

AC 2007-1636: THE DEVELOPMENT OF A DIGITAL TELECOMMUNICATION LABORATORY

George Moore, Purdue University

George Moore received the PhD degree from the University of Missouri in 1978. From 1978 to 2001, he was a member of the technical staff at Bell Laboratories and Lucent Technologies. Currently, he is an assistant professor at Purdue University, West Lafayette, Indiana. His interests include software methods, telecommunication and distributed networking. He is a member of the IEEE, the IEEE Computer Society, and the ACM.

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Abstract

This paper describes an approach to the analysis, design and development of laboratory requirements. It uses learning objectives derived from laboratory experiments, as one component in an equipment selection process. We then delineate our strategy for a comparative assessment of this approach to one less directed.

The laboratory experience is an active learning experience that increases the technological, scientific and quantitative literacy of students; because it engages major cognitive processes which lead to meaningful learning. This higher order thinking allows students to assimilate, apply and retain more fully the information learned. The assimilation of information is of critical importance to students pursuing degrees in science, technology, engineering, and mathematics, for it represents an accumulation of the body of knowledge of the discipline. Research shows that educational institutions facilitate the development of critical thinking when they incorporate an active learning style in their instructions and laboratory experiences. Experiential learning models presents us with the four modes on which learning styles are based – concrete experience, reflective observation, abstract conceptualization and active experimentation. Studies conducted on knowledge retention, found that using these learning modes, individually and in pair wise combination, from twenty –to- sixty percent increase in retention has been achieved. However when experiments are designed that includes all four stages of learning, retention rates of approximately ninety percent are possible. The laboratory experience supports experiential learning by emphasizing practical application, i.e. learning to do by doing. It is therefore an example of the “active experimentation” learning style exclusively; however, what is not clear is the extent to which the retention of technical knowledge can be enhanced by laboratory experiments that are systematically developed and structured with components from the various learning styles.

Recently the department was presented with an opportunity to update its digital telecommunication laboratory around state of the art communication equipment. There were several issues surrounding this equipment acquisition. Ultimately we sought to determine just what equipment we should select. Given our concern with experiential learning, we saw this as an opportunity to reexamine our laboratory experiences incorporating components from the various learning styles. We then used elements derived from these experiments as criteria for our equipment selection. We did not expect the results from this component would lead to the selection of a specific piece of equipment; rather we believe it establishes a framework on which the desired capabilities of our laboratory facility can be based. This aspect of our work guided our requirements and ultimately our equipment selection.

This study indicate that the craft interface, a component often de-emphasized in equipment acquisition in academic telecommunication laboratory, may significantly enhance the experiential learning of the participants, when it provides visual renditions of network elements, and network topologies, and the ability for the participant to centrally control the operations, administration, maintenance, provisioning and testing of the elements in a digital telecommunication network.

I. Introduction

Laboratory experiments are a major instructional component in the Electrical Engineering and Computer Technology curriculum at Purdue University and at many other peer institutions. Our laboratory experiences require students to gather information regarding the equipment; interpret specific problem spaces; select an appropriate subset of the equipment to address the specific problem at hand; develop a strategy for equipment, component and sub-system interconnections; make measurements on devices, component, and sub-system; and finally report their findings based on an analysis of their collected data. We have embraced this approach because it engages the student's major cognitive processes, thereby leading to more meaningful learning. Research suggests that this higher order thinking allows individuals to assimilate, apply and retain more fully the information learned^{1, 6, 7, 8, 9, 11, 12.}

Recently the department was presented with an opportunity to enhance the capabilities of its digital telecommunication laboratory around state of the art communication equipment. We sought to establish equipment selection criteria using conventional components and to also derive them from our experiences in experiential learning.

In the sections that follow we describe the selection criteria and the resulting equipment acquisition. Section II discusses the pedagogical issues being addressed. Section III describes the set of laboratory experiments on which the learning criteria are derived. Section IV discusses the design of our selection criteria. Section V describes the resulting laboratory equipment, and gives an assessment on this methodology. Section VI contains inferences that may be drawn from this exercise.

II. Laboratory Equipment and Pedagogy

The telecommunication field continues to evolve at a tremendous pace. The ultimate challenge for those of us within the discipline is to have our instructional materials and our laboratory equipment advancing at a rate comparable to the technology. Universities often have great difficulty in establishing and maintaining their telecommunication laboratories, primarily because of the cost associated with telecommunication equipment. The approaches taken by most universities in meeting these challenges include: partnering with industries that in turn fund such facility, initiating equipment grant proposals through government funding agencies, or through the acceptance of donated equipment. In the case of grants and industrial partner, there is great latitude in the equipment choices that one can make. Equipment decisions can be made based on the type of laboratory experiences desired. This particular type of concern becomes secondary when the equipment is donated.

Laboratory experiences are used in academic curriculums to bring experiential learning to students. This type of learning emphasis practical application, i.e. learning to do by doing, and is therefore an example of an "Active Experimentation" learning style. There is a broad base of research supporting this type of instructional model^{2, 3, 4, 5, 10, and 13.}

Kolb⁷ in his book on experiential learning model presents four modes on which learning styles are based – Concrete Experience, Reflective Observation, Abstract Conceptualization and Active Experimentation. Concrete experience focuses on the personal involvement in experiences. The emphasis in this mode is on feeling as opposed to thinking. In the reflective observation mode the focus is on understanding the meaning of ideas and situations by carefully observing and impartially describing them. Here the emphasis is on understanding as opposed to practical application. Abstract conceptualization uses logic, ideas and concepts as its focus. The emphasis is on thinking as opposed to feeling. Lastly active experimentation focuses on actively influencing people and changing situation. The focus is on practical application as opposed to reflective understanding.

Stice¹² conducted a knowledge retention study. The study showed that when using abstract conceptualization (AC) exclusively, there was 20 percent retention by participants. Combining reflective observation (RO) with abstract conceptualization (AC) achieved 50 percent retention. When concrete experience was added the retention increased to 70 percent. The inclusion of all four stages led to 90 percent retention.

As an institution of higher learning, we are committed to the long-term goal of establishing academic experiences that support the development of critical thinking, and problem solving skills, in ways that expand the retention of knowledge within the technology. The objective of this work is to establish a set of requirements for laboratory equipment that incorporates aspects of experiential learning as a component in the selection process.

III Description of Laboratory Experiments in Digital Telecommunication

The candidate laboratory experiments for this study are those from our Digital Telecommunication course. This particular course is offered as a service to the Computer and Information Technology department at Purdue University. It includes the investigation of: the digitalization of analog signals, modulation of digital signals, signaling techniques, multiplexing, de-multiplexing, and protocols. We discuss: the application of transport technologies utilizing the underlying digital communication protocols, the transfer of digital information through diverse communication media. The practical application of the technologies and protocols are investigated in the laboratory.

The Digital Telecommunication laboratory consists of approximately fourteen experiments. These experiments can be classified into three broad categories; (1) basic experiments on laboratory instrumentation and telecommunication concepts, (2) network services provisioning and (3) distributed/multi-nodal network services. A description of these experiments is given in table 1 and the section that follows.

Table 1 Description and Characterization of Laboratory Experiments

No	Description	Category
01	Introduction to the Laboratory	Basic Concepts
02	Instrumentation and Measurements	Basic Concepts
03	Analog-to-Digital Conversion	Basic Concepts
04	Pulse Code Modulation & Companding	Basic Concepts
05	Line Coding	Basic Concepts
06	Errors and SNR	Basic Concepts
07	Initialization of Network Elements	Network Services
08	Crossnet - Interconnections	Network Services
09	Crossnet – Service Provisioning	Network Services
10	Sonet Frames & Service Provisioning	Network Services
11	ISDN – Equipment Basics	Network Services
12	ISDN – Service Provisioning	Distributed Network Services
13	ATM – Multi-Node Service Provisioning	Distributed Network Services
14	ATM - ATM Network Performance	Distributed Network Services

Lab Experiment 01 – Introduction to the Laboratory

The objectives of this are to have the students identify all the elements contained within the digital telecommunication laboratory, and explain the principal function of each. A fundamental component of this exercise is the differentiation of the laboratory’s test equipment, and its network elements. In addition students must discover the locations of stored equipment such as cables, modems, terminators, etc. It is important that each student become familiar with “what” the equipment is, “how” and in “which” circumstances they might be required to use it. This lab is a forum for demonstrating the proper technique for handling the equipment.

Lab Experiment 02 - Instrumentation and Measurements

The overall objective of this lab is to have the students identify and apply methods of using basic test equipment to measure transmission line properties. Students are to interpret from these measurements the status of the transmission line facility being tested. In addition students are expected to identify the operations, capabilities and limitations of the test equipment used and describe the pieces of equipment most appropriate for different measurements.

Lab Experiment 03 - Analog-to-Digital Conversion

This particular lab as currently structured, is a simulation lab with several objectives. The first objective is to have the students calculate using the analog-to-digital conversion process, specific binary and hexadecimal values for various analog signals. Student must interpret from these calculations the relationship between conversion range, and step resolution. Another objective is to have the students determine the relationship between input signal frequency and the sampling frequency. A final objective is to have the laboratory participant determine empirically conversion errors, and to explain the concept of quantization errors.

Lab Experiment 04 - Pulse Code Modulation and Companding

This laboratory experience is structured as a series of simulation exercises. The overall objective is to have the participants apply a μ -law companding algorithm to an analog signal and determine in a piecewise fashion the significance of quantization errors on total signal error, and the significance of errors from compression losses.

Lab Experiment 05 – Line Coding

In this particular lab, participants begin by describing the AMI coding technique and the method used in the B8ZS coding scheme to maintain timing synchronization. The objective of the lab is to have the participants, given known line encoding schemes to understand the significance of “floating grounds” by demonstrating the setup, capture and measurement of such signals over a telecommunication transmission facility.

Lab Experiment 06 – Errors and SNR

This lab experience follows a lecture series on T-carrier system. The objective of this lab is to have the participant’s measure and compare the error handling features of Super Frame and Extended Super Frame and be able to explain the advantages and disadvantages of each framing scheme. In addition participants must discuss the relationship of bit energy, pulse density, and signaling rate and their effect on Signal-to-Noise ratio.

Lab Experiment 07 – Initialization of Network Elements

Each participant prior to this lab describes the primary functions of each network element. The objective of this lab is to have the participants familiarize themselves with the procedures for provisioning various network elements by having them perform administrative configuration of each element through its craft interface.

Lab Experiment 08 – Crossnet - Interconnections

This lab is the first in a two lab series focused on crossnet network elements. The objective of this particular lab is to have participants plan, and implement, point-to-point T1 connections between crossnets. The crossnets are provisioned for multi-channel Super Frame and Extended Super Frame service. Participants research and outline a procedure for validating the interconnection and the service.

Lab Experiment 09 – Crossnet – Service Provisioning

The objective of this lab is to have the students plan, establish, and verify end-to-end voice traffic between crossnet.

Lab Experiment 10 – Sonet Frames & Service Provisioning

In this laboratory exercise participants observe the attributes of Fiber Optics, and learn to properly test Fiber Optic cables using a Tektronix CTS-710. This experience also reinforces SONET frame structure values (e.g. H1, H2, A1, and A2). The objective is to have the participants plan for and implement a simultaneous voice and data transmission test over a fiber medium.

Lab Experiment 11 – ISDN – Equipment Basics

The objectives of this lab are to have the participants learn the basics of ISDN functionality and properly provision PRI and BRI modules on the Adtran Atlas 800plus. Participants create a plan for implementing the ISDN and voice call test.

Lab Experiment 12 – ISDN – Multi-Node Service Provisioning

The objective of this lab is to have the participants use the plan created in the previous laboratory experiment to provision two PRI/BRI locations. Participants must successfully complete an ISDN data transfer, observe and record ISDN transmission statistics.

Lab Experiment 13 – ATM – Multi-Node Service Provision

The ATM-Multi-Node Service provisioning lab has as its objective the establishment of end-to-end voice and data connection using all four of the Integrated Access Devices. The network must be configured however, to use the ATM protocol

Lab Experiment 14 – ATM Network Performance

The objective of this lab is to evaluate the performance of a network that is configured with an ATM switch network topology. Participants began to understand the use of virtual paths and channels in an ATM network and how they are provisioned.

IV. A Method for Establishing Equipment Selection Criteria.

Our digital telecommunication laboratory facilities consists of eight stations each equipped with a standard oscilloscope, power supply, a digital multi-meter, a Function generator, and an RF signal generator. Four of these eight stations are also equipped with a TSI-1524 DS-1 Multi-Channel BERTS, a Tellabs Crossnet 442 Network Multiplexing Node (obs), an ADTRAN 800 ADM w/ISDN Termination, and a Fore System ATM Switch Network platform. There is a single Tektronix CTS 710 Sonet Test Set for this lab.

We began establishing the equipment selection requirements by analyzing our current capabilities, and determined from these the sub-set of capabilities that we wish to retain. We then created based on this equipment a subset of our requirements. We then looked for capabilities that represented an enhancement to our laboratory, and from this, extracted requirements. Finally we tried to envision the laboratory of the future, and derived requirements from this component as well. The requirements resulting from this analysis are discussed in the sections that follow.

A. Current Laboratory Capabilities

Our analysis of the collection of experiments previous described suggested that these experiments can be grouped under three broad classification. The first group of experiments primarily focuses on a basic understanding of laboratory instrumentation and telecommunication concepts - basic measuring instruments, the Nyquist theorem, and PCM and line coding schemes. These particular experiments require basic laboratory instrumentation and are to be retained in future labs. The next class of experiments involves the provisioning of network elements for voice and data transmission. They require the use of a variety of technologies and mediums for point-to-point communication. The last class of experiments involves establishing voice data and video connections in a multi-nodal network.

The current 442 Crossnet Network Multiplexing node gives us the capability of aggregating voice and data over a T1 line. The units had become very difficult to administer and no longer have industrial support. We therefore wanted to replace them with comparable devices. An

examination of these experiments and the associated equipment used, suggested the following as requirements based on the current capabilities of our laboratory.

- Network shall be capable of economically supporting the integrated access of voice (Analog/Digital), data and high-speed Internet connections via T1 TDM networks.
- Network elements shall contain features that support an integral V.35 interface, IP routing and DSX-1 for PBX connectivity.
- Network shall be capable of extending analog or T1 station ports from a central PBX to remote phones over a point-to-point T1 link.
- Network elements shall support LAN connectivity.
- The network shall include a cost-effective carrier-grade fiber multiplexer that supports: Ethernet interfaces, OC-3 interfaces, DS3/STS-1 ports, DS1s, and any combination of interfaces to deliver services over OC-3/OC-12 SONET.
- The network elements shall support IP, ATM, or TDM networks.
- The network elements shall support AAL2 (voice) and AAL5 (data) for ATM applications.
- The network shall support IP routing for internet access, Frame Relay, and PPP.
- The network should provide support for Layer2 PPP, Frame Relay, HDLC and ATM protocols.
- There will be an adequate complement of network elements to support four (4) independent laboratory stations.

B. Desired Enhancements

There are several enhancements that we desired for this laboratory. One critical one was wireless support. Neither the laboratory equipment nor any of the experiments are currently designed around wireless communication and the issues associated with administering and provisioning services over such facilities. We sought to ensure that this capability would not be mitigated as a result of our selection requirements. We therefore added the following additional requirement.

- The choice of network elements should not preclude the later expansion and integration of wireless network elements that support point-to-point connectivity.

Since our laboratory is a learning environment, we sought to determine if there were requirements that might facilitate experiential learning. In order to do this we collected information during the course, following each experiment on issues encountered during the exercises. Students were asked to respond to questions on difficulties encountered during the experiments and indicate what was learned as an integral part of their reports. We examined their comments, identifying difficulties that the students encountered. An overwhelming number of responses indicated their frustration in administering the 442 Crossnets. A significant portion of their responses as indicated in their reports, suggested that many of the students could not extrapolate the provisioning steps into a visualization of the networks that they were creating. This empirical data suggest that students may benefit from a laboratory network management tool, containing graphical rendering of the network elements, that gives them the capable of creating a holistic view of the network topologies and in addition display multiple views or each

network provisionable network element within the laboratory environment. This would permit the students to dynamically configure and provision the elements at their respective station or multi-nodal network elements from a common terminal interface. Such a tool would significantly enhance the experience of the visual learner. This idea became a desirable component in our equipment selection; resulting in the following requirements.

- The laboratory stations should contain a network management tool that permits the visualization and provisioning of all network elements.

C. Laboratory Visioning.

The current laboratory in actuality supports four stations. Students must work in groups of from two –to- four in order to perform several of the point-to-point and point-to-multi-point configurations. Students are restricted to a single two-hour laboratory each week. It would be extremely useful for the laboratory to be so networked that various combination of laboratory equipment can be made remotely available to the students twenty-four hours a day, seven days a week.

- The laboratory stations and all the associate network elements should be capable of being administered and provision remotely.

Table 3.0 is a summary of the complete set of requirements developed for this acquisition. The table maps the requirements to current and future experiments that we envision for our digital telecommunication courses.

Table 3.0 Mapping of Requirements to Laboratory Experiments

Req#	Description	Experiments
1.0	Network elements shall be capable of economically supporting the integrated access of voice (Analog/Digital), data and high-speed Internet connections via T1 TDM networks	Lab 07 – thru- Lab 09
2.0	Network elements shall contain features that support an integral V.35 interface, IP routing and DSX-1 for PBX connectivity	Lab 09 Future Labs
3.0	Network shall be capable of extending analog or T1 station ports from a central PBX to remote phones over a point-to-point T1 link	Lab 08 & Lab 09
4.0	Network elements shall support LAN connectivity	Lab 09 Future Labs
5.0	The network shall include a cost-effective carrier-grade fiber multiplexer that supports: Ethernet interfaces, OC-3 interfaces, DS3/STS-1 ports, DS1s, and any combination of interfaces to deliver services over OC-3/OC-12 SONET	Lab 10, Lab 13, & 14, Future Labs
6.0	The network elements shall support IP, ATM, or TDM networks	Lab 08 - 14
7.0	The network elements shall support AAL2 (voice) and AAL5 (data) for ATM applications	Lab 13 & 14
8.0	The network shall support IP routing for internet access, Frame Relay, and PPP	Lab 11, 12 & Future Labs
9.0	The network should provide support for Layer2 PPP, Frame Relay, HDLC and ATM protocols	Lab 11, 12 & Future Labs
10.0	There will be an adequate complement of network elements to support four (4) independent laboratory stations	All Labs
11.0	The choice of network elements should not preclude the later expansion and integration of wireless network elements that support point-to-point connectivity	Future Labs
12.0	The laboratory stations should contain a network management tool that permits the visualization and provisioning of all network elements	Lab 08 - thru-14 & Future Labs
13.0	The laboratory stations and all the associate network elements should be capable of being administered and provision remotely	Future Labs

V. An Assessment of the Digital Telecommunication Laboratory.

The digital telecommunication laboratory today consists of eight stations each equipped with a standard oscilloscope, power supply, a digital multi-meter, a Function generator, and an RF signal generator. Four of these eight stations are also equipped with a TSI-1524 DS-1 Multi-Channel BERTS, an ADTRAN 604 or 624 or 850 Integrated Access Device, an ADTRAN OPTI - 6100, an ADTRAN 800 or 800 Plus ADM w/ISDN terminations, and a Fore System ATM Switch Network platform. There is a single Tektronix CTS 710 Sonet Test Set for this lab. This set of equipment allowed us to replace the 442 Crossnet Network Multiplexing Nodes with the

ADTRAN 604/624/850 series Integrated Access Devices. It added to our laboratory sonnet capability through the ADTRAN OPTI-6100. Figure 1.0 is a picture of a typical telecommunication laboratory station.



Figure 1.0 Digital Telecommunication Laboratory Station

The requirement for a common cross platform visual network management tool could not be met with this equipment acquisition. This particular capability remains a desire of our telecommunication laboratory.

Selecting network elements based on required capacity and capabilities is not a new process. Most academic institutions and industries approach such acquisitions in a similar manner. However, there are to this author's knowledge, no known institutions that have attempted to incorporate an experiential learning component in their requirement. It should be pointed out that all hands-on laboratory experiments contribute to the learning process. The results of this experience suggests that an enhancement to this process might be facilitated when the requirements for a visual network management tool is included as a component in telecommunication laboratory requirements. Visual network management, across multiple network elements is more generally associated with user interfaces or ease of use requirements. Such a tool in a telecommunication laboratory can be used to create networks and serve as tutorials or other self-training tools for the learner. Vendors of network equipment provide some form of craft interface for administering their system. These terminal interfaces are in general command line driven and are therefore not user friendly. The fundamental feature desired by students who provision various network elements into a system is an ability to create and display a network wide view of connecting elements, at multiple points within the network and to also be able to select, configure, provision and test each network elements from a single terminal

interface. Although this capability has not been met with the equipment that we acquired through this experience, it does serve as a guide for future developments within our telecommunication laboratory.

VI Summary and Conclusions

This paper describes an approach to the analysis, design and development of laboratory requirements. It uses learning objectives derived from laboratory experiments, as one component in an equipment selection process. A strategy is developed for selecting the network elements. This strategy is derived from an analysis of the present capabilities of the lab and the desired capabilities of the laboratory we envisioned for the future. An experiential learning component was derived from student reports as well as through observations of students as they implement the laboratory experiments. The component derived from this analysis results in our requirement for a cross platform tool capable of creating, displaying and administering a broad cross-section of network elements. This requirement was not realized in the equipment acquired. The results of this work suggests that a visual network management tool with cross platform operation, administration, maintenance and provisioning capability may facilitate the learning process in a digital communication laboratory. It also the direction of future research in our study on tools for laboratory learning.

A comparative assessment of this approach to the more convention ones suggests that the learning requirement component provides a meaningful lead into the specification of user interfaces. In the case of a telecommunication laboratory, it may enhance the ability of students to familiarize themselves with network elements, network topology, and the servicing and provisioning of network elements through the use of a more robust craft interface.

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