TEACHING LAB-BASED COMPUTER NETWORKING THROUGH PERFORMANCE-CENTERED APPROACH

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Abstract

This paper describes the curriculum design of performance-cantered learning course of lab-based computer networking.

The course is compulsory for students of engineering specialties in the field of communication and computer engineering. The objectives of the course, the structure of the curriculum content, the type and the specificity of the studied and simulated practical computer networking lab experiments are described.
The organization of the training activities is carried out through an e-learning management system for performance-centered learning – DIPSEIL (https://v4.dipseil.net/). A brief review of the DIPSEIL system is made of its Performance support system implementation methodology in engineering education and the basic educational tools used by lecturers and students.

The design of the course in the DIPSEIL system is organized around tasks for performances from the students. The concept of "learning by doing" is used, with about six lab experiments running for 12 weeks and one final project for final assessment of students' knowledge. At a macro level, the course is organized as a blended learning course (face-to-face lectures and exercises, web based learning activities in LMS and practical lab experiments) in the DIPSEIL e-learning environment - https://v4.dipseil.net/.

The course organization provides a constant relationship with a teacher and colleagues via email, in the e-learning environment and through chats, monitoring and feedback. The results from experiments show that students who used DIPSEIL system in a performance-centered course perform significantly better on learning tasks for solving problems and practical lab experiments in computer networking than students that are imposed to traditional methods.

Keywords: performance-centred learning, lab-based computer networking, DIPSEIL learning environment

1 INTRODUCTION

The telecommunications sector is an area of high growth in the world economy and its important stimulator. This growth is dictated by the emerging need for faster and better telecommunications services.

The subject Computer Networks is fundamental for engineering students studying computer and communication systems because more and more modern telecommunications are based on the use of TCP/IP protocols for data transmission of voice, video and multimedia.

There are many different textbooks on computer networks, which are taught in both undergraduate and graduate level courses and introduce students to the theoretical foundations of data transmission, OSI model, different architectures and protocols working on the Internet.

By studying the theoretical aspects of computer networks, in most cases students do not acquire the necessary practical skills and hands-on experience with real networks and network hardware.

Realizing such shortcomings of traditional networking courses, some researchers have been developing complementary lab-based networking courses [1], [2], [3], [4].

Our literature study shows that practical laboratory experiments in computer networks that can be used in engineering education are shifting to simulations and the use of virtual laboratories instead of working with real network hardware [5], [6], [7], [8].

The use of practical laboratory exercises in the training of engineering students is fundamental in providing solid theoretical knowledge and practical skills and competencies that explain the abstractness of the taught material and turn it into practical experience.

Accordingly to [7] three main practical laboratory delivery methods have been identified, which are characterized by different use of hardware, software and virtualization technologies: physical lab, hybrid Lab and virtual laboratory solutions.

Some authors believe that there are limitations in the use of real hardware - network switches, routers, etc., related to the high cost, need for maintenance, upgrades, and the need to plan access to the real laboratory with a limited number of spots. To address these limitations, hybrid and virtual networking laboratory models are offered in the training of students in a university environment.

Physical Network Laboratories are characterized by 100% use of real network hardware, through which students gain valuable practical experience in the physical network environment in which they apply the acquired theoretical knowledge. Accordingly, to [9], the lab configuration and set up may vary accordingly to business case, requirements and related factors including cost, maintenance and operability.

Hybrid Laboratory models feature the integration of virtual software components into a real physical network configuration. To make it easier for teachers to design and use complex network experiments while improving students' learning experiences, hybrid laboratories offer a number of networking capabilities such as IPv4 , IPv6 routing, Secure Socket Layer (SSL) and Open Virtual Private Network (VPN) [10]. Main disadvantages are identified in high system requirements of the equipment that will host the virtualized instances and general issues related to physical IT networking hardware such as cost, maintenance and frequent upgrades [7].

Pure Virtualization Laboratories are characterized by a complete virtualization of physical networking devices and their related interconnection. They are usually deployed on an open-source cloud platform in combination of different virtualization technologies [7]. Virtual Networking laboratories are based on the use of software such as Cisco Packet Tracer and GNS3, which allows students to create, manage, install and study complex network topologies in a closed and secure environment without affecting external real networks or telecommunications devices [11]. Graphical Network Simulator-3 (shortened to GNS3) is a network software emulator first released in 2008. It allows the combination of virtual and real devices, used to simulate complex networks. It uses Dynamips emulation software to simulate Cisco IOS.

However, this type of program offers limited functionality and features in terms of switching / routing capabilities. The main limitations are identified in the inability to support some network protocols and Internet operation, Cisco operating system (IOS) and ISO routers, inability to connect to existing IT network infrastructure and reasonable minimum requirements for the host machine. However, GNS3 cannot replace the real use of physical hardware such as routers and switches as it provides students with virtual copies with low fidelity compared to real networks.

Limitations and disadvantages of Hybrid Laboratory models and Pure Virtualization Laboratories create the necessity of the implementation of a laboratory solution within a real hardware devices capable to address and overcome those drawbacks through the enhancement of network reliability, efficiency and stability factors.

In addition to real-world lab experiments, the use of Pure Virtualization Laboratories solutions such as GNS3 and other useful software for Layer2 frame analysis, IP packets and datagram analysis such as Wireshark, Advanced IP scanner, and NMAP should not be ruled out.

These virtual tools and real-world software solutions must be carefully combined with the use of physical network hardware such as switches, routers, access points, optical network equipment and thus increase students' knowledge and practical skills for analyzing network traffic and simulating complex network topologies.

In order to provide engineering students practical knowledge on basic networking subjects such as physical layer, data link layer, network and routing configuration, routing protocols, IP address allocation, remote connection with telnet or Secure Shell (SSH) we have created lab-based with real hardware computer networking course which is presented to students through performance-centered learning approach.

2   A STRATEGIC ADOPTION OF PERFORMANCE-CENTERED LEARNING

Performance-centered learning is an approach to teaching and learning that emphasizes students being able to do, or perform, specific skills because of instruction. In this framework, students demonstrate the ability to apply or use knowledge, rather than simply knowing the information. Performance-centered learning (PCL) typically includes activities and tasks that are authentic and meaningful to the students. PCL focuses on how the content is taught and assessed, not on the specific information covered in a course, so it can be applied across different content areas and instructional levels.

Adapting existing courses to the PCL model provides an opportunity for faculty to think through the goals and pedagogical approach for their course. It does not require that course content be changed, nor does it dictate how a course will be taught, or limit the instructor's creativity. All courses can be adapted to a PCL framework with the instructor retaining full control over how the course will be delivered. To adapt courses to the PCL model, the emphasis shifts from evaluating what the students know to a more student-centered focus of evaluating what the students are able to do with their knowledge and skills.

Computer networking as a subject in engineering education and the design of complex computer networks and topologies, by its very nature, is project driven; therefore, from the outset, project-based learning (PBL) with addition of Performance-centered learning has been identified as the pedagogical tools best suited to the teaching of the lab based networking course. These pedagogical approaches are well established and there are many studies. [12],[13],[14],[15],[16].

The Faculty of Physics and Technology of the University of Plovdiv has for many years used the method of project-based learning and performance-cantered approach for students in engineering specialties in the field of electronics, computer and communications and information technologies. For this purpose, a specialized Learning Management System (LMS) - DIPSEIL (https://v4.dipseil.net/) is developed, based on the method of project-based training and performance support systems by solving real-world engineering tasks from the respective scientific discipline [14] ,[16].

The main characteristic, which distinguishes DIPSEIL LMS from other LMS', is the Performance-Cantered learning method [16] and the system geographical distribution. The use of Performance-cantered learning method in Higher University education leads to different course design where all educational activities and student learning paths are integrated around of "tasks for performances". This means that all learning content is divided in small tasks which student has to perform for a given time period for example 1 or 2 weeks. The tasks are with practical approach and the student has to perform it and solve many practical problems, which are related with the learning outcomes which course design has defined. For each task, DIPSEL LMS offers 5 educational virtual instruments: task description; task specific training; reference information; instructions how to perform; expert advises; connection with remote labs. These virtual educational instruments contain the all the information which student needs to perform the task. The task description instrument contains a file, which forms the task – it can be any web page, multimedia file, schematics and so on. Task specific training instrument is built by DIPSEIL learning objects designed to supply the theoretical foundations and the necessary minimum of knowledge related to the task. Reference information about the task virtual instrument provides dynamically web-links and external for DIPSEIL content regarding the task – more information, books, bibliography, etc. Instructions how to perform is fundamental virtual education instrument which provides students with specific instructions for dealing with the problem - a sequence of actions, the algorithm to work, concrete steps in implementing - measurements, simulations, etc. Expert advises educational instrument is a tool by means of which the student meets predefined expert advice from experts or automated expert system for performing the task. For performing complicated engineering problems in the field of Electronics, Communications and Information technology, DIPSEIL LMS offers a connection with remote laboratories for performing experiments in real time.

3   COURSE STRUCTURE AND OBJECTIVES

The course "Computer Networks" is taught in the 5th semester of the 3rd year of all engineering specialties of the Faculty of Physics and Technology of the University of Plovdiv. Prior to this course, students study fundamental disciplines such as Electrical Engineering, Electronic and Semiconductor Devices, Analogue Electronics and Digital Electronics. The learning objectives of the course is to acquaint students with the basic knowledge for the computer networks, OSI model, Physical layer, Data link layer, IP v.4 protocol, TCP/IP, different routing protocols and their usage.

The key aims of the course are to ensure that students gain a general theoretical understanding of the design, operation, and performance of network architectures and to appreciate the practical issues and processes involved in actual network design. To achieve these goals, a three-threaded delivery approach is adopted as shown in Fig. 1.

COMPUTER NETWORKS COURSE

LECTURE THREAD

Theoretical understanding of computer networks, topologies, protocols and operation

1. OSI Model
2. Physical Layer
3. Data Link Layer
4. Network Layer,IP v4., v6.
5. Transport Layer – TCP/IP
6. Sesion Layer
7. Presentation Layer, SSH
8. Application Layer, HTTP
9. Network Security

LAB EXPERIMENTS THREAD

Practical Lab experiments with real networking hardware
1. Design and imple-mentation of LAN with structured cabling
2. Optical network design and implementation
3. Layer 2 basics. Setup of managed switch. Create VLANs and Trunk ports.
4. Routing. Setup Ubiquity router. DHCP server. Setup static routing and NAT rules.
5. Wi-Fi experiments. Setup Wi-Fi access point.
6. Create and research of Wi-Fi link bridge.

DIPSEIL LMS PROJCT AS A SOUTION FILE

1. Simulate the designed and implemented in LAB 1 computer network using GNS3. Upload as a solution file in Dipseil LMS.
2. Upload a solution file for the optical network in LAB2.
3. Simulate the network topology of LAB3 and upload the results as a solution file.
4. Simulate the network topology of LAB4 and upload the results as a solution file.
5. Upload solution file for LAB5
6. Upload solution file for LAB6

FINAL ASSESMENT WITH MCQ TEST – 50%

TWO ASSESMENTS WITH MCQ TEST – 25%
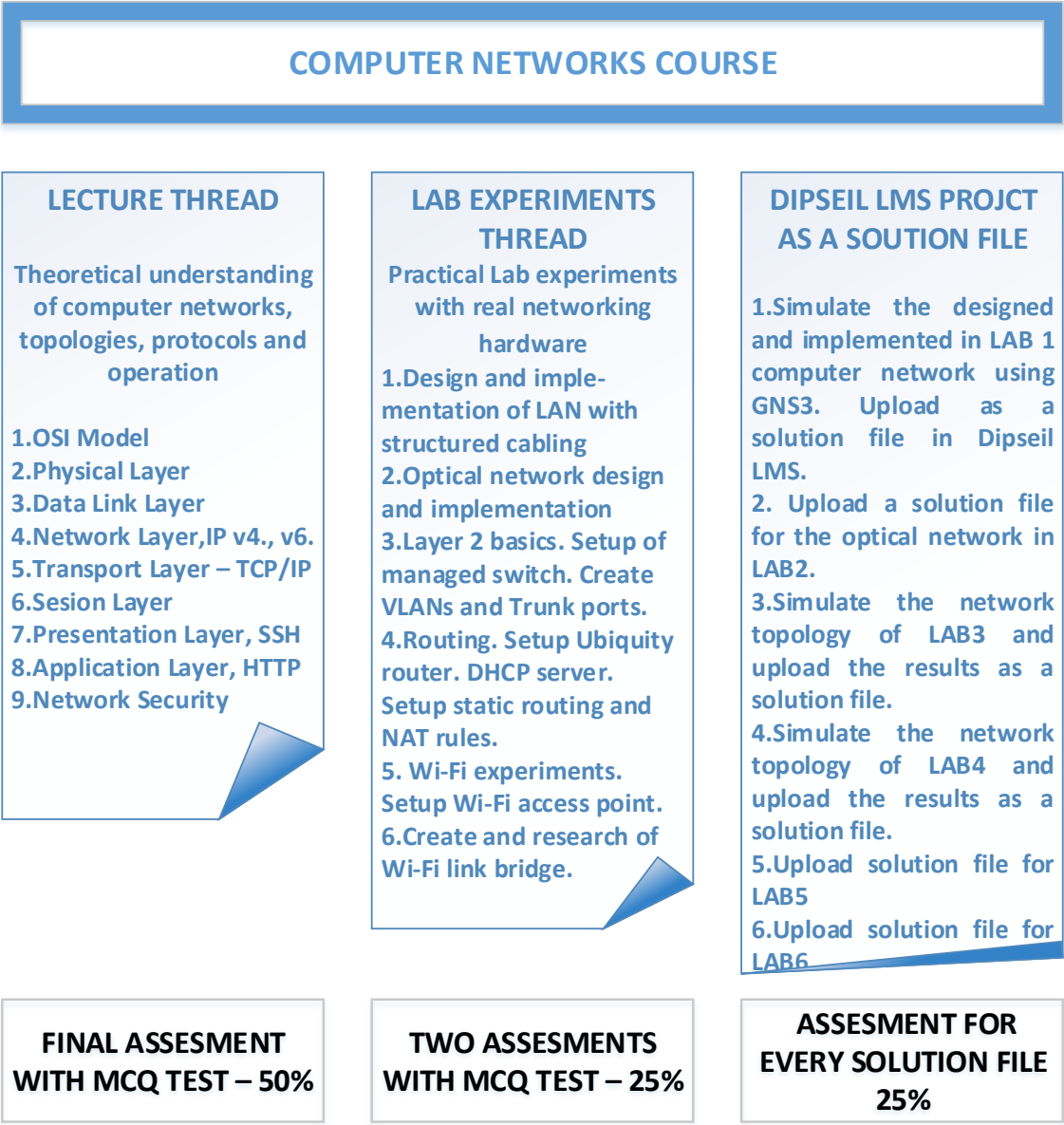
ASSESMENT FOR EVERY SOLUTION FILE 25%

Fig.1 Three thread delivery approach

This approach comprised a lecture thread that is used to convey the theoretical understanding of the operation of computer networks, Lab experiments thread that is intended to develop the student's practical skills to design, deploy and setup network topologies, and project based learning thread, which ensures the students with knowledge for simulation and design of complex computer network projects.

The lecture thread is delivered as 30 hours of lectures in which the class contact sessions are used for discussion and debate of key issues, and supported with online materials made available through the DIPSEIL LMS. This aspect of the module is carefully designed to take the students on a journey through basic computer networks theory. It is starting with the basic LAN topologies, the OSI model, Physical and Data Link layer. Then the IPv.4 and IPv.6 protocols are introduced with TCP/IP suite of protocols. From here, Session and Presentation layer protocols are described, followed by Presentation layer functionality. Next, a review and understanding of network security aspects are

discussed, which led into a detailed analysis of issues relating to protecting an organization's network infrastructure. Assessment of the lecture thread is carried out by a 30 multiple choice questions computer based test made in faculty, which carry a weighting of 50%.

The LAB experiments thread comprised 24 hours of lab works with real networking hardware and is designed to complement the lecture thread by placing the students in a situation where they are required to work with real-life network hardware equipment. Here, performance-centered and project based learning approach is used specifically to develop hands-on experience and practical skills to setup and maintain managed network switches and routers. All lab experiments are organized around tasks for performance, as DIPSEIL LMS require it. Another 6 hours are left for working with network simulation software GNS3 for simulation of complex networking topologies. Two assessments after each block of three lab works are performed out by 30 multiple choice questions computer based test which students made in faculty, which carry a weighting of 25%.

After each lab work, the students are asked to develop a small project in written form or a simulation of the network topology, which was experimented with the real-life hardware equipment and to upload it in DIPSEIL LMS as a solution file. Each task for performance is assessed individually and the student receives a grade for it. Then the final grade for this thread is formed by all six task for performance solution grades and carry a weighting of 25%.

Table 1.Class schedule with lecture topics, Lab experiments and tasks for performances in DIPSEIL

Week	Content	LAB Experiments	Tasks for performances in DIPSEIL LMS in form of solution file
1-2	**Lecture:** Basic Network topologies. OSI model of computer networks	Wiring and assembly of a computer network with FTP cable, 24-port patch panel, computer sockets and 24 port managed switch. Network testing.	Submit a task for performance in DIPSEL LMS with simulation results for the network assembled in lab experiment
3-4	**Lecture:** Physical Layer. Network transition media. Fiber optic communications.	Wiring and assembly of a computer network with single mode fiber optic cable, 2 optical distribution frames with 12 ports. Use media converters and SFP modules. Network testing.	Submit a task for performance in DIPSEL LMS with simulation results for the network assembled in lab experiment
5-6	**Lecture:** Data Link Layer. Network Layer. IPv.4	VLANs setup of managed switch. Define access ports and trunk ports. Spanning tree protocol setup in a series of 3 interconnected managed switches.	Submit a task for performance in DIPSEL LMS with simulation results for the network topologies used in lab experiment.
7-8	**Lecture:** Network Layer. IPv.4. Routing protocols. Transport Layer	Setup managed router for static route to 3VLANs with different IP networks.	Submit a task for performance in DIPSEL LMS with simulation results for the network topologies used in lab experiment.
9-10	**Lecture:** Session Layer	Setup Wi-FI network with access points (AP) and software/hardware controller. Setup access lists and different authentication WPA2/WPA3	Submit a task for performance in DIPSEL LMS with simulation results for the Wi-Fi network used in lab experiment.

11-12	**Lecture:** Presentation Layer.	Setup Wi-Fi bridge between 2 networks using parabolic antennas.	Submit a task for performance in DIPSEL LMS with simulation results for the Wi-Fi network used in lab experiment.
13-14	**Lecture:** Application Layer. HTTP, SMTP, IMAP, FTP	Capture and analyze of network traffic with Wireshark	Submit a task for performance in DIPSEL LMS for analyzed network traffic.
15	Lecture: Network security	Setup VPN tunnel between 2 managed routers.	Submit a task for performance in DIPSEL LMS for the tunnel from lab experiment.

Table 1 describes the Class schedule with lecture topics, Lab experiments and tasks for performances in DIPSEIL.
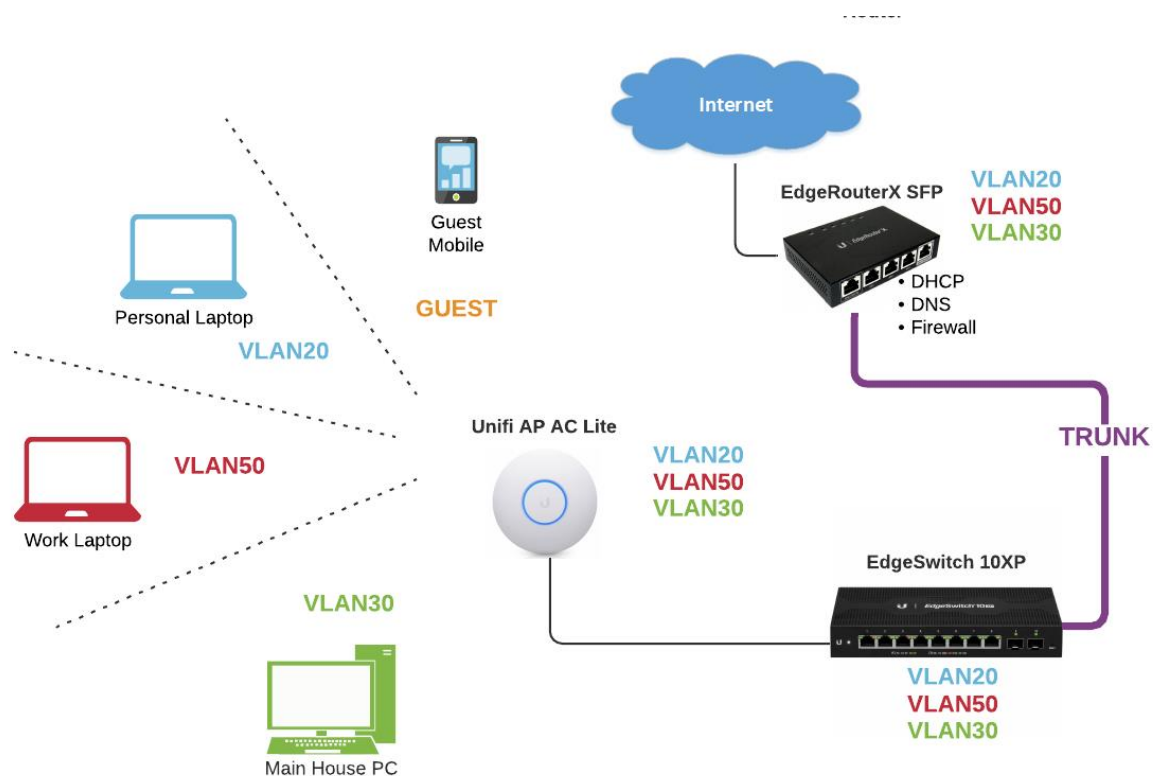
Fig.2 Task for performance for LAB4

Fig.2 shows the task for performance which the students have to solve in the lab4 (week 7-8). The task to perform is the following: Create the network topology from Fig.1. Connect the SFP port of the ER-X SFP router to an optical fiber in the network lab that connects you to the Internet and receives DHCP settings. Configure 3 virtual networks both in ER-X router and in EdgeSwitch10XP VLAN20, VLAN30 and VLAN50 each with its own DHCP server distributing network addresses in a different networks. Configure Trunk port on ER-X eth0 and port10 on EdgeSwitch10XP. Test the network configuration and make sure everything works. Report all settings in a solution file and upload it into DIPSEIL LMS.

4   RESULTS

In our research the question is how effective is the use of performance-centered approach along with project-based learning methodology provided by DIPSEIL system in the domain of lab-based computer networking course.

The main requirement is to ascertain the students' perception of the module of laboratory experiments with real networking hardware and in particular of the achieved effectiveness of performance-centered approach and project-based learning as pedagogical methodologies. For this purpose, an assessment questionnaire was developed, which was given to the students after the last lab experiment.

The results from this questionnaire are presented in Table 2 in which students were asked to score each question in the range of 0 to 4 and where the satisfaction level is a weighted average of these scores for each question. A maximum score given by all students for a given question would result in a satisfaction level of 100% for that question

Table 2.Questionarie results

Question	Satisfaction level
The performance-centered learning sessions in DIPSEL LMS for computer network lab experiments module improved my understanding of the knowledge that lectures provided.	84%
The performance-centered learning sessions helped my understanding of theoretical statements about the operation of computer networks.	82%
The performance-centered learning sessions have improved my hands-on experience and practical skills to setup and maintain networking hardware.	78%
I appreciate the efectivness of project based training in laboratory experiments sesions on computer networks.	80%
Having participated in both performance-centered and project based learning sessions my confidence and ability to setup complex real network topologies has been enhanced.	72%
The project based working sessions helped my ability for teamwork.	84%
The performance-centered learning and project-based training were well organized and effective.	74%
The performance-centered learning and project-based training should be kept as pedagogical methodologies for teaching lab based computer networking.	90%

Overall strong support for the specific use of performance centered training (PCL) and project based learning (PBL) pedagogical approaches are exhibited in this questionnaire. This support is evidenced by the consistently high satisfaction levels, with all respondents strongly rating PCL and PBL as having helped their understanding of the theoretical aspects of computer network operation. Similarly, students acknowledge that the PCL and PBL sessions have improved their hands-on experience and practical skills to setup and maintain networking hardware. Students have also generally acknowledged that the PCL and PBL sessions have helped to enhance their confidence in being able to setup complex network topologies. The PBL sessions have assisted the students, the authors believe, in teamwork. Finally, support exists for PBL to be retained as a key pedagogical tool for the delivery of lab based networking course in engendering education.

5 CONCLUSIONS

This paper has described the experience and philosophy behind the use of PCL and PBL methodologies to facilitate the teaching of lab based computer networks course to students in engineering specialties in telecommunications and information systems at the Plovdiv University "Paisii Hilendarski", Plovdiv, Bulgaria. Teaching students how to gain practical hands-on experience in working with real-life network hardware represents a challenge. A three threaded approach was adopted in which a lecture thread was used to develop the students' general understanding of computer networks theory and its operation , LAB experiments thread that is used to facilitate students to gain hands-on experience to setup and maintain networking hardware and a PBL thread that is used to develop design skills. The design of the LAB experiments thread exploited the practical experience of the module facilitators and allowed the students to take on the role of network administrators, working with real-life networking hardware and scenarios that had a strong practical dimension and realism. Evaluation of this PCL and PBL methods has indicated generally strong support from the student cohort, reflected in an encouraging set of results obtained from the lab based computer networks course.

ACKNOWLEDGEMENTS

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