AC 2011-1107: ENHANCE COMPUTER NETWORK CURRICULUM US-ING COLLABORATIVE PROJECT-BASED LEARNING

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Enhance Computer Network Curriculum using Collaborative Project-based Learning

Abstract

It has been widely recognized that hands-on design and implementation is one of the essential skills that students should acquire to become qualified computer networking engineers. To enhance the training of students' design skills, the computer networks community has made significant efforts to create a number of network simulation tools to support hands-on projects in various network layers. However, how to develop an effective teaching strategy to integrate the network simulator-based projects into network courses as project-based and inquiry-based learning tools still remains a challenging task. In addition, due to the huge difference among different institutions, successful implementation experience in one institution usually cannot directly apply to the others. Recently, California State University Los Angeles (CSULA) received a CCLI grant from NSF to explore a good solution to enhance the learning of a very diverse student body in a multicultural campus that serves a significant number of underrepresented minority students. The project goals are three folds: 1) Establish a cyber-infrastructure to enable remote learning which significantly improve the learning efficiency of students on a commuter campus; 2) Foster students' hands-on design and implementation skills in networking field; 3) Improve teaching and learning efficiency by integrating project-based and inquiry-based learning pedagogy.

This paper presents our current progress on the CCLI project, which is focused on the development of a sequence of scalable remote labs using OPNET to enable the integration of collaborative project-based and inquiry-based based learning into existing computer networking courses in both Computer Science and Electrical Engineering departments. The remote lab sequence offers projects of three different scopes to progressively build up the students' design and implementation skills. Small scope projects can be incorporated into lectures to expose the students to basic design and simulation process. The knowledge and skills acquired through small scope projects allow the students to work collaboratively on median scope projects after class remotely. The large scope projects require the students to apply what they have learned to solve some open-ended problems. The developed projects cover all five layers in TCP/IP model to reinforce the students' understanding of various protocols. Furthermore, the current effort to revise the computer networking curriculum using collaborative project-based and inquiry-based learning is presented. Preliminary assessment results are included to show the impact of the curriculum revision.

Introduction

Hands-on design and implementation is one of the essential skills that have been recognized not only by the engineering education community and ABET, but also by industry that employs graduates from engineering and computer science programs. In the computer networking area, the industry advisors in College of Engineering, Computer Science and Technology (ECST) at California State University Los Angeles expressed a strong needs of qualified networking engineers who not only have a solid understanding of theoretical knowledge of network infrastructure and protocols, but also have good design and development ability to improve the

current networks standard, to propose and implement new infrastructure / protocols, and to devise practical solutions to address emerging problems. To enhance the training of students' design skills, the computer networks community has made significant efforts to add active learning components in both introductory and advanced level computer networking classes. A number of network simulation tools have been created to support hands-on projects in various network layers [1-9]. Some outstanding representatives such as NS-2[1], VNS[3], Emulab [6], etc. have been widely adopted by a number of institutions worldwide.

The efforts of educators in computer networking community provided ample learning materials including projects and labs based on network simulators. In many institutions, project-based learning (PBL) has been adopted as an effective teaching methodology to enhance the students' understanding of theoretical knowledge as well as their hands-on skills [10, 11]. However, due to the huge difference among institutions, successful implementation experience in one usually cannot directly apply to the others. For minority institutions like CSULA, how to develop an effective teaching strategy to integrate the network simulator-based projects into networking courses as project-based and inquiry-based learning tools still remains a challenging task. Recently, CSULA received a CCLI grant from NSF to explore a good solution to enhance the learning of a very diverse student body in a multicultural campus that serves a significant number of underrepresented minority students in computer networking field. The project goals are three folds: 1) Establish a cyber-infrastructure to enable remote learning which significantly improve the learning efficiency of students on a commuter campus; 2) Foster students' hands-on design and implementation skills in networking field; 3) Improve teaching and learning efficiency by integrating project-based and inquiry-based learning pedagogy.

This paper presents the current progress on the CCLI project, which mainly focused on the establishment of a cyber-infrastructure and the development of a sequence of scalable projects using OPNET. So far two different types of projects have been developed: exploratory and design-focused. The former refers to simple and engaging projects that stimulate students' interest and guide them to "discover" principles of protocol design; the latter offers projects of three different scopes to progressively build up the students' design and implementation skills. Specifically, small scope projects can be incorporated into lectures to expose the students to basic design and simulation process. The knowledge and skills acquired through small scope projects allow the students to work collaboratively on median scope projects after class remotely. The large scope projects require the students to apply what they have learned to solve some open-ended problems. The developed projects cover all five layers in TCP/IP model to reinforce the students' understanding of various protocols.

The paper is organized as follows. Section 2 provides a brief overview of the project. Section 3 describes the established infrastructure and explains how remote PBL can be supported. The details of the developed project sequence are presented in Section 4. Section 5 describes how the computer networking curriculum is revised to incorporate collaborative project-based and inquiry-based learning. Our assessment plan and preliminary results are included in Section 6.

Project Overview

As a federally designated Title III institution, CSULA has an historic commitment and record of service in meeting the educational needs of Los Angeles' culturally diverse communities. CSULA student body is 53% Hispanic, 22% Asian-American, 15.6% White, 9% African-American, and 0.4% American Indian. As seen by many other minority-serving institutions, students from underrepresented minority groups usually encounter significant learning barriers that prevent them from achieving their academic goals. As many of our students are first generation college students in their families, lack of family support usually leads to less persistence and low self-efficacy in learning. In addition, poor financial condition imposes another significant barrier to student learning. An estimated 70% of our students work 30 or more hours per week to support themselves while enrolled in college. Consequently, they have less time to study and less access to educational resources such as books, computers, software, etc. In computer-related disciplines, this disadvantage is more severe since the students have less opportunity to develop hands-on skills that are critical to their career.

Nevertheless, the above-mentioned learning barriers also present significant challenges to the implementation of project-based learning. Students with low self-efficacy may easily feel frustrated with projects if they cannot complete in a few attempts. While an added lab session that offers real-time TA or instructor help can be a good solution to the above problem, it does not work on a commuter campus where most of the students are reluctant or unable to spend extra hours on campus due to their work schedule. One successful effort to address the above challenge is the Collaborative Project Based Learning model (CPBL), which was developed by the PI through the support of HP project since 2005 [12]. The core of CPBL is to incorporate small in-class collaborative projects to inspire students' interest in learning new theory, to reinforce theory with design examples, and to guide students through the design process. CPBL has been implemented in a few courses related to digital engineering design and generated very positive impact on student learning outcomes. Specifically, the collaborative learning environment and the real-time help on the in-class projects are very helpful for the minority students to overcome their learning barriers.

Our CCLI project aims at extending the scope of CPBL by creating a sequence of scalable remote labs to enable the integration of project-based and inquiry-based based learning to existing computer networks courses. The remote lab sequence offers a rich variety of projects, e.g. small scope projects that can be incorporated into lectures, median scope projects that can be used to reinforce the students' design skills, and large scope projects that can lead to independent study or senior design project. Similar to our previously proposed CPBL, the remote lab sequence will create a pipelined structure to enhance students' design skills step-by-step, but it goes beyond the boundary of classroom by incorporating remote learning. To provide necessary help to the students, an online virtual classroom will be created to facilitate the remote lab sequence via MediaSite technology [13].

The established remote lab sequence is used to enhance the undergraduate computer networks curricular in both electrical engineering and computer science departments. Previously, none of the existing computer networking classes integrates substantial hands-on training to build up students' design and problem-solving skills due to the deficiency of lab facility at CSULA. In addition, there was no structural model in the networking curricula to systematically prepare students through this specialization. Thus, an important component of our CCLI project is to

redesign the current networking courses in both departments. The course redesign will reduce the overlap among the existing courses, embed collaborative project-based and inquiry-based learning to stimulate the students' interest and reinforce their understanding of theoretical knowledge, and progressively build up the students' design and implementation skills. As a result of the course redesign, a specialization track in computer networks for both CS and ECE students will be established. In summary, through our proposed CCLI project, we are expecting to achieve the following outcomes:

- To establish an infrastructure to deliver virtual networking labs to allow students work on the projects remotely
- To develop a series of progressive OPNET-based labs that lead to real-world design experience as well as detailed guidelines to help other educators integrate the lab sequence into their own courses.
- To redesign the undergraduate computer network curriculum that incorporates the OPNET-based virtual labs.
- To seek an effective teaching strategy for a commuter campus to incorporate inquiry-based learning to motivate students and project-based learning to enhance students' design skills.

Infrastructure Establishment

To fully support Collaborative Project-based and Inquiry-based learning using virtual labs, the first step is to establish an effective e-learning infrastructure. Figure 1 shows a 16-blade HP server that is used to host the OPNET software to allow remote access. The server is connected to Gigabit network to ensure fast online access. Currently, 60 OPNET licenses have been obtained, which allows 60 students to work on the project simultaneously. OPNET has easy-to-use graphic user interface and supports both system level and node level design/simulation. These nice features of OPNET software allow us to design projects of different scopes and difficulty levels.

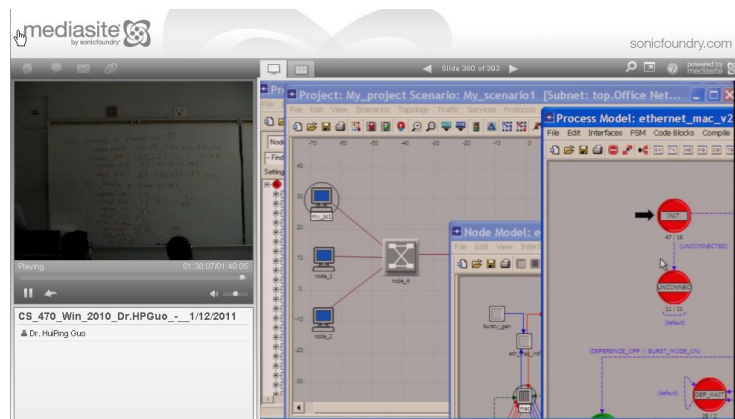
Figure 1. HP blade server

Figure 2. A snapshot of MediaSite streaming video for computer networking class.

To support in-class projects, a dedicated computer networking laboratory as well as a mobile classroom using Tablet PCs have been established. Remote Graphic Receiver software has been installed in the computers and Tablet PCs to allow real-time access to the blade server. In

addition, a virtual classroom using MediaSite Streaming technology (as shown in Figure 2) was created to allow the students to access the tutorial video of OPNET simulation procedure, the instruction video related to after-class projects, and to offer real-time interaction with the instructors remotely to receive help.

OPENT Project Development

The established infrastructure allows every student team to work together virtually on one project. Figure 3 shows the structure of on-line collaborative project-based learning. Usually, team contained two to three students, and they will be assigned to work on a designated blade in the server. The team can access the blade simultaneously to design the simulation scenarios together using OPNET and exchange ideas using Google Chat. After the scenarios are created, they can divide the tasks and work independently at time of their own convenience. This model offers a lot of flexibility to our students to arrange their project tasks along with their work schedules. Figure 4 displays a snapshot of remote access of OPNET software using RGS software.
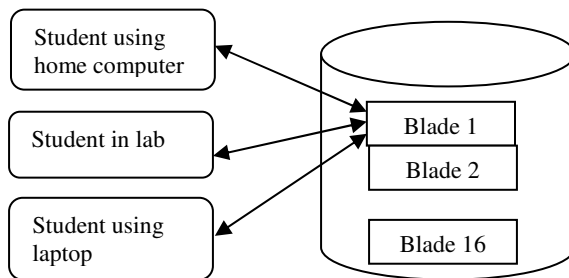

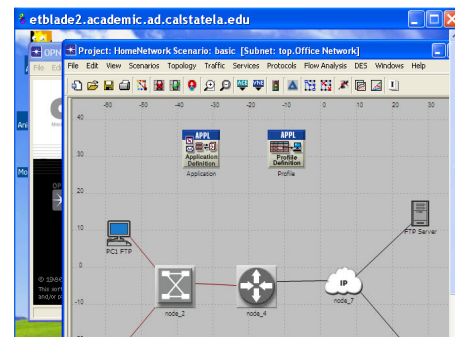**Figure 3. Online collaborative project-based learning scenario**

Figure 4. A snapshot of remote access of OPNET via RGS

Our developed project thus far can be classified into two types: 1) practical design project to facilitate project-based learning; 2) exploratory projects to incorporate inquiry-based learning. More details about how to integrate these two types of projects in CPBL model can be found in our previous papers [13, 14]. The uniqueness of our current effort is to extend our previously developed CBPL model beyond classroom settings. Consequently, the students can apply what they have learned through in-class projects to solve more complicated problems that can not fit in the class time. This extension is essential for senior-level courses which focus more on the development of students' critical thinking, creativity and system-level design skills. The collaborative learning feature is still retained through the virtual infrastructure for after-class projects.

Table 1 provided a summary of our developed projects, including the correspondent learning objectives (knowledge to be gained in computer networking field and the skills to be developed).

Table 1. OPNET Projects to support project-based and inquiry-based learning.

Class Project	Knowledge Objectives	Design Skills and Tools	Type
1	**Create your own link** • Review link-level parameters: data rate, error rate, link utility • Learn to select proper link for various types of networks	Introduction to OPNET Software (EE440) • How to create new project • Get familiar with existing link model (widely used) • Learn how to use OPNET link editor to create new link	In-class design project (Small scope)
2	**Failure! Failure!** • Explore the impact of node and link failure on different type of networks • Learn the characteristics of various topologies	Create simple scenarios in OPNET • How to select network parameters to evaluate performance • How to analyze experimental results to seek answers of practical problems	In-class exploratory project (Small scope)
3	**Collision on Ethernet** • Reinforce the understanding of CSMA/CA • Study the relationship between load vs. collision	Scenario duplication and management in OPNET • How to design proper scenarios to evaluate the Ethernet performance • Improve the skills to analyze the performance of a provided network protocol	In-class design project (Small scope)
4	**Plan your own office network:** Use simulation to decide which is a better solution for an office network considering delay, link utility and load balance. • Review the LAN component properties • Review various protocols for LAN • Review the characteristic of different topologies	Critical thinking and problem solving skills • How to create proper scenarios based on what was learned in class • How to design a proper evaluation and analysis strategy to seek answer for "open-ended" problem • How to configure various applications	After-class design project (Median scope)
5	**Go wireless?** Using wireless modeler to create a Wi-Fi network, apply CSMA to evaluate the performance, and recommend how to improve the media access protocol based on the simulation. • CSMA/CD vs. CSMA/CA • Virtual reservation using RTS/CTS • Impact of bit errors and	Learn how to use wireless modeler and further improve critical thinking and problem solving skills • Configure wireless station and traffic model • (possibly) configure applications for hybrid network • Choose proper network parameters for best analysis performance • (possibly) change protocol	After-class design project (large scope)

	collision in network performance	parameters to explore their performance	
6.	***Home network for your study***. • Review the components of a network • Start with OPNET	Introduction to OPNET (CS470) • Get familiar with the workspace of the Project Editor • Learn how to choose statistics, run simulation and analyze the results	In class (small scope)
7	***What can you do with home network***? • Given limited resources, decide whether your home network works for different kinds of applications • Improve your design by choosing different components.	• Critical thinking and problem solving skills • Learn how to create a project and a scenario • Learn how to configure applications profiles • Learn how to compare and analyze simulation results of multiple scenarios	After class (Media scope)
8	***How to find a route?*** • Reinforce the understand of RIP/OSPF • Study RIP/OSPF in a small network • Explore functions of RIP/OSPF routing protocols.	• Review the concepts of the routing protocols • Review the steps of network simulation • Learn how to adjust the attributes of the protocols	In class small scope)
9	***TCP sliding window***: • Understand the basic concepts of reliable data transmission • Explore the impact of sequence numbers and acknowledge number on TCP transmission	• Reinforce the concepts of reliable data transmission • Learn how to modify variables of TCP in OPNET • Review basic OPENT operations	In class small scope
10	***Performance of HTTP***: • Understand different versions of HTTP • Investigate the performance of HTTP applications under different scenarios.	Improve network design and analysis skills • Review network simulation skills • Learn how to configure the number of concurrent connections and the number of pipelined requests. • Reinforce simulation analysis skills	After class (Media scope)

In addition to the project series, we are also developing video tutorials to teach students the basics of OPENT and the simulation procedure. The combination of PowerPoint slides and OPNET itself is used in the tutorial. The OPENT basics and the step-by-step simulation procedure are described in detail on the PowerPoint slides. The instructor first gives students a bird-view of the topics along with an explanation of the overall simulation procedure. A

demonstration using OPENT is then used to link theoretical instruction with practical operation. For example, when introducing how to create a network model, the overall workflow is detailed in the slides with a diagram and text description as shown in figure 5 (a). When it comes to create a scenario of a project, the instructor switches to OPNET to show how to drag and drop some specific network components to the workspace from Object Palette to create the network topology as show in figure 5 (b).

(a)   (b)
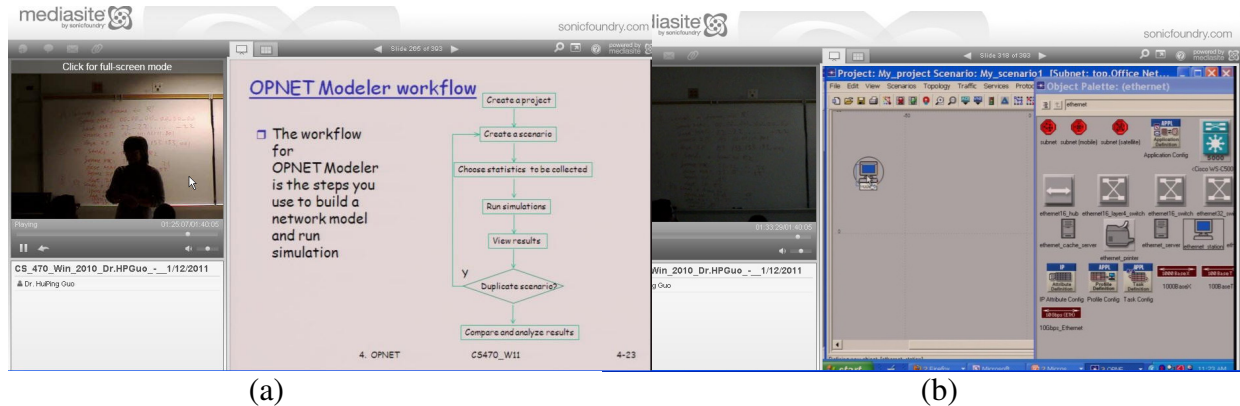
Figure 5. Illustration of OPNET tutorials: a) A snapshot of the streaming video tutorial using PowerPoint slides; b) A snapshot of the tutorial using OPNET.

Course Revision

There are three major problems in the current CS/ECE curriculum in the network field: 1) Significant overlap among some CS and ECE computer networking classes; 2) Lack of coherence in the content of these isolated courses; 3) Lack of hands-on training in design and implementation skills. An important component of our CCLI project is to revise and redesign the related courses (CS470 and EE440) in CS/ECS to minimize the overlap and streamline the course content. Our developed projects will be incorporated in both courses as CBLP and IBL tools.

Winter 2011 sees the first-time implementation of the revised CS470 class. To incorporate CPBL and Inquiry-based learning (IBL) in a tight 10-week quarter schedule, we revised the curriculum to conduct in-class projects weekly or biweekly. The expected time to conduct each in-class hands-on project is forty minutes. Five minutes are spent introducing the project and downloading any necessary files, the students work on their project for 25 minutes, and at the end 10 minutes are set aside for discussion. For exploratory projects, the OPNET model file are provided by the instructor in advance, and the students run the simulation, observe the results and discuss the "stimulating" questions that prompt inquiry-based learning. For practical design project, students work in groups to learn how to build a simple network component (a node, a link or a scenario) to reinforce the learned concepts. To facilitate the student learning, each project is accompanied with follow-up questions to allow the students to expand the provided scenario and evaluate the network design with different configurations. Tablet 2 depicts the weekly schedule of the revised CS470 curriculum and shows how to integrate the project experience with the instruction.

Table 2. Revised CS470 Weekly Schedule

	Course Topics	In-class project	After-class project
Week 1	Internet architecture Data link layer LANs	Home network for watching video	
Week 2	Routers and IP addressing, ARP OPNET	How congestion happen?	
Week 3	Subnetting, RIP, OSPF	How to find a route?	Why BGP?
Week 4	BGP, ICMP		
Week 5	Midterm		
Week 6	NAT, UDP, DHCP Overview of TCP	UDP or TCP?	
Week 7	TCP connection establishment and teardown, sliding window	TCP sliding window	TCP reliable data transmission
Week 8	TCP flow control and congestion control		
Week 9	FTP, HTTP,SMTP, DNS	Slow HTTP server?	Performance of HTTP
Week 10	Multimedia applications		

Preliminary Assessment

To evaluate the effectiveness of the course redesign and to quantify the impact of CPBL and IBL using OPNET project on student learning outcomes, we plan to use the following assessment instruments to collect the feedback from both the instructor and the students:

Direct measurements:
❑ Scores on various course components such as OPNET projects, quizzes and exams are archived and compared to measure the students' understanding of course material, their design ability and overall performance.
❑ Classroom observation/evaluation was performed to measure the students' advancement in design ability exhibited by their in-class projects.

Indirect measurement:
❑ Pre and post survey has been devised to evaluate the change of the students' learning attitude, their understanding of key concepts in networking field, and their skills in protocol design and analysis using OPNET simulator.
❑ A focus group discussion will be conducted by our external evaluator to collect the students' feedback on various course components including their experience with hands-on in-class and after-class projects. Their recommendations will be also collected to improve the instruction in future quarters.

Currently, the pre and post survey questions have been designed. Table 3 lists a set of knowledge and skills that were evaluated by the pre and post survey. Analysis of the survey results reflects how well the redesigned course contributed to the development of the listed knowledge/skill set.

Table 3. Knowledge and skill sets evaluated via pre and post surveys.

| *Concepts related to digital design*	*Skills*
Knowledge of network design process	General computing skills
Knowledge of network simulation	Communication skills
Knowledge of network performance analysis	Math skills
Knowledge of layered network architecture	General design skills
Knowledge of network topology (bus, star, etc.)	Computer network design skills
Knowledge of IP addressing and subnetting	Ability to design and implement a network scenario in OPNET
Knowledge of Internet routing	Ability to analyze the network performance using simulations
Knowledge of ARQ	Ability to choose an optimal design based on realistic constraint
Knowledge of TCP flow control and congestion control	Ability to use OPNET to explore and learn new network protocols
Knowledge of DNS, SMTP	
Knowledge of HTTP and FTP	
Knowledge of OPNET Software	

Since we just started the implementation of the revised course, the only data collected so far is the pre and post surveys for CS470. Figure 6 shows the analysis results. In the survey, students ranked their knowledge and skills using the sets listed in Table 2 (1- "None", 2- "poor", 3- "Fair", 4- "Good", 5-"Excellent"). Clearly, prior to taking the course, students generally do not have confidence in the listed knowledge topics and network design/simulation skills. However, many of them do have high confidence in their general computer skills since they are in senior level. The pre-survey result is compared to the post survey results (which were collected by the end of this quarter) to study the impact of the implementation of in-class and after-class projects. From the comparison, it is clear that students have gained much more confidence on the knowledge and skills on the subject in general. Particularly, the biggest increments of the rating occur on the following outcomes:

- Knowledge of ARQ
- Knowledge of TCP flow control and congestion control
- Knowledge of OPNET Software
- Ability to design and implement a network scenario in OPNET
- Ability to analyze the network performance using simulations
- Ability to choose an optimal design based on realistic constraint
- Ability to use OPNET to explore and learn new network protocols

The above knowledge and skill outcomes are directly related to the in-class and after-class projects. Hence, the assessment results indicate promising effect of the project-based learning experience using OPNET. Nevertheless, to further study the impact of the teaching strategy and to reach convincing conclusion, more data need to be collected in the future.
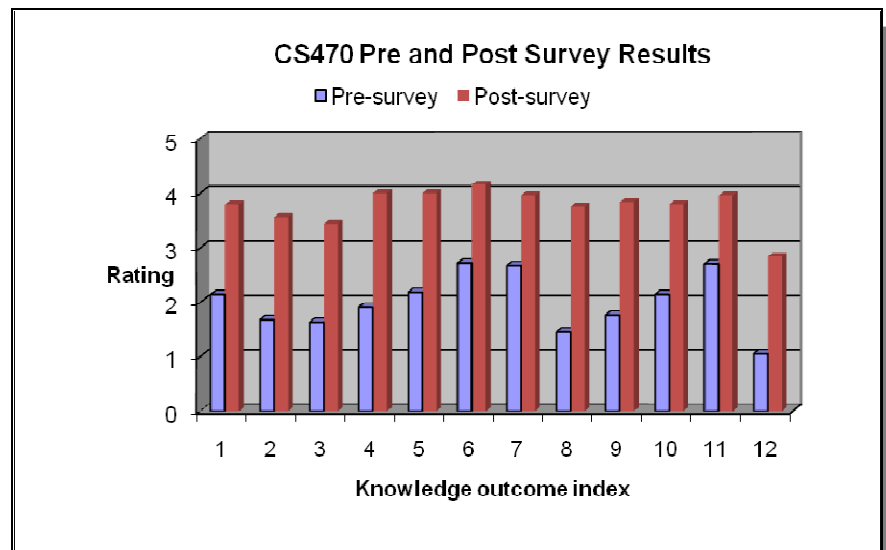
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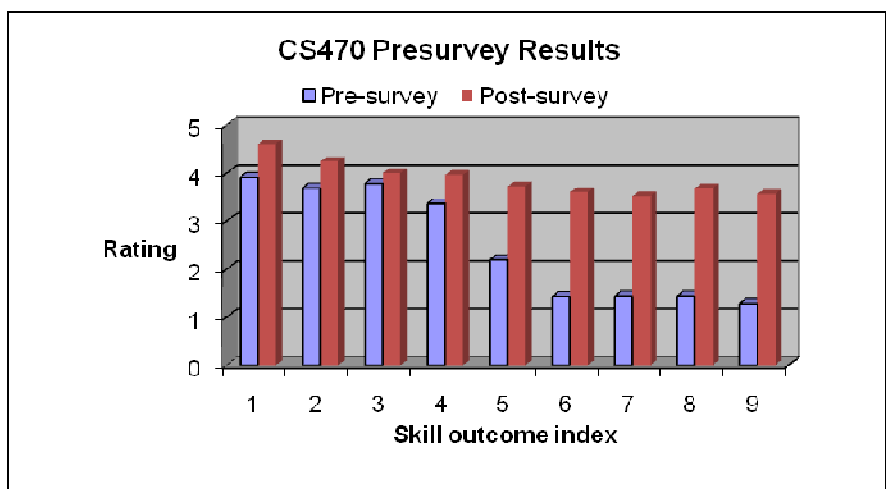
(b)

Figure 6. Pre survey results in CS470, Winter 2011: a) Students feedback on knowledge outcomes; b) students feedback on skill outcomes; prior to taking the course

Conclusion and Future Work

In this paper, we presented the current progress of the NSF sponsored CCLI project, entitled "Enhancing Undergraduate Computer Networking Curriculum using Collaborative Project-based Learning". So far the cyber-infrastructure to support remote project-based learning has been established. A series of OPNET based projects of different scopes have been developed, and we start to incorporate the project in CS470 in Winter 2011. The projects are expected to enhance

the students' understanding on network protocols in different layers, develop their skills of using OPNET which is a widely adopted network simulator in the industry, and foster their ability to analyze the network performance, solve real problems and get them prepared for the design of new network components or system. Since our work is still on the early stage, the paper only presents very preliminary assessment results at this point. In the future, more comprehensive assessment data will be collected and analyzed, and the findings will be used to further improve the course redesign.

Acknowledgment

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