A Cost-Effective Implementation of an Information Technology Laboratory

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Abstract – The implementation of an information technology curriculum relies heavily upon the creative use of institutional resources to maximize student access to technologies at minimum cost. This paper describes the design, implementation, and usage of a single multi-purpose networking technology laboratory to accommodate a student constituency of 250 majors. The flexible, cost-effective implementation provided an integrated solution to maximize student contact with technology while minimizing implementation and maintenance costs.

Keywords: Information Technology, Networking, Technology, Classroom, Cost Effective

BACKGROUND

The Information Technology program at The University of Southern Mississippi began as a transfer option for community college students majoring in computer programming technology. When implemented this option satisfied resource constraints of space, funding, and faculty. For the first two years, the option worked in that the degree offered was interdisciplinary with major courses provided by computer science and business. The only expenditure was faculty advisor time for less than fifty majors. This degree option might have continued, but a program accreditation visit required curriculum changes and the need for a separate degree program. An application for a new degree program was approved in 1997. The concept was to offer the degree as an interdisciplinary program with most of the required courses taken from different academic units within the university, e.g. computer science and business.

The interdisciplinary program would have been implemented; however, a proposal to establish an articulated degree program was approved by the National Science Foundation (NSF). Because of budget constraints and the difficultly of having a new degree program approved by the state governing board, university administration decided to utilize the approved interdisciplinary program to develop the new degree program. As a subcontract of NSF grant number DUE-9950085, the university received funds to develop a four-year articulated curriculum in computer networking. This funding provided the justification to acquire laboratory space and equipment that would not have been available otherwise.

LABORATORY DEVELOPMENT

New space was not available from university administration to accommodate the articulated degree program; however, space was reallocated from another academic unit to house it. The reallocated space provided a 1000 sq ft area for design, development, and implementation of the program. Additional space would not be available from university administration if needed, so the laboratory had to be highly functional to support multiple courses with laboratories. Twenty-one courses were developed to utilize the space which included a four-course sequence in local area networking, a four-course sequence in wide area networking, a four-course sequence in information security, a

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five-course sequence in Windows client-server networking, a two-course sequence in open source client-server networking, and a two-course senior capstone sequence. The faculty used a modified systems development life cycle as a guideline in formulating a workable solution – investigation, analysis, design, and implementation.

Investigation and Analysis

Since the laboratory would be used for more than one course, a compromise had to be made between network topology, hardware & software compatibility, space, and cost. The network topology for the laboratory had to be highly configurable to support multiple network configurations while different operating systems had to be accommodated for some courses.

The systems analysis showed that the laboratory network topology not only had to be highly configurable in the software sense, but also in the hardware sense. The network's physical layout had to be interchangeable, meaning that the network design had to allow for actual changes to the physical topology. Each course utilized the workstations and it was necessary to find a solution that would allow for different operating system installations on the same workstations. After much research, the solution was determined to be Removable Hard Drives (RHD) for the workstations.

Design

The RHD solution allowed the laboratory to leverage the investment in workstation hardware while minimizing cost and space requirement. The workstations were provided with a single RHD containing all of the software applications used by faculty and students for general computing and additional RHD sets were purchased to support other courses.

Two additional workstations with Microsoft Windows Server 2003 were used to maintain a stand-alone, Active Directory domain. The two systems provided centralized authentication, authorization, auditing, file and print services, network infrastructure services including DNS, DHCP, WINS, and MSDNAA software distribution services.

A flexible network infrastructure shown in Figure 1 was developed around the use of three networking devices: 1) a Cisco router was deployed to provide firewall protection, Network Address Translation (NAT), and Virtual Local Area Network (VLAN) routing; 2) a managed layer-2 switch in conjunction with the Cisco router provided multiple distinct broadcast domains; 3) four low-cost unmanaged hubs were used for workstation connectivity with up to eight workstations connected a hub with each hub connected to the layer-2 managed switch. Hubs were selected instead of switches to facilitate packet sniffing when using protocol or network analyzers.

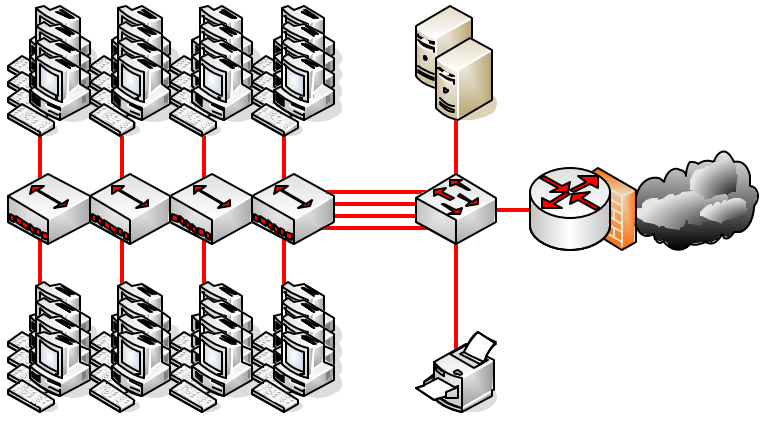

Figure 1
Laboratory Network Topology Diagram

To permit internet access, the outside interface of the Cisco router was configured with a campus IP address which managed internal dynamic and static routing for the laboratory. Network security was implemented by using Access

Control Lists (ACL) and Content Based Access Lists (CBAL) to block known hostile traffic (netbus, nimda, backorfice), to block access to certain sites (gaming or hacker), and to block student file downloads (MP3 and AVI). The Cisco router's inside interface was configured using IEEE 802.1q trunking and was provisioned for as many sub-interfaces as deemed appropriate. Sub-interfaces were designed with private IP addresses in compliance with RFC 1918. The first class B address space was selected and subnetted to provide 14 subnets with each subnet managing 4000 host addresses. This provided a sufficient number of subnets to support a wide array of instructional topologies and an adequate number of host addresses to permit student implementation of variable length subnet masks. This addressing scheme provided a unique subnet for each row of computers depicted in Figure 2. Students were provided sufficient addresses to plan, coordinate, and deploy redundant DHCP services for their subnet. Additionally, students could implement DHCP relay agents and deploy centralized DHCP services for multiple subnets from a single server.

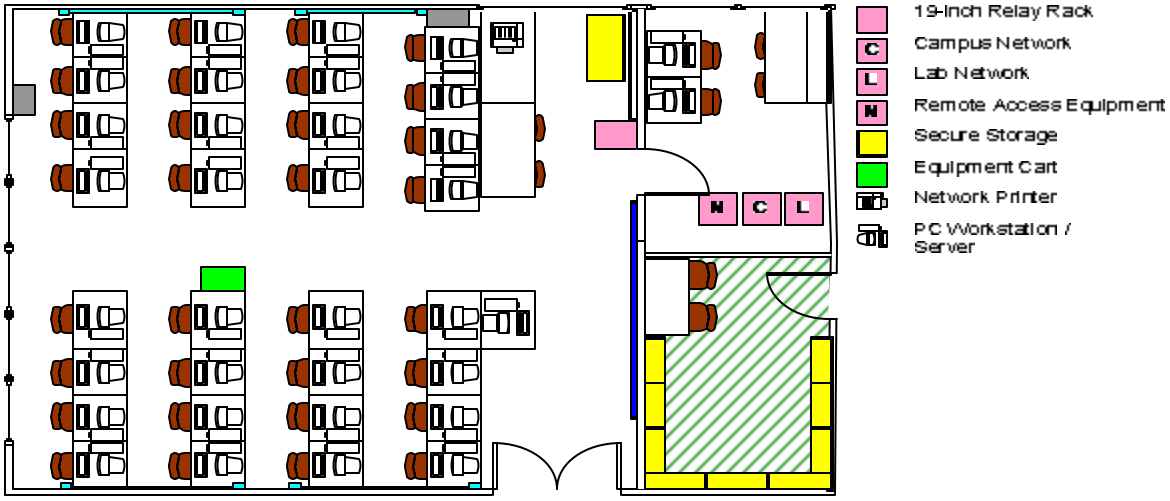

Figure 2
Physical Layout for 32 Workstation Laboratory

The design provided 14 subnets for the laboratory. One subnet was used for routine applications with 4-8 additional subnets left for instructional purposes. This design provided a flexible topology for lecture environments and all other instructional needs. A total of 14 VLANs were configured in this topology. The first six VLANs were allocated as indicated in Table 1. The remaining eight VLANs (112, 128, 144, 160, 176, 192, 208, and 224) were provided for future applications.

Table 1
Laboratory Network Virtual Local Area Networks

VLAN	Purpose	Network Address
VLAN16	Routine Use	172.16.16.0 / 20
VLAN32	Instructor Use	172.16.32.0 / 20
VLAN48	First Row	172.16.48.0 / 20
VLAN64	Second Row	172.16.64.0 / 20
VLAN80	Third Row	172.16.80.0 / 20
VLAN96	Fourth Row	172.16.96.0 / 20

Implementation and Management

The primary set of RHDs was configured so that all workstations were on a single broadcast domain and permitted student group activities such as reviewing online curricula, online testing, or other individualized student activity to be monitored by faculty. The software configuration for the primary RHD set included Microsoft Windows XP Professional, Office 2003 Professional, Projects 2003 Professional, Visio 2003 Professional, Visual Studio.NET 2003, Symantec Antivirus, Fluke Network Analyzer & Protocol Analyzer, NetFormx, Netscape, and Adobe Reader 6.0. This resulted in an installation in excess of 6 GB.

Using imaging software provided significant time savings over individual workstation installations. An open-source imaging and restoration package, *Ghost for UNIX* (G4U), was selected for use in the laboratory. The reasons for selecting this package included cost and the ability to deploy the created image from either CDROM or a local network FTP connection. The only drawback for this option required that all workstations have identical hardware.

To determine if imaging software could be justified, consider an example in which it would require six hours to configure and join a workstation to the network and then repeat this operation 31 times. For this example, it would require eight days to complete the laboratory installation. Obviously, this example would not be feasible to implement and would be impossible to maintain. With G4U, restoring a corrupted workstation image has averaged less than two hours and restoring the entire laboratory has averaged less than twelve hours.

As noted in a previous section, other RHD sets were purchased to support certain courses. Five RHD sets were needed to cover topics in NOS I, NOS II, Windows Networking, Linux I, and TCP/IP. Including the primary RHD set, this required 192 hard drives to populate six RHD sets for the laboratory. During a laboratory exercise, faculty would assign students individual RHDs onto which they would install an operating system. By changing uplink cables on the managed layer-2 switch, the laboratory was changed from a single broadcast domain to a segmented network with different VLANs. This permitted students to enable services such as DHCP, IIS, DNS, and mail services without interfering with the campus network or other students in the laboratory. Upon completion of the laboratory exercise, the layer-2 switch would be reconfigured to the default single broadcast domain.

COST ANALYSIS

A prime consideration in the development of the laboratory was the significant cost savings realized from a single multi-purpose laboratory compared to multiple single-purpose laboratories. Since space was fixed, it was even more important that the laboratory be able to satisfy all program course requirements. With ever increasing hardware requirements needed to support current operating systems, the laboratory has received three different workstation upgrades since 1998. From Table 2, it can be determined that computing performance increased with each upgrade; however, the acquisition cost remained about $700 per workstation. Display costs were similar with increased display quality while cost remained about $300 per unit. Each RHD required mounting frame for the workstation. This was a one-time cost of $50 per workstation. Since the RHD frame was a one-time expense, the recurring cost for the laboratory averaged $1000 per workstation on a three-year replacement cycle. No cost savings were realized when compared to one single-purpose laboratory; however, significant cost savings were realized when the $32,000 upgrade cost for the laboratory was compared to the $192,000 cost required to upgrade six single-purpose 32 workstation laboratories. The 192 RHDs used in the laboratory added another $19,200 to the initial cost. Once purchased the cost would not recur unless hard drive replacement was required. With the primary RHD set not considered, it could be stated that five additional single-purpose laboratories were obtained at no cost.

Table 2
Workstation Specifications

Generation	CPU	RAM	Video	Display	Media 1	Media 2	Media 3	Media 4
		(MB)	(MB)	(in)	FDD	CD	CDRW	CDRW/DVD
1998	P3-866	256	4	15-CRT	X	X	N/A	N/A
2001	P4-1.4	512	32	17-CRT	X	X	X	N/A
2004	P4-2.8	512	128	17-LCD	X	N/A	N/A	X

In addition to the workstation replacement cost, software cost had to be managed. Costs were minimized by the use of educational software, Microsoft Developer Network Academic Alliance (MSDNAA) licensing, and volume licensing. Use of the MSDNAA software in the laboratory reduced the cost of the initial procurement of the workstations as well as the upgrade cost for new operating system versions.

MSDNAA products allowed students access to the most current versions of a wide range of developer tools for educational use. MSDNAA products most frequently downloaded by students for use in their courses can be found in Table 3. Even with educational pricing most students would be able to purchase the software; however, with the MSDNAA program the only cost for students would be the $80 to obtain Microsoft Office 2003 Pro. The MSDNAA program permitted legal operating system installations by the students for the networking laboratory courses and students were permitted to legally download a copy of all MSDNAA products for their home use.

Table 3
Typical Student MSDNAA Software Downloads

Application Title	Educational Price	Student Source	Student Cost
Microsoft Windows XP Professional (Full Copy)	$300	MSDNAA	$0
Microsoft Office 2003 Pro	$240	Campus License	$80
Microsoft Projects 2003 Pro	$200	MSDNAA	$0
Microsoft Visio 2003 Pro	$160	MSDNAA	$0
Microsoft Visual Studio 2003 Pro	$90	MSDNAA	$0
Microsoft Windows Server 2003 (Full Copy)	$470	MSDNAA	$0
Symantec Antivirus	$33	Campus License	$0
Total	**$1493**		**$80**

For any laboratory yearly expenses will be incurred to maintain the facility. The recurring cost for the laboratory discussed can be found in Table 4. If these costs were compared to the cost of maintaining multiple single-purpose laboratories, additional cost savings would be realized. Using the previous example of six single-purpose laboratories, the recurring costs would be $48,600 per year.

Table 4
Recurring Laboratory Costs

Source	Cost per Year	Comments
Laboratory Supplies	$2000	Consumable laboratory supplies
Workstation Maintenance	$2000	PC Parts replacements
Labor (work study)	$3200	Work study undergraduates
MSDNAA License Agreement	$300	$600 startup, $300 renewal
Electronic License Management System	$0	Included with MSDNAA
Open Source License Agreement	$200	Annual acquisition of Linux master media
Monitoring Software License	$400	LAN School $400 per classroom
Antivirus Software	$0	University site license
Microsoft Windows XP Pro	$0	MSDNAA Lab License
Microsoft Office 2003 Pro	$0	University campus license
Microsoft Projects 2003 Pro	$0	MSDNAA Lab License
Microsoft Visio 2003 Pro	$0	MSDNAA Lab License
Total	**$8,100**	

LIMITATIONS

With 21 unique courses offered in the laboratory, it had to be operational at all times. Workstation repairs could only be accomplished between class changes. Because of the time required to deploy an image, a restoration schedule had to be developed for OFF peak periods, e.g. nights or weekends. With the laboratory used for instruction over 80 percent of the time, students had limited access to the laboratory. To provide more open periods, the laboratory was

opened on weekday evenings and weekends. The management of the laboratory required a level of technical competency common for faculty within the field, but would be beyond the abilities of non-technical faculty using the facility.

CONCLUSIONS

A single multi-purpose laboratory is presented that provides a cost-effective integrated solution to maximize student contact with technologies while minimizing implementation and maintenance costs. The advantage of this laboratory design is cost savings in equipment, software licenses, student labor, and laboratory supplies. The major disadvantage to this design is that it is a single space. The laboratory is utilized over 80 percent of the time during normal business hours which limits scheduling options, workstation repairs, image restorations, and extra laboratory time for students. If space is limited to a single area when planning an information technology program, then the laboratory design presents a workable solution.

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