Teaching Computer Networking Fundamentals Using Practical Laboratory Exercises

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Abstract - Motivating students to learn computer networking concepts is often difficult because many students find the subject rather technical, dry, and boring. To overcome this problem the author has prepared some practical laboratory exercises (practicals) and other materials. They are designed around a network operating system and a multi-user, multi-tasking operating system and are suitable for classroom use in undergraduate computer networking courses. The effectiveness of these practicals has been evaluated both formally by students and informally in discussion within the teaching team. The implementation of the practicals was judged to be successful because of the positive student feedback and also students scored better in the final exam. This paper describes the practicals, their overall effectiveness, and plans for further projects. The impact of practicals on student learning and comprehension is also discussed.

Index Terms - Computer networking education, Linux, NetWare, server-based networking, Transmission Control Protocol/Internet Protocol (TCP/IP).

I.   INTRODUCTION

Computer networking is often included as a subject in computer science, engineering, and business courses because computer networks are a fundamental component of information technology (IT) systems today.

The author strongly believes that students learn more effectively from courses that provide for involvement in practical activities, e.g., setting up a customized network, installing and configuring a server, assigning user rights to files and directories, writing and testing login scripts, etc. This view is extensively supported in the literature [1]-[3], [6]-[10]. Yet, only a limited amount of material designed to supplement the teaching of

computer networking is publicly available, as searches of the Computer Science Teaching Center [4] and Special Interest Group in Computer Science Education (SIGCSE) Education Links [5] sites reveal.

Therefore, the author has prepared some practical laboratory exercises (practicals) and other material that facilitate an interactive approach to teaching and learning computer networking. These practicals are designed around two operating systems: (1) a network operating system, Novell NetWare 5.1 [11] and (2) an open source multi-user and multi-tasking operating system, Red Hat Linux [12]. The practicals can be used either in the classroom as a demonstration to enhance the lecture environment, or in the computer laboratory to provide practice at an introductory level.

Computer networking is described in many textbooks [13], [14], and commercial local area network (LAN) design strategy is discussed extensively in the computer networking literature [15], [16]. A number of sophisticated network simulators exist for building a variety of network models [17]-[21]. Nevertheless, by setting up and configuring actual computer networks, the students gain first-hand experience that cannot be gained through computer simulation and modelling. To date, the author has focused on developing practicals to support teaching a traditional computer networking course at the undergraduate level (second year). Such a practical learning approach to teaching and learning computer networking has been successfully applied for two years now in the Networking and Telecommunications undergraduate course (computer and information sciences curriculum) at the Auckland University of Technology (AUT). The course covers various aspects of computer networking, including server hardware and software, LAN administration and management, and transmission control protocol/internet protocol (TCP/IP) networking. The practicals and other materials are

revised annually, and the use of the latest version is discussed in this paper.

The main contribution and strength of this paper is the emphasis that practical experience with server hardware and software is crucial to effective student learning. The most innovative aspect of this paper is the structuring of the laboratories and crafting of the specific exercises to be effective in complementing the lecture content of the course. The course context in which the practicals are presented is described next.

II. COURSE CONTEXT: LEARNING OUTCOMES AND TOPICS DELIVERY

The networking and telecommunications in which the aforementioned practicals are introduced has a total of 56 contact hours assigned. This course is at Level 6 or second year degree level (one quarter of a full semester's course of study) at AUT [22], [23]. The Level 5 'Programming I' is the prerequisite for this course. The course goal is to produce graduates who will be able to work for networking and telecommunication companies world-wide.

A.   Learning outcomes

The course learning outcomes are listed below.

On completion of this course students will be able to:

1. Discuss the relative advantages and disadvantages of various media, topologies, encoding, and protocols employed in computer and data communication networks.

2. Write a cost-benefit analysis report for a networking project based on a business case scenario.

3. Draw a detailed diagram for the networking solution of a business case scenario involving designing a network spanning multiple floors in two or more buildings.

4. Gain practical experience with server hardware and software, including installing and configuring a LAN server.

5. Gain practical experience in LAN administration and management.

6. Configure IP sub-netting, and explore TCP/IP connectivity and interoperability using telecommunications network protocol (telnet) and file transfer protocol (FTP).

B.   Weekly programme

The course is delivered over 14 weeks, four hours of class contact per week (a two-hour laboratory and a two-hour lecture). An overview of the weekly plan for topic delivery is shown in Table I.

TABLE I
WEEKLY PLAN FOR TOPIC DELIVERY

Week	Topic	Learning outcomes
1	Introduction to networking; networking hardware and software; data encoding methods	1
2-3	Network design and analysis; LAN media, topologies, and protocols	1-3
4	Client-server architecture; LAN installation and configuration	4
5-7	Network administration and management	5
8	Revision 1	1-5
9-10	TCP/IP networking	6
11-12	IP sub-net addressing; network and transport layers	5, 6
13	Application layer	6
14	Revision 2	6
15/16	Final exam	1-6

III. LABORATORY SETTINGS

There are 25 computers (networked PCs; MS Windows XP clients) in a typical network laboratory at AUT, which accommodates up to 24 students and one tutor. These computers accommodate removable hard disk drives so that students can install different operating systems and modify various system settings without changing the standard classroom disk image for other users. Each student is given a removable hard disk at the beginning of the laboratory sessions. Hard disk costs are included in the course fee, and the students are allowed to take away their own disks at the end of the course. Students can later use the same disk for other courses, e.g., Linux, Web development.

Figure 1 illustrates how a customized server-based LAN can be set up in a typical network. At the beginning of each laboratory session, the tutor disconnects the lab network from the university backbone network by unplugging the cut-through switch. The lab network is also physically isolated from the university network when students use the lab outside of scheduled lab times. The reasons for disconnecting the lab network from the university backbone network are twofold: to eliminate any concerns related to campus network security and to allow students to modify various system settings and configurations without interfering with the campus network. Students work in pairs and are assigned two adjacent PCs in the laboratory. They select one of the two PCs as a server by inserting a removable hard disk drive (containing the NetWare server or Linux host) into its drive bay. The second PC is used as a client to access the NetWare server or Linux host. Note that the client PC does not require a removable hard disk because all PCs have an MS Windows XP client pre-installed.
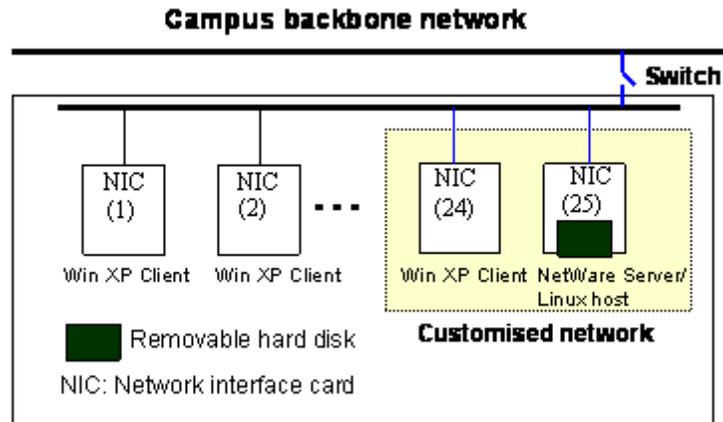
Fig.1. A customized client-server network in a typical network laboratory.

Students are well disciplined in the laboratory and become accustomed to following some basic rules. For example, at the end of each laboratory session, students must return their removable hard disks to the tutor and have their log sheets signed. Students can further explore the practicals outside of scheduled lab times by booking a time slot.

IV. DETAILS OF PRACTICAL LABORATORY EXERCISES

Table II lists the eleven practicals that have been developed to date and have run over two years in the networking and telecommunications undergraduate course. About 65 students completed this course in the two years during which the practicals have been used. Two-hour practical sessions are held weekly in a network laboratory.

TABLE II
PRACTICALS AND RELATED NETWORKING CONCEPTS

Practicals	Networking concepts
1. Cost benefit analysis for a networking project	Network analysis; key terms related to cost-benefit analysis
2. Server-based LAN design	LAN design, media, topology, and protocols
3. Server installation and configuration	Setting up a server-based LAN; LAN configuration

4. NetWare administration 1: Managing users	LAN administration and management
5. NetWare administration 2: Managing Novell Directory Services	
6. NetWare administration 3: User and file security	
7. NetWare administration 4: Login scripts	
8 – 9. Linux host installation and configuration	Setting up and configuring a Linux host
10. IP sub-net addressing	TCP/IP network design; IP addressing and sub-netting
11. TCP/IP connectivity	TCP/IP connectivity; FTP and telnet

Laboratory 1: Cost benefit analysis for a networking project

A model cost-benefit analysis (CBA) report is given to students as a reference. This introductory practical shows students how to write a CBA report based on a business case scenario (i.e., networking project). Students (in pairs) first identify potential costs and benefits for the implementation of the networking project, and then they compute (using a spreadsheet) cost saving as a result of hardware and software depreciations, net present value, internal rate of return, and break even point. Students are asked to present their CBA report to the rest of the class for further discussion and feedback.

In completing this practical, students develop a sound knowledge and understanding of network analysis for the implementation of a networking project.

Laboratory 2: Server-based LAN design

In lectures, the basic concepts of network topology, channel access protocols, LAN media, and networking hardware and software are introduced, and students are shown how to draw network diagrams from a given business case scenario. Server-based

network design is reinforced in this practical. In particular, this practical provides a walk-through in designing a network solution for a real-life business case scenario involving a network on multiple floors in two or more buildings.

In completing this practical, students achieve the following learning outcomes: (1) determine a physical topology for the proposed network; (2) select an appropriate transmission medium; and (3) draw a detailed network diagram.

Laboratory 3: Server installation and configuration

Lab 3 shows students how to install and configure a NetWare server. Students (in pairs) install a NetWare server onto a removable hard disk. Students are required to keep a journal of the major steps of server installation, including problems encountered and their solutions. After successful installation, students are asked to shut down the server and then restart it to verify that the server is running as expected. Students develop a better understanding of the networking terms and concepts: client/server architecture, network interface cards and drivers, internetwork packet exchange/sequential packet exchange (IPX/SPX), NetWare disk partition, and server IP address. Students are then asked to configure a NetWare server by using TCP/IP as the primary protocol since most of the organizations are moving away from Novell's proprietary IPX/SPX to avoid supporting multiple protocols.

In completing this practical, students gain sound experience in LAN administration, server software installation, network configuration, troubleshooting, and documentation.

In the next four NetWare practicals (Labs 4-7), students practise LAN administration and management. At the completion of each NetWare practical students are required to

show their laboratory worksheets to their tutor, have them signed, and have the date of completion recorded.

Also from Laboratory 3, these practicals endeavor to provide students with an appreciation of LAN administration (i.e., the type of work a LAN administrator does on a day-to-day basis to manage the network).

Laboratory 4: NetWare administration 1 - Managing users and objects

Students first logon to a new server (described in Laboratory 3) from a Windows client to study the system's NDS tree. Next, the practical shows students how to create a new user account called 'TUTOR' and assign it 'admin' rights. Students are then asked to create more user objects on the system based on a business case scenario. For example: "Slackwear Limited" is a fashion clothing company which has five departments (Accounts, Sales, Marketing, Distribution, and Production) in total, and each department has 10 employees. Students are encouraged to explore the system using various NetWare administrative tools, e.g., NWCONFIG.

In completing this practical, students gain an appreciation of administering users and objects.

Laboratory 5: NetWare administration 2 – Managing the NDS tree

The basic concepts of NDS tree and LAN administration are introduced during lectures, where students are also given a handout on the NDS tree and NetWare administration. This practical continues from Laboratory 4 in which students implement a NDS tree for the outlined Slackwear scenario. This practical guides students in creating an organization called Slackwear on the NDS tree. Slackwear's five departments can be thought of as organizational units, and students are asked to create five organizational

units under Slackwear: (1) Accounts; (2) Sales; (3) Marketing; (4) Distribution; and (5) Production. Students then observe the expansion of the NDS tree as they add new objects to it.

Students are also asked to devise naming schemes for both 'group' and 'user' objects, and to create one group object and 10 user accounts for each department. Students are encouraged to discuss the user requirements of Slackwear and then assign each user to one or more groups. For example, a user 'accountant' in the Accounts Department may require frequent access to sales data; therefore 'accountant' must be a member of both Accounts and Sales groups.

In completing this practical, students gain an appreciation of managing the NDS tree.

Laboratory 6: NetWare administration 3 - User and file security

Students are shown how to assign user rights to the appropriate directories and files. Students are instructed to create a new directory called 'APPS' on the SYS volume and three sub-directories under the APPS for three applications: (1) MYOB; (2) MS_ACCESS; and (3) MS_OFFICE.

MYOB is used by Accounts and Distribution users; MS_ACCESS is mainly used by Marketing and Sales users; and MS_OFFICE is accessed by all Slackwear users. Students are asked to give each user rights to the relevant directories and files based on their requirements mentioned above. Next, students are asked to create a home directory for each user on the DATA volume of the network disk.

In completing this practical, students gain experience in setting user and file security.

Laboratory 7: NetWare administration 4 - Login scripts

Students are shown how to create a profile object for each Slackwear department. The basic concept of login scripts is introduced during the laboratory session and students are given a set of problems to solve: (1) write a login script to display a message to all accounting staff on login each Tuesday, reminding them of a staff meeting at 11 am; and (2) write a login script to display 'logout' message for any production staff who try to login on weekends.

In completing this practical, students gain an appreciation of the importance of practical learning in LAN administration and management.

Laboratories 8 - 9: Linux installation and configuration

Students are given a walk-through in installing a Linux host. As in the NetWare server installation, students are asked to keep a journal of the major steps of the Linux host installation and configuration, including problems encountered and their solutions. After completing the Linux installation, students must reboot the machine to verify that the host is up and running as expected.

By installing the Linux host, students achieved the following learning outcomes: (1) prepare a Linux installation boot disk; (2) partition a hard disk for Linux installation; (3) create a new user account; (4) set up a root password and configure password authentication; (5) install various packages; and (6) discover the network status of the host machine.

Next, students are asked to explore the Linux host configuration by completing the following tasks: (1) experiment with some of the network configuration files; (2) identify the model of the network card; (3) assign super-user rights to a user; (4) use Linux

commands (e.g., cat) to display the contents of files; and (5) check and interpret the content of various files.

In completing the practicals, students develop an understanding in Linux host administration and management.

Laboratory 10: IP sub-net addressing

The basic concepts of IP sub-netting, including different classes of IP addresses and sub-net masks, are introduced during lectures where students are also given a handout on IP addressing. This Linux practical shows students how to assign IP addresses to the two sub-networks shown in Fig. 2. Students are asked to explore IP sub-netting by working through a problem based on the following scenario.

"An organization has been assigned a class B IP address: 115.115.0.0. The organization's LAN is shown in the Fig. 2. You are given the task of assigning IP addresses to two sub-networks, each with eight hosts and a router that connects the two subnetworks. The network mask used by the organization is 255.255.240.0. Assign a valid IP address to each network interface and show the broadcast address and the subnetID for each subnetwork."
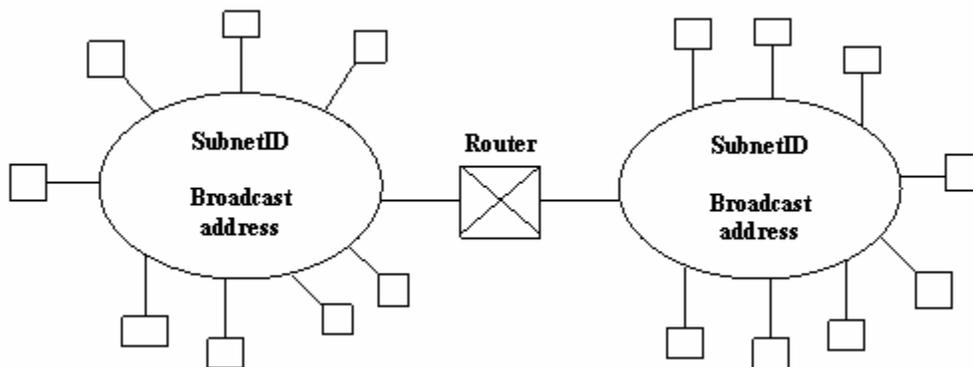

Fig. 2. A LAN comprising two sub-networks linked by a router.

In completing this practical, students gain experience in TCP/IP network design and IP sub-netting.

Laboratory 11: TCP/IP connectivity

Students are shown how to set up TCP/IP network connectivity and interoperability using telnet and FTP. The basic concepts of FTP, telnet, address resolution protocol (ARP) and domain name systems (DNS) are introduced during laboratory sessions. Students are asked to create a text file and then transfer it from an MS Windows client to a Linux host using ftp. Next, students establish a telnet session between the MS Windows client and the Linux host, and locate the text file on the Linux host. Students are encouraged to explore TCP/IP connectivity and interoperability using telnet and anonymous ftp and to perform name resolution without using DNS.

In completing this practical, students develop a better understanding of TCP/IP network connectivity and interoperability.

Additional projects: The following practicals are being considered.

- **NetWare printing**: Practical learning activities including management of print queues and print servers, printer to print server assignment, and setting up remote printing for a workstation.

- **Network file system (NFS):** Practical learning activities including configuring NFS servers and sharing files across a network.

- **Static and dynamic routing**: The learning activities include configuring static routing, routing table information, configuring routing information protocol (RIP), and interior gateway routing protocol (IGRP) routing.

V. BENEFITS OF PRACTICALS

The practicals and other materials described in this paper provide the following benefits.

- Hands-on**:** The practicals are hands-on and reinforce learning.

- Usefulness: The practicals are easy to set-up and use either in the classroom to enhance the lecture environment, or in the laboratory.

- Challenging: The practicals provide the students with a challenging yet friendly environment where they can test their knowledge of computer networking.

- Student-friendly: Students can learn at their own pace.

- Economical / Secure: Having students set up servers on removable hard disks has the advantage of leaving laboratory PC configurations unaltered for other users.

- Reusability: Students can reuse removable hard disks for other courses.

VI. EVALUATION BY STUDENT FEEDBACK

To assess their educational value, the practicals were evaluated extensively both formally by students and informally in discussion within the teaching team. The formal evaluation of the laboratory exercises was conducted in the classroom by a tutor, and the anonymity of the respondents was protected. As part of the formal evaluation process students were asked to complete a questionnaire. They were asked the following five questions.

(1) Prior knowledge: How well did you understand computer networking fundamentals before entering this course?

(2) Easy to follow: How easy (overall) did you find the laboratory exercises to use and follow?

(3) Measure of success: How effective were the laboratory exercises in helping you to improve your understanding of computer networking?

(4) Hands-on: Would you like to have more laboratory exercises of this kind as part of your course?

(5) Time to explore: Would you like to have extra time (apart from the scheduled laboratory time) to further explore the laboratory exercises?

A five-point Likert scale was used in the questionnaire. For Questions one to three, one on the scale was *Poor*, and five was *Excellent*; for Questions four and five, one was *No* and five was *Yes*. Over three semesters, 60 undergraduate students (about 60% male and 40% female) completed the questionnaire, and their responses are plotted in Fig. 3. The responses were interpreted as follows.

Forty-seven students have indicated that they had no prior knowledge of server-based networking before entering this course. Three students indicated that they had sound knowledge of server-based networking; whereas, the rest, 10 students, had some prior knowledge (Fig 3a). The lab exercises and materials were found to be reasonably easy to use and follow. Forty-two students were satisfied with the current version. Two students expressed some concern with the remaining 16 students being neutral (Fig. 3b). Forty-eight students indicated that the lab exercises had clearly assisted them in developing a better understanding of the concepts of server-based networking. However, two students indicated that they were not totally satisfied with the current lab materials; the remaining 10 students were neutral (Fig. 3c). Forty-four students indicated

that they would like to have more practicals in the course. Two students were not very interested in trying more lab exercises with the remaining 14 students being neutral (Fig. 3d). Forty-five students indicated that they wanted time outside the scheduled lab sessions to further explore practical activities. Eight students indicated that the scheduled lab time was adequate, and the rest, seven students, were neutral (Fig. 3e).

In summary, about 75% of the respondents felt quite positively about their experience with the practicals and wanted more; about 20% seemed to be indifferent; whereas, less than 5% were disaffected by some aspect.

The author observed that by participating in practical activities, students were motivated to learn about computer networking and enjoyed this course more than previous courses that consisted of lectures only. The author is seeking feedback regularly both from students and the teaching team for further improvement of the laboratory materials.
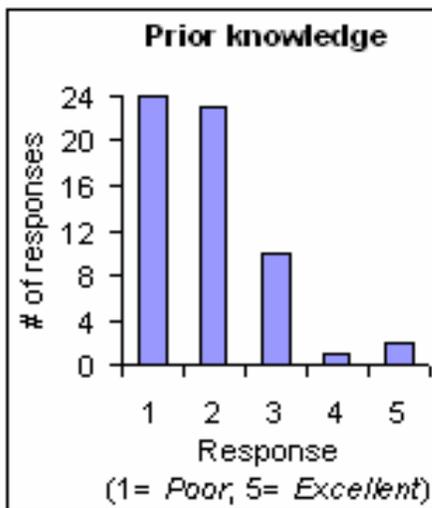

(a)
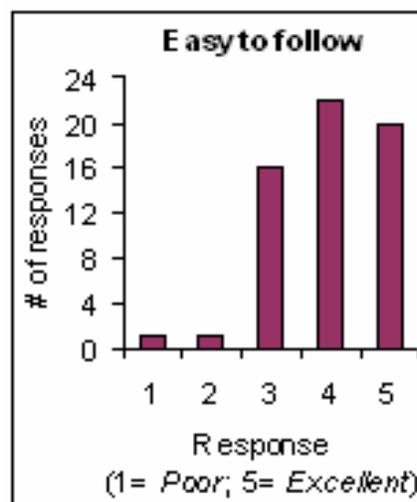
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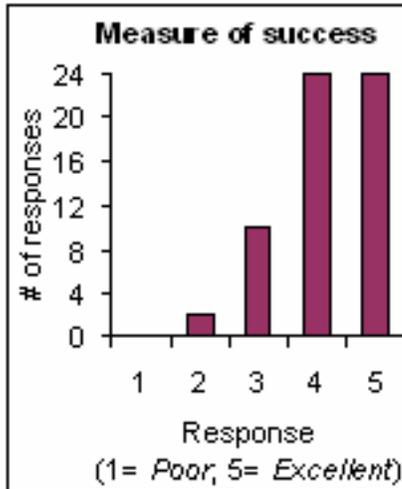
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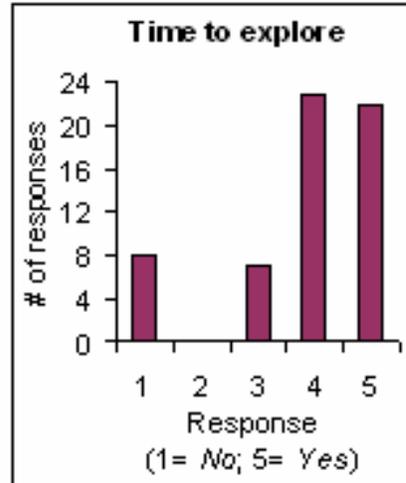
(d)
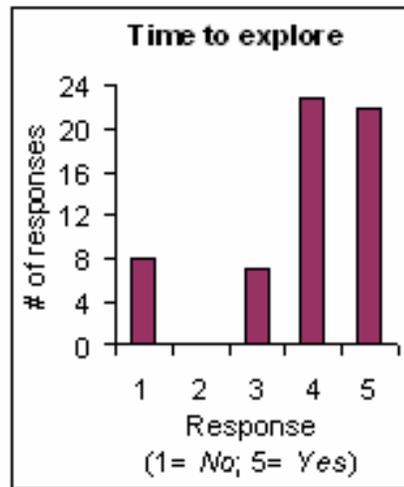
(e)

Fig. 3 Student-response graphs illustrating the number of respondents in each category for each of the five questions in the questionnaire.

VII.   IMPACT OF LABORATORY EXERCISES ON STUDENT LEARNING AND COMPREHENSION

As mentioned in section IV, the practicals have been used in the networking and telecommunications undergraduate course over the last two years, and the experiences of both the author and students is very positive. Students are highly motivated in learning computer networking concepts, including LAN administration and management, by doing practical activities, an observation confirmed by student feedback (Fig. 3c).

During 2001-2002, only computer simulation and animation were used to reinforce the theoretical networking concepts. However, students who completed the practicals attained a deeper knowledge of computer networking fundamentals. Particular topics in which students' learning and comprehension have been improved were as follows.

- Server hardware and software

- Server-based LAN design and configuration

- LAN administration and management

- TCP/IP networking (i.e., design, configuration, IP sub-netting)

To estimate (quantitatively) the impact of the practicals on student performance, an analysis of the student grades in the written final exam for the last four years (2001-2004) has been conducted. The performance of students with and without practice is shown in Table III.

As seen in Table III, the overall student pass rate in the final exam in both 2003 and 2004 is higher than in 2001 and 2002. Since the final exams were of comparable style and levels of difficulty, the higher pass rate can be accounted for by the students in 2003 and 2004 who used practicals; whereas, the students in 2001 and 2002 did not get an opportunity to use the practicals at all.

One could argue whether the results of the written final exam precisely reflect laboratory work. The final exam (closed book) was comprehensive and covered the material taught throughout the semester. Theory presented in lectures is enhanced by laboratory demonstrations and the practicals.

TABLE III
COMPARISON OF STUDENT PERFORMANCE IN THE FINAL EXAM WITH AND WITHOUT
PRACTICE

Semester	Year of study	With practice	Without practice	Student pass rate (%)
2	2001		√	74
1	2002		√	76
2	2002		√	70
1	2003	√		94
2	2003	√		95
1	2004	√		96

VIII.   CONCLUSION

A set of new laboratory exercises has been developed that can be used either in the classroom for class demonstrations, to liven-up the lecture environment, or in the computer laboratory for practical work in computer networking at an introductory level. Students evaluated the practicals, and their responses to the questionnaire were highly favorable. They indicated that they had found the practicals easy to use and that these helped them gain a better understanding of computer networking. The practicals also had a positive impact on students' performance. Results show that the students with practical experience scored better in the final exam than those without practical experience. More practicals, such as network printing and routing, are under development. The practicals described in this paper can be applied to courses in other fields, such as computer engineering. The author's ongoing effort is to develop more networking courses following this practical learning approach.

ACKNOWLEDGMENT

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