMs)—programs installed on a computer that can imitate particular computer systems. A VM runs as a process in a window on the 'real' computer and can be used to run a different operating system. Multiple VMs can run on a single computer and function as various networked servers and desktops [2,14]. In a distance learning environment, VMs can be installed on servers owned by the learning institution (or a third party) and configured to provide students with an "online lab" experience. Students remotely log in to VMs, or

access them via web browsers, and undertake prescribed tasks on them. Multiple students can log on simultaneously and undertake tasks from home at any time they please.

Whilst all of these options can provide students with excellent opportunities to develop their practical skills, they also have different challenges associated with them. The quality of the experience when using simulation is dependent on the quality of the simulation environment [5]. Whilst there is academic argument that the simulated experience is not as valuable as true hands-on experience, other evidence has shown that simulated labs can be at least as effective as hands on labs [9,8,10]. Day schools held in computer networking laboratories require considerable financial investment and organization and can only provide access to resources and expertise for a limited period of time. This may not be convenient for distance learners who are often juggling their studies with work and family life. Providing remote access to laboratory equipment still requires the financial investment, and maintaining and managing this is a challenging task [5,1]. In addition, booking time slots, whilst helping ensure a reasonable experience, is not always popular with students who may not know when they will be available or are unable to book the slots they require. Online labs, where students log onto VMs installed on computers owned by the learning institution, are often preconfigured, with software installed by the instructor, and machines configured ready to undertake set tasks. Whilst this enables students to get straight into the tasks sets and reduces the likelihood of problems with the initial set up, it can also limit students' opportunity to "tinker." Tinkering, a term which is generally used to refer to exploratory activities and experimentation without a set plan, has been shown to be a valuable part of the learning process in areas related to computer networking, such as programming [6] and other STEM (Science, Technology, Maths, and Engineering) areas [7]. Installing software and configuring machines can be an important part of the learning process. Another challenge in using online labs is that resources may be limited and if many students use the labs simultaneously they can become slow or unresponsive.

This paper explores another alternative—providing distance learning students with the resources and support needed to install and configure VMs on their own computers and then carry out practical activities originally designed for the classroom. There are still challenges to this approach but some of the drawbacks highlighted above can be overcome. For example, students have constant access to "their" machines so are not restricted by schedules drawn up by others. Students' are not required to share resources, plus they have more freedom to "tinker" and try out tasks or configurations not prescribed by the learning activities. This paper presents an initiative where this approach was used in a first year university module in computer networking and server technologies where practical skills were central to the module's learning outcomes. Various support mechanisms were used that enabled students to recreate the necessary computer networked environment on their own computers and carry out the required practical exercises. Existing classroom based lab manuals that detailed practical exercises were used and support was provided through a combination of materials and mechanisms, described later.

Findings from a survey that was undertaken to investigate the learning experiences and perceptions of students that took the module, and that installed VMs on their own computers, are discussed in this paper. It identifies the successes and failures of the approach with the aim to contribute to, and inform future development of, pedagogic strategies for practical skills based courses. This paper addresses the following research questions:

- What are the main challenges faced in adapting practical labs designed for the classroom for use in a distance learning module?
- How can students be best supported in creating and using virtual machines at a distance and what coping strategies do they develop?

2 | BACKGROUND

2.1 | Context

The pedagogic initiative being investigated in this research was part of a Computing & IT module (unit of study) run by the UK Open University (OU). The OU is the largest provider of distance education in the UK and has a policy of open entry, enabling learners to access higher education whatever their background. Learners typically study part-time from their own home or workplace and are divided into groups of around 20, with a tutor who provides support via telephone, email, and online forums. Most modules also provide module wide online forums where advice and guidance is provided by members of the module team, tutors, and fellow students. Module materials and forums are accessed via the module website but students often receive print based study materials in addition.

The module presented here formed part of the level 1 study towards a Computing & IT undergraduate degree and focused on providing students with opportunities for developing practical skills fundamental to careers within the IT industry. More specifically, students developed the skills and understanding needed to work towards becoming an IT professional working with Microsoft Server products. As a Microsoft Academy, the OU provided students with access to

Microsoft learning materials that support preparation towards Microsoft Certification exams.

Other further and higher education institutions are also academies within the Microsoft Academy programe, where the typical mode of study is a face to face environment combining weekly lab activities with underpinning theory. The instructor, in Microsoft parlance, guides students through practical labs. Students learn by "doing" and have a direct dialogue with the instructor and peers relating to the purpose of each lab. Well established and recognized text books and lab manuals are available and are frequently used by Microsoft Academies for classroom based learning.

The Microsoft Academy learning materials also include online labs. These were purposely designed for those studying towards certification at a distance and were an obvious mechanism for providing an equivalent practical experience for students studying the OU module. The online labs were used in the first two presentations of the module. Students logged onto labs via a web page where they had access to multiple virtual machines set up as Microsoft servers. They were then required to work through labs that developed their skills in configuring and administering these servers.

2.2 | Changes to the module-a localized virtualization approach

As discussed earlier, online labs, such as those used by the module in its first two presentations, have inherent benefits and challenges. One challenge is the potential for slow response times if many students attempt to use the labs at the same time. The OU module attracted around 350 students in its first year and 750 in its second year. Due to assessment deadlines and usage patterns (many OU students conduct the majority of their study in the evenings), students often required access to labs during the same time period. In the third year of the module, and with another increase in student numbers to over 1,000, the strain on the online labs was predicted to increase. In addition, the team responsible for the module were interested in ensuring students developed some of the more basic skills—such as installing the operating system on servers and networking computers. Therefore, the decision was made to revise the approach to the practical side of the module. There were, however, time and resource constraints.

Given that reputable text books and lab manuals already existed, and were popular with other Microsoft Academies, the team chose to enable students to carry out these labs through the use of VMs installed on students' own computers. The labs in these books were designed for an environment where students have access to a minimum of two computers that are locally networked. These two computers are what classroom based students work on and configure as servers through the series of labs. The labs also require the presence of an additional "instructor" computer that performs several crucial server roles but is not used by students. The configuration and initial set-up of the instructor machine is vital to the networked environment being used. Students would therefore be required to install, create and work with, three VMs.

To create a VM on a computer, virtualization software first needs to be installed. There are several types of virtualization software available. In this instance, Oracle's VirtualBox, available as a free download, was used. Students were guided, step-by-step through the download and installation of VirtualBox and the creation of three VMs on their own computers: VM1, VM2, and the instructor-VM (plus an optional VM-3 should students chose to undertake additional labs). They were also guided through the process of installing the required server operating system, and configuring and networking the three computers ready to undertake the labs. Throughout the rest of the module they were guided through the tasks and exercises described in the original lab manuals.

2.3 | Adapting a classroom based model for distance learning

Adapting classroom based models for distance learning is not a unique endeavor. Work has been published that discusses what needs to be considered in the decision as to whether adapt existing materials or develop new ones [18]. This module is not the OU's first venture in adapting third party practical work to be used in distance learning as it had successfully adapted the Cisco Academy CCNA educational experience, using a combination of remote labs and face-to-face day school experiences [4]. The approach being used in this module differed from the Cisco model in that day schools were not to be used. The aim was to enable access to a wider range of students, not just those able to attend face-to-face sessions.

As already mentioned, the aim was to use existing, third party text books and lab manuals. One requirement for their use in this context was to make sure these texts were accessible for students using them in isolation. For example, ensuring all the additional information needed to complete the labs, normally provided by an instructor in the classroom (such as IP addresses of computers or the necessary network security settings), was available to students. Another consideration was to ensure that students had access to ongoing support that, again, would usually be performed in real-time by an instructor. The main challenges that students were expected to face, and therefore the areas that would need support, were: ensuring correct installation and initial configuration of VMs; solving, and coping with the frustrations of, ongoing technical problems; keeping on track with study; and relating the practical tasks undertaken to the

theory being studied. The following materials were developed and support strategies implemented in order to support students.

2.4 | Web-based study guides and videos

Web-based written materials were produced with the aim to guide students through the labs. These materials included a series of four initial study guides for setting up and getting started with the VMs that took place in the first week of the main study block. Videos that demonstrated these tasks being carried out were also produced as successful completion of these activities was crucial so that students could then carry out the subsequent labs. Details of the activities covered by these initial study guides and videos are shown in Figure 1 (the script file referred to in study guide 4 is explained later).

Following on from the initial study guides that focused on setting up the VMs, week-by-week study guides were produced. These fulfilled several functions, including: introducing students to topics each week; directing them towards the week's labs in the lab manuals; providing additional information needed to complete the labs; errata identified in the existing materials; key skills activities for their study towards an undergraduate degree; and links to useful third party resources, such as technical websites.

As identified earlier, one concern the module team had was ensuring students kept on track with their study. Approximately 1.5 times the recommended time was allowed for each lab to allow for the fact that they were being undertaken in isolation and instructor support was not available in real-time. So, for example, a lab with an estimated completion time of 2 hr was allocated 3 hr. Whilst students were actually able to spend as much time as they chose on each lab this planning was to ensure students workload did not exceed the expected number of study hours each week.

2.5 | Script files-for set up and recovery

Script files are simple program files that contain a series of commands or instructions, which can be executed by running the file. Script files were produced that changed the configuration parameters of the instructor-VM to ensure it was set up and configured correctly. Students were guided through running the files on the instructor-VM using the study guides and videos described above. This was an easier task for students than configuring the instructor-VM themselves and guaranteed that the machine was configured correctly. Following the initial study guides illustrated in Figure 1 and using the set-up script files described here, the virtual machines students had hosted on their computers are illustrated in Figure 2.

As the labs students were undertaking were sequential and often built on previous labs, students were also provided with recovery script files. These were scripts that, if run on the appropriate VM (VM1 or VM2), would
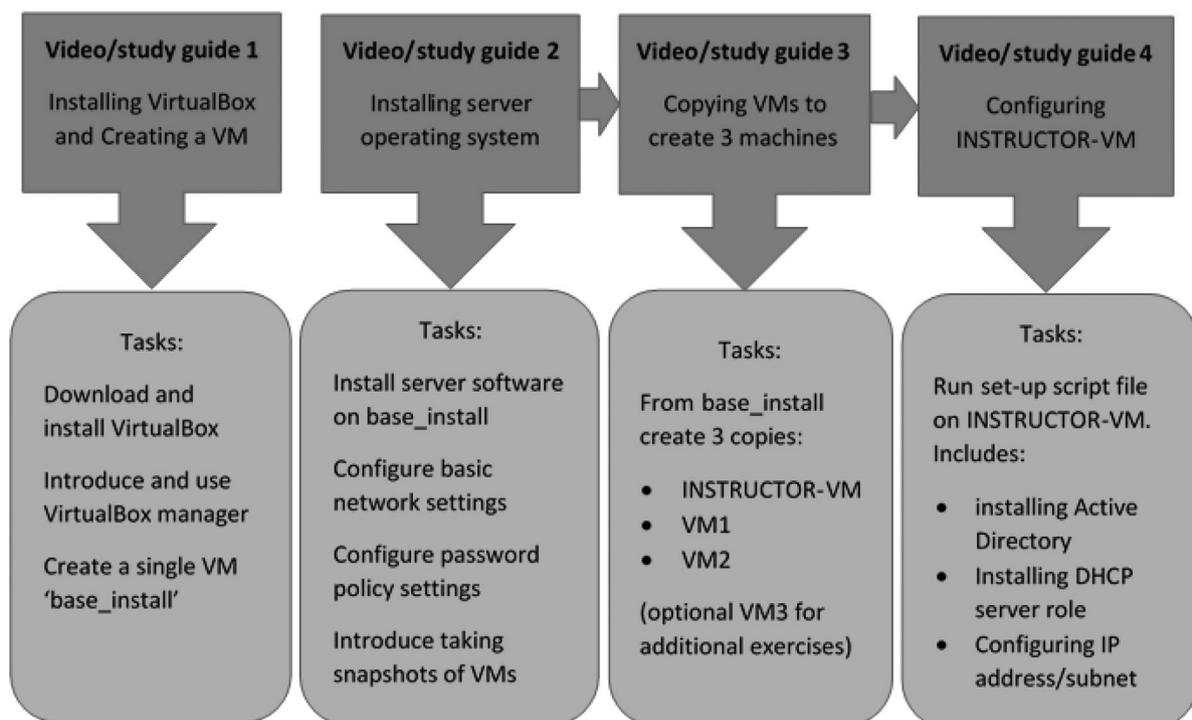

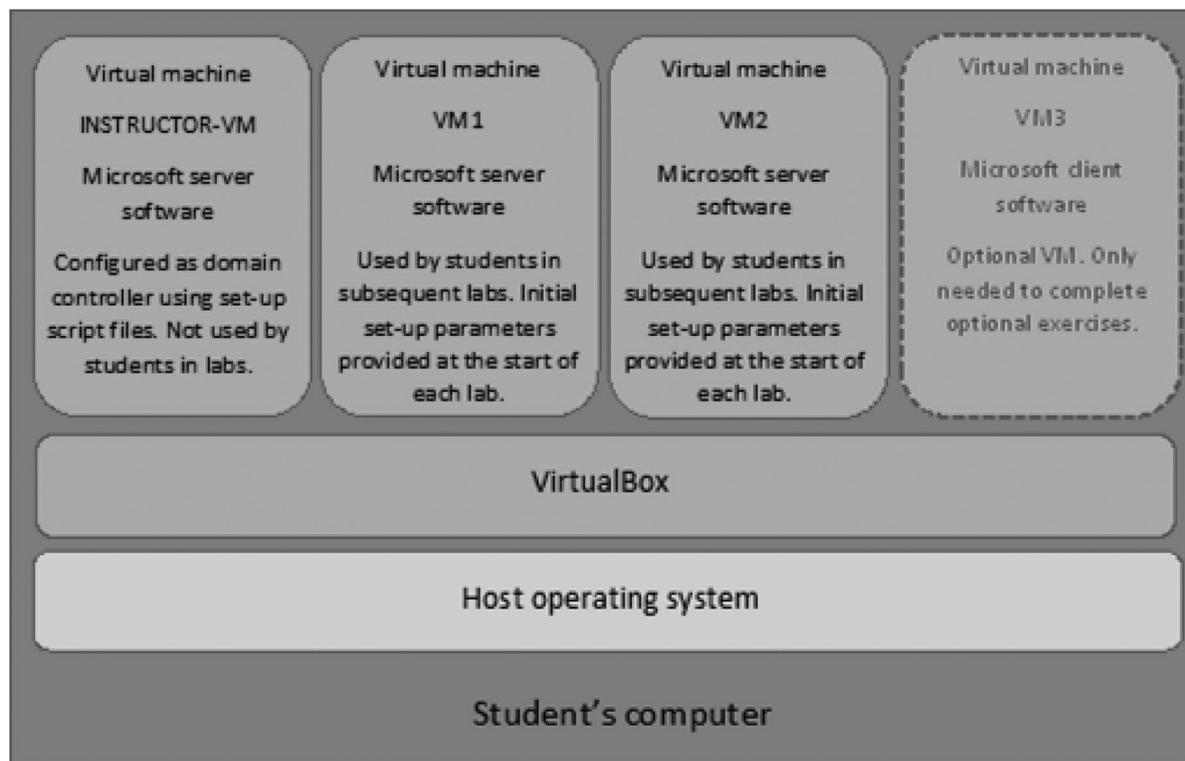**FIGURE 1** Videos and initial study guides for supporting VM set up tasks

FIGURE 2 Virtualization abstraction on a student's computer

enable students to roll forward a failed lab. This was an important support mechanism as it allowed students to continue with future labs even if they did not successfully finish the previous one. In order to ensure students completed a selection of key labs themselves without using the script files, screen shots of some of the labs were required by the module assessment. An example is shown in Figure 3.

2.6 | Online forums and tutor support

Finally, as with all modules at the OU, all students studying the module were allocated a tutor who was their first port of call for any problems. Module wide online forums were also available to all students in the cohort. They were used by the module team and expert tutors to answer queries raised by students. They also enabled students to share and discuss solutions to technical problems as they encountered them.

3 | METHOD

The research presented in this paper focuses on understanding students' experiences of studying computer networking using VMs installed on their own computers and evaluating the support structures and materials put in place.

A mixed methods approach, using an online survey to collect quantitative and qualitative data from a sample of students, was used. The survey sought to identify examples of successes and problems encountered by students in order to evaluate the pedagogic methods employed. Data was collected via closed questions that provided a small number of options (2, 3, 4, or 5), and qualitative data in the form of open comments boxes. The open comments were used to explore key issues in further depth. The survey questions are included in Appendix 1. The survey was conducted online as this enables a quick and cost effective way to gather feedback [3]. The survey questions were designed by the academic team responsible for both the delivery of the module and for conducting the research. The research was approved by the University's Student Research Project Panel who review the proposed research methodology and ensures ethical guidelines are followed.

The invitation to take part in the survey was sent via email to 500 students who had studied the module in the first presentation that the VM based labs were introduced. This was lower than the actual number of students that studied the module as some students were not able to be surveyed due to rules observed by the Student Research Project Panel. Eighty-five completed responses were received giving a response rate of 17%. Whilst this may seem low, it is in fact a reasonable response rate in the context of a distance learning environment, where most students are in full-time employment.
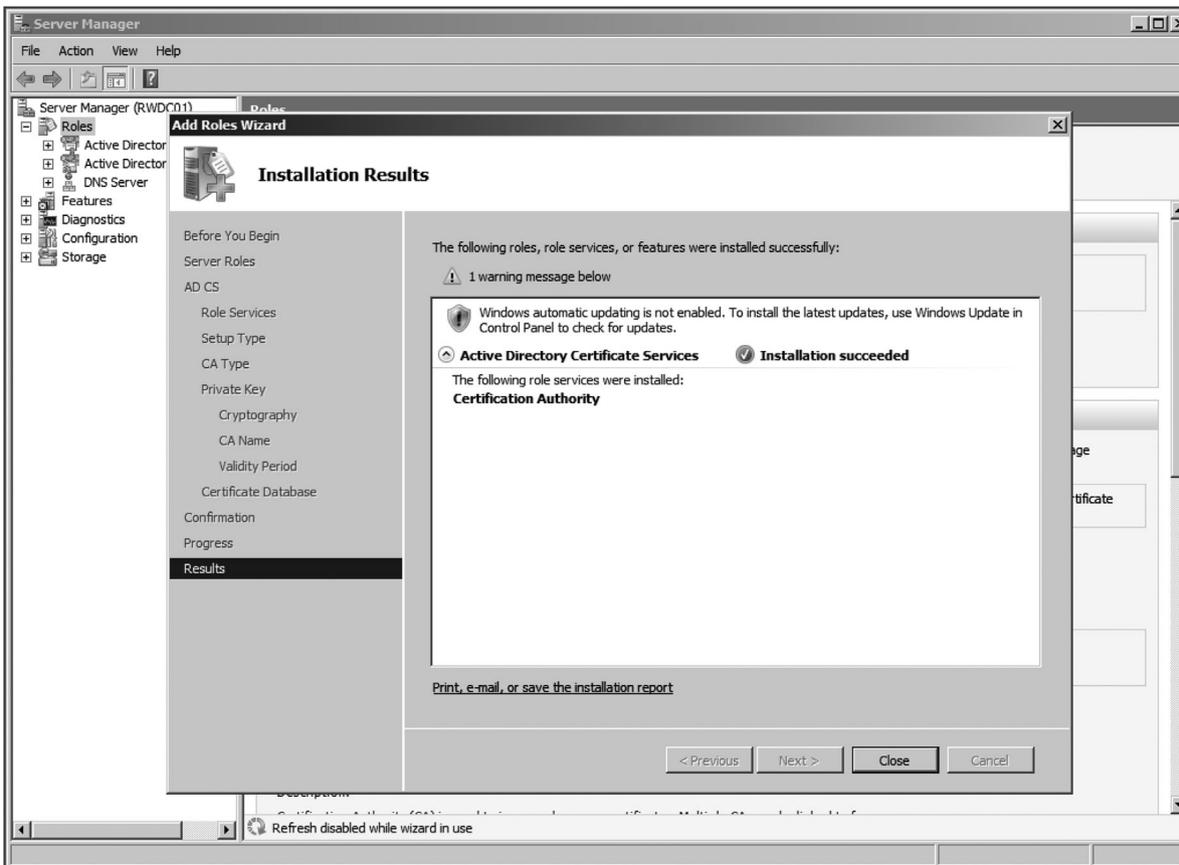
FIGURE 3 Example screen shot required by students for assessment purposes

Descriptive statistics are used to highlight the main results from the quantitative elements of the survey. Thematic analysis was used to apply codes to the qualitative data obtained through the open comments boxes. These codes were used to identify specific examples to either complement or contradict the quantitative data and facilitate a more in-depth investigation and discussion around the research questions.

The main findings presented in this paper are based on the survey described above (referred to as the "online survey" throughout). A secondary source of data came from an "end of module survey." These are run as a matter of course for all modules, and whilst useful for gauging the overall success of a module, are fairly generic and do not investigate different aspects in detail. The results of two end of module surveys, one following the first year the module ran (when all students were using the online labs) and one following the implementation of the new VM based labs (being explored in this paper) were compared. The exact number of students invited to participate in these surveys are not known and the number of response is low (see Table 1) therefore the results are treated with caution. They are useful however for gaining an overall impression of the student experience using the two different practical approaches and are therefore include in the discussion.

4 | RESULTS

4.1 | Overall study experience

Figures from the end of module survey after the first year of the module indicated that overall students were struggling, with only 35% (14 out of a total of 40 respondents) indicating a positive overall study experience. The same survey conducted 2 years later, following on from the implementation of the VM based labs showed an increase, to over two thirds (69%) of students (118 out of a total of 168 respondents). Whilst this shows a substantial improvement in the learning experience, the figures are still lower than preferred, indicating that there were still some challenges to overcome.

The 85 responses to the online survey form the basis of discussions in the following sections.

4.2 | Supporting materials

Survey questions explored how useful students found the supporting materials that were provided in the module—specifically the web-based study guides and videos.

The first major practical tasks that students studying the module encountered were setting up and configuring the VMs—this occurred in the first week and tasks were detailed

TABLE 1 Summary of data collection methods and analysis

Data source	Number of students	Number of responses	Response rate	Purpose	Data analysis
Online survey	500	85	17%	Primary data source	Descriptive statistics (quantitative data), Thematic analysis (qualitative data)
End of module survey (following the first year the module ran)	Around 300	40	–	Secondary data source	Indicative only
End of module survey (following implementation of VM labs)	Around 500	168	–	Secondary data source	Indicative only

in the initial study guides and videos described in Figure 1. The survey asked students about which of these materials they had used and how useful they found them. 94.1% (80 out of 85) of survey respondents said that they found the study guides useful or very useful and 76.5% (65 out of 85) said the same for the videos. A total of 14 students out of 85 did not use the videos at all in this first week, compared to only two students who did not use the study guides. Although both the study guides and the videos were presented as "required" study items they effectively covered the same thing so some students may have felt they did not need the videos if they were happy following the instructions in the written study guides. Several students commented that more videos would have been useful.

> "I would strongly recommend [...] videos for each of the labs"

> "It would be useful to have more video tutorials/ explanations and pictorial step by step guides"

Following on from the first week, week-by-week study guides were provided that introduced the concepts that would be covered that week, directed students towards the labs that should be undertaken and provided any additional information that students would need to complete the labs. Students were then required to follow the instructions in the third party lab manuals to carry out the actual labs. The survey asked students if they felt the study guides, combined with the instructions in the lab manual, sufficiently supported them through the practical tasks each week. Just under half of respondents (48%) said that they had used additional resources, on top of the study guides and lab manuals, to reinforce their understanding of some of the concepts. Via the open comments box respondents identified videos from sites such as YouTube and "techie" forums such as Microsoft TechNet, as well as using basic internet searches. Links to forums such as TechNet were provided in the module materials so there was some expectation that the students would explore and familiarise themselves with these forums.

4.3 | Keeping on track

In the first week, where students were setting up the VMs, 7 hr was scheduled for these activities. A total of 89.4% (76/85) of survey respondents said they completed these tasks within this time. In subsequent weeks, 61.2% (52/85) of respondents said they kept up with or got ahead of their study, whereas 30.6% (26/85) said they fell behind. The open comments box enabled respondents that fell behind to expand on how they spent the additional time. The majority of comments related to the labs.

> "Labs consumed much more of the time than they should have done…."

Most of the comments about labs referred to errors in the labs and the additional time spent trying to get them to work. Several students also talked about spending significant time in forums looking for help. As mentioned previously the week-by-week study guides included information on known errata in the third party lab manuals. Frustration at having to jump backwards and forwards between the study guides and lab manuals to locate errors was commented on by some of students.

> "Try to resolve the multiple issues with the lab instructions and the contradicting instructions on the study planner."

4.4 | Technical problems and coping strategies

The survey explored the nature of the technical problems students experienced, whether they were aware of, and made use of, the available support mechanisms that were available, and how well these mechanisms worked.

In the first week, when students were setting up their VMs, 81% (69/85) of respondents said they did not have any technical problems with these tasks. For the 19% (16 out of 85) that did experience some technical issues, more details on the actual problems were solicited via the open comments box.

The two main problems that were identified (and that also arose in the module's online forums, which implies that these were experienced by a greater number of students than captured by the survey), were: configuration issues, in particular incorrect firewall or network settings; and downloading and running the script file. Both these issues were discussed and resolved by tutors in the forum early in the module. Several students also commented that their VMs crashed or became corrupted which again was a common discussion topic in the forums. Unfortunately, with issues like this it is difficult to know the source of the problem although similar problems can be experienced when using machines in the classroom and resetting machines is often the only solution.

The proportion of students experiencing technical problems increased after the first week, that is, more students experienced problems with the labs than the initial setting up tasks. 31% (26 out of 85) of respondents said they had experienced technical problems later in the module compared to 19% (16 out of 85) in the first week. This is illustrated in Figure 4.

Here, the majority of problems captured by the survey, and again supported by forum messages observed during the module, involved VMs crashing during labs, error messages occurring and commands not working as expected.

The survey asked students how they resolved these ongoing technical problems. These are summarized in Figure 5.

The module's online forums were the most popular method (fourth and fifth bars in Figure 5) with 22 out of the 26 students indicating that they had solved a problem this way—more interestingly, through advice from other students most frequently (fifth bar).

> *"I found the [...] lab forum invaluable. I got round to search and reading any relevant messages before I progressed to the next lab"*
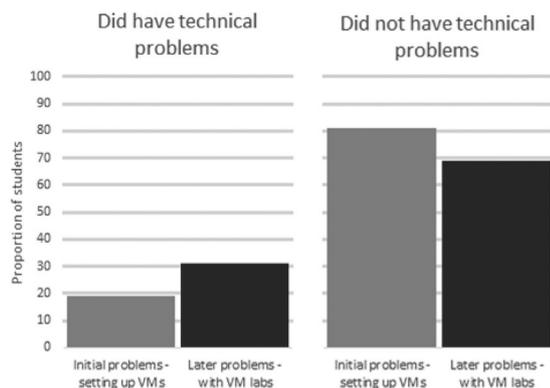

FIGURE 4 Proportion of students experiencing technical problems
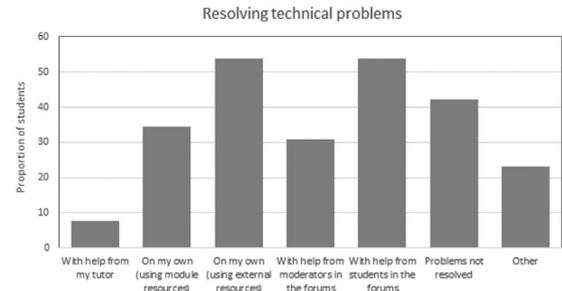

FIGURE 5 Proportion of students using different methods for resolving technical problems

> *"I had to change the default network adapter to get a network connection. A student helped me in the forum and it took us a couple of hours to work out what was wrong. In the end it was easy to sort out"*

More negatively worded comments were also received about the forums that were due to the fact that there was a high volume of messages making finding relevant information difficult. There were examples of simultaneous discussion threads being created—discussing the same issues.

> *"trawling many forum posts to try and find resolution"*

Another popular method for solving technical problems throughout the module was through using external resources (14 out of 26)—that is resources that were not part of the module materials.

Eleven out of the 26 students that had technical problems said they had experienced a problem that remained unresolved.

The recovery scripts were used by some students, however open comments data showed that others chose to take a "snapshot" of the VMs at the beginning of a lab (a copy of the VM at that particular instant) and if things went wrong they would simply start again.

> *"There were instances [...] where rather than trying to fix problems it was easier to return to a previous 'snapshot' of a virtual machine and start from scratch"*

4.5 | Learning

The survey asked students whether they felt that they fully understood what they were doing in the practical tasks. 62% (53 out of 85) said that yes they did understood the tasks that they undertook. An additional 28% (24 out of 85) said that

they did understand some of the time. 6% (5 out of 85) said that they didn't understand what they were doing (the remaining 3 selected "other" but did not specify further).

Students were also asked whether they would feel confident carrying out the practical tasks again. 79% (67 out of 85) said that they would be able to carry out most of the tasks again without the use of the step-by-step instructions, whereas 20% (17 out of 85) said they would need the step-by-step instructions (i.e., the original lab manual instructions) to be able to do the same tasks again.

When asked whether they felt that the practical tasks they carried out supported their understanding of the theories and concepts they had been learning about on the module the majority, 84% (71 out of 85) felt that they had.

> "I found the practical element of configuring virtual servers reinforced the theory [...]"

> "It gave me full understanding of the aspect of server administration"

5 | DISCUSSION

The first research question addressed in this paper asked what are the main challenges faced in adapting practical labs designed for the classroom for use in a distance learning module? There are two main perspectives to consider here; challenges for those running the module and for those studying the module.

A single presentation of the module ran for almost nine months and during this time students required a varied level of online support, peaking around assessment dates. Whilst expert tutor and module team support can be provided in the online forums, dealing with technical problems at a distance means it is sometimes difficult to fully appreciate the exact problems students are facing. Students were asked to send screen shots with the requests for support they made and whilst these helped in the diagnosis of problems it may have been easier to resolve some of these in a face-to-face environment. When problems were on-going and could not be recreated by the tutors, students were advised to roll forward labs using the scripts made available. Management of forum discussions was also challenging with simultaneous discussion threads, discussing the same issues, being created.

The feedback gathered from students presented in this paper illustrates that the majority of students, and a significantly higher proportion than those using the online labs in previous years, had a positive learning experience. The majority of students understood what they were doing in practical tasks and how these activities were related to the theory they were studying. Having said that, 16% of students

that responded to the survey felt that the practical tasks did not support their understanding of the theoretical concepts. This may have been picked up, and therefore addressed, earlier in a face-to-face environment.

Real-time online support was not a viable option in this module but may be something that designers of future courses would consider. The frustrations voiced by students often stemmed from the time it took to find solutions, rather than the solutions not being found. This was mostly due to the volume of messages in the forum but at other times it was because there were several different resources available to them. It was important that students worked through materials in the correct order. For example, the written correction of errata relies on students reading this information before starting a lab.

There were a significant number of students experiencing technical problems which affected their overall experience. The module guidance included a minimum technical specification that computers to be used to study the module should meet. In particular, a minimum amount of memory (RAM). Whilst there was still some requirement for reasonable bandwidth connections and speeds this was much less important than when using online labs in the initial presentations of the module. Unlike classroom based labs, distance learning has no control over the devices used by students. The OU has an open access policy and creating unnecessary demands on students in terms of the equipment they require does not sit easy with this policy. However, this did not appear to be an issue to students. A small number of students enrolled that were using computers that didn't (or barely) met these requirements and these students were given the option of using the original online labs used in previous presentations.

The OU also has a tradition of not having pre-requisites in terms of previous studies. The module guidance advised that the technological demands of this module were "high." However, in this case there were unavoidable expectations from students that wished to study the module. The first was with relation to competencies. While this module was at undergraduate degree level one, it was not a "starter" IT module. Server certifications from Microsoft do not cover "computing and IT fundamentals" and are typically aimed at technology specialists. Whilst the module did include a "Networking Fundamentals" component at the start, the time needed to assimilate the concepts and fundamental skills before encountering the server based practical labs was still very challenging for some students.

The second research question asked how students can be best supported in using virtualization at a distance and what coping strategies do they develop?

The online forums were an extremely popular resource for students. Whilst these were very busy, and often a cause of frustration for some students when answers were not immediate, they were also how the majority of technical issues were solved. Some students learnt to use these very

effectively, searching for potential issues before starting labs. In subsequent years, some of the congestion in forums was alleviated through the creation of frequently asked questions (FAQs)—where threads addressed recurring problems that could be readily solved. Students requesting help could then be directed towards these FAQs. There was evidence of a community of practice developing, featuring peer support and ongoing discussions on a range of related topics (e.g., trouble shooting, studying towards certifications). Students also made use of external technical forums for solving technical problems.

Whilst the majority of students could relate the practical and theoretical side of the module there were a small proportion that struggled with this. It may be that the inclusion of online tutorials (using real-time web conferencing software) to highlight some of the fundamental concepts and how the practical tasks are related to these may be something that could be used in future courses. The majority of students also felt confident that they would be able undertake most of the tasks again which is of vital importance if IT certifications exams are being considered.

All the material produced for the module was well received and used by the majority of students. Most of the students used both the web-based study guides and the video demonstrations. The majority of students found the initial set-up scripts and instructions easy to use and did not struggle with the setting up of VMs. Many more students did however need support in undertaking the labs, where the module relied more heavily on existing lab manuals. Several suggestions were received from students that guidance videos for more of the labs would have been very useful. Whilst it does not seem practical to make videos for all of the labs, it may be worth considering the production of videos for some of the key labs. This again could be used to emphasize areas where it is important that the theoretical concepts underpinning the labs are grasped. Given the feedback received from students it may have also been useful to develop one set of detailed lab instructions. The module expected students to use the existing third party lab manuals but to refer to the web-based study guides (developed by the module team) to identify additional parameters or errata that had been identified. Jumping between these two sets of instructions was sometimes inconvenient and time-consuming for students.

Whilst the use of recovery scripts proved critical in enabling some students to learn from their mistakes and continue with the labs when errors did occur, some students made use of "snapshots" of VMs instead of using the scripts. This is interesting and worth commenting on the fact that students, as well as developing their practical skills in relation to networking and server technologies, also as by-product were developing skills in using desktop virtualization. The use of snapshots is an example of how some students used their knowledge of the virtualization software to cope with

unforeseen technical difficulties. It is also interesting and encouraging that students chose to use this to persevere with tasks even though scripts were available that would enable them to skip to the next task.

6 | RECOMMENDATIONS

Drawing on the findings in this paper, the research team have identified some recommendations for those considering a similar approach.

- In a course with a high technical content but no pre-requisites to study, a complete study path should be considered that begins with a "network fundamentals" experience using fewer VMs. This should enable familiarity with VMs before the more challenging practical tasks.
- The use of recovery scripts and/or guidance in the use of snapshots is critical in enabling students to learn from their mistakes and move forward through labs.
- Online forums are an extremely useful tool for supporting students however these need to be managed closely. FAQs can help avoid forums becoming too cumbersome to be useful. Encouraging students to help each other and share solutions to technical problems experienced helps build a community of practice.
- Where possible the use of online tutorials or face-to-face sessions could help students identify the links between the practical tasks they are undertaking and the theoretical concepts they are studying. Where not possible, students do find value in the use of video demonstrations to support textual explanations of practical tasks and theoretical concepts.
- When adapting existing labs the instructional materials should be thoroughly tested. If many errata exist it is worth considering rewriting so that students only have to follow one set of instructions rather than jumping between different ones.

7 | CONCLUSION

The initiative presented here has explored one solution for developing practical networking skills in a distance learning environment. The use of VMs installed on students' own computers obviously reduces costs for the institution, but this research has shown that adapting existing classroom based labs is a feasible approach that enables modules to be implemented in a short time frame. This is beneficial when the software, technologies, and therefore the required skills, are constantly evolving. The evaluation presented here, based on feedback from students, has shown that there were significant improvements in the student experience compared to using

online labs. Written materials and video demonstrations are popular support mechanisms, however there is a tension between providing adequate supporting materials and over-loading students with too many avenues from which to assimilate information. Technical forums for solving ongoing technical issues, whilst extremely valuable, cannot solve all of the technical issues students encounter. Fall back measures, such as the script files used here, or the use of "snapshots"—a strategy adopted by students, are also necessary to enable students to progress.

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APPENDIX 1

Survey Questions Relating to the Using of VM Based Labs

*Indicates open comments boxes

- How useful did you think the guidance documents and videos were when setting up your virtual machines at the beginning of Block 2? (e.g., The documents and videos such as "Creating a Virtual Machine" and "Installing Server2008 on a Virtual Machine" etc.).
  Documents: *Not useful/Quite useful/Very useful/Don't know/Didn't use*
  Videos: *Not useful/Quite useful/Very useful/Don't know/Didn't use*
- Setting up the VMs at the beginning of Block 2 (Week 7) should have taken no more than 7 hr. How much time did you spend setting up your VMs for Block 2?
  I spent much less time that this/I spent about this amount of time/I spent much more time than this/Other (please specify)
- Did you have any initial technical problems with setting up the VMs?
  Yes/No
- Can you tell us a little more about the nature of your initial technical problems?*
- Can you tell us how you resolved your initial technical problems? (Tick all that apply)
  With help from my tutor/On my own (using module resources)/On my own (using external/additional resources)/With help from moderators in the forums/With help from other students in the forums/The problem(s) was-(were) not resolved / Other (please specify)
- Did you generally stick to the guidance in the Study planner for when to complete each lab?
  Yes, mostly/No, I got ahead of the Study Planner/No, I fell behind the Study Planner/Other, please specify
- Was the information provided on the Study planner and within the module texts enough to understand the concepts you studied or did you need to find additional information (e.g., online tutorials, YouTube videos etc.)?
  I didn't need to find any additional information/I did need to find additional information

- Can you tell us a little bit about the additional information/content you used?*
- Did you spend about the recommended amount of time (an average of 10 hr/week) studying [module code]?
  Yes, mostly/No, less than 10 hr/week/No, more than 10 hr/week
- Can you tell us what you spent the extra time on (e.g., reading or labs?)*
- Did you have any ongoing technical problems with the [. . .] labs or virtual machines?
  Yes/No
- Can you tell us a little more about the nature of your on-going technical problems?*
- Can you tell us how you resolved the technical problems? (Tick all that apply.)
  With help from my tutor/On my own (using module resources)/On my own (using external/additional resources)/With help from moderators in the forums/With help from other students in the forums/The problem(s) was-(were) not resolved/Other, please specify
- Did you generally feel you understood what you were doing in the practical tasks?
  Yes, mostly/Some of the time/No/Other, please specify
- Would you feel confident carrying out the practical tasks you did in these labs again?
  Yes, I would be able to do the majority of tasks again, without assistance/Yes, I would be able to do the majority of tasks again, but I would need some notes as a reminder/No, I would need to follow the step-by-step instructions to be able to do the majority of tasks again/Other, please specify
- Did you feel the practical tasks were supporting your understanding of the theories you were reading about in the [...] textbooks?
  Yes, mostly/Some of the time/No, rarely/Other, please specify
- These final questions are about your previous technical experience prior to starting [module code].
  ○ Did you have any experience of using Virtual Machines prior to starting [module code]?
    Yes/No
  ○ Did you have any experience of setting up or configuring servers prior to starting [module code]?
    Yes/No
  ○ Did you have the required computer specification needed to run the VMs prior to starting [module code]?
    Yes/No
  ○ Do you intend to go on and take the Microsoft certification exams in this area?
    Yes/No