CHALLENGING PROJECTS AND VIRTUAL LABS IN WEB-ENHANCED NETWORKING TECHNOLOGY CLASSES*

Vladimir V. Riabov**
Associate Professor, Department of Mathematics and Computer Science, Rivier College

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Abstract

Effective ways of instruction in networking technology classes (students' papers with technology overviews, research projects, virtual labs, analytical exercises, and Web resources) are discussed with demonstration of lecture notes, OPNET™ lab assignments, "warm-up" exercises, homework and test problems, and final projects that are available on the instructor's Websites. The project-based approach motivates students in selecting topics for their technology overviews and research projects and provides them with knowledge, instructions, and hands-on experience.

1 Motivation

The collapse of networking industry in 1999-2000 and visa restrictions for international specialists and students (that were enforced after the terrorist attacks of September 11, 2001) changed dramatically the student population in colleges and universities nation wide [1]. The enrollment continues declining in both undergraduate and graduate computer science programs [2, 3], the fact that puts at risk especially small computer science programs in liberal arts colleges, which heavily depend on the international students' enrollment. At the same time, the networking companies still demand fewer, but better prepared computer engineers with solid knowledge and hands-on experience.

All these factors have to be considered seriously and reflected in searching new approaches for teaching the computer science courses, and the networking classes in particular. In this paper, the author shares his experience in teaching various courses in networking technologies. His teaching methods [4-6] are based on several techniques [7-9] that challenge and motivate students to become passionate in their studies and be active in the classroom. Starting every class with small challenging exercises [10, 11], the instructor encourages students to select and develop their own projects. He demonstrates to them the best achievements of professionals in the related fields of expertise [12-14], the best projects of students (available on the instructor's Website, http://www.rivier.edy/faculty/vriabov/), who took the similar courses in the past, and the challenges of the discipline [15].

This paper demonstrates the advantages of using the project-based approach [4-9] in the course delivery that motivates students in studying and learning modern networking technologies. The "warm-up" exercises, discussions of recent research publications, lectures, field trips, and labs stimulate students in selecting topics for their technology overviews and research projects and provide them with knowledge, instruction, and hands-on experience. The students, who accept the challenges of innovations in networking area, achieve the summits through delivering their presentations at national and international conferences [16], publishing their first articles in professional journals [17-19], and promoting their findings among college peers and colleagues in companies and organizations [20-21].

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The paper is organized as follows. In section 2 the author presents an overview of some Web-enhanced classes in networking technologies that he teaches at Rivier College. Examples of "warm-up" exercises, lecture notes, and course assignments are discussed in section 3. The students' feedback on the field trip to the college IT Services Center is analyzed in section 4. The core of the paper includes sections 5-7, in which the author describes what makes the courses challenging and valuable for students. These sections also include students' responses on developing virtual labs by using the OPNET IT Guru™ Academic Version software [22-24], examples of their overviews of modern networking technologies with demonstration of OPNET and OMNeT++ network simulations [18, 19], and examples of students' research studies [16-19]. The paper concludes with Acknowledgments and Conclusions sections.

2 Web-Enhanced Networking and Information Technology Classes at Rivier College

Rivier College offers computer science programs at both undergraduate and graduate levels (A.S. in Computer Science, B.S. in Computer Science, Undergraduate Certificate in Computing Technology, M.S. in Computer Science, M.S. in Computer Information Systems, and Graduate Certificate Programs). The following information-technology and networking courses represent the core and electives of the programs:

- CS553: Introduction to Networking Technology
- CS572: Computer Security
- CS573: Advanced Wide Area Networks
- CS575: Advanced Local Area Networks
- CS597: Multimedia and Web Development
- CS612: Information Technology
- CS632: Client/Server Computing
- CS685: Network Management
- CS690: System Simulation and Modeling
- CS699 Professional Seminar in Computer Science, and others.

All the courses have three interrelated major goals:

- Introduce students to fundamental concepts in networking and some of their relevant applications,
- Have students take an active role in their learning by experimenting with various networking techniques and tools [19, 22, 23], and
- Instruct students in writing overview papers on modern networking technologies and in conducting their own first research studies.

The courses are Web-enhanced, and a student can access remotely any course material (a syllabus, class schedule, assignments, lecture notes, lab manuals, examples of project papers and research reports, Internet links, lists of recommended readings, etc.) from the instructor's Web sites. This "virtual" learning environment supports communication between students and the instructor, as well as among peers working together on a team project beyond the classroom. Also, it becomes a valuable resource for those students, who have missed a class for some reasons, or continue working online.

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3 Lecture Notes, Assignments, and Web Resources

3.1 Instructor's Web sites (Teaching, Research & Publications)

The author's website (http://www.rivier.edu/faculty/vriabov/) is the gateway to the instructor's courses, his research agenda, publications, and numerous Web resources. Each course has a portal to various course-related materials, including syllabi, class policies, schedules, assignments, lecture slides and notes, software installation instructions, tutorials, lab manuals, examples of project topics and papers, research reports, Internet links, lists of recommended readings, etc. The instructor designs assignments and tests, which require the students to use resources from the Web sites, digital libraries, and the Internet (through the World Wide Web, TELNET, and FTP services). This skill can be directly transferred to others, when students will work for the companies.

The project-based teaching strategies (including lectures, homework-, computer-lab-, and project assignments, resources on the instructor's Websites for supporting the students' studies and learning, author's publications, and presentations) are interdisciplinary. They combine research from Computing Education, Computer Science, Mathematics, Networking Technologies, Physics, Sociology, and Ethics.

3.2 Lecture Notes

The introductory classes in networking technologies (e.g., CS553) cover network basics [25-27], ASCII code standards, OSI and TCP/IP reference models, circuit and packet switching principles [26], local and wide area networks [28], history of the Internet, connection-oriented and connectionless networks, broadcast topologies, routing network interconnections, TCP/IP protocol architecture, X.25, Frame Relay, and Asynchronous Transfer Mode.

The advanced networking classes (e.g. CS573, CS575, and CS685) cover analog and digital data transmission methods [27], data communication media, data encoding, multiplexing, TCP/IP protocols and services [26], IPv4 vs. IPv6, application protocols [14], distributed systems, and network management issues [29]. Topics also include overviews of computer and information security [14], traditional wireless networks [26], wireless sensor networks, storage area networks [13], tunneling, and virtual private networks (VPNs). Students are encouraged to establish the VPN connection between their office (home) computers and the College network system to utilize remotely and securely the entire campus computing resources.

Network- and Information-Technology-related topics covered in the CS699 Professional Seminar course include "Fine Living in Virtual Reality," "Ambient Intelligence," " Human-Centered Systems," "How to Think About Trends," "How Biology Became an Information System," "Automated Music Composer," "Life After Internet," "Environments Become Smart," "Somatics in Cyberspace," and others [39].

The instructor's lecture materials, homework-, computer-lab-, and project assignments, presentations and publications combine research from various disciplines. For example, in the CS553 Introduction to Networking Technologies and CS575 Advanced Local Area Networks classes, we study selected topics from the Mathematical Theory of Numbers, Theory of Graphs, Physics of Electromagnetic Fields, Optical Physics, Theory of Algorithms, Mathematical Statistics, Mechanics, Management, Marketing, Encryption, and Psychology. The instructor discusses with students the secure ways of sharing the network resources, issues of confidentiality, medical and personal information security on the Internet, and protection from electronic spam.

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The lecture notes for each course are available online for students. Both undergraduate and graduate students have access to materials of all the courses. This option helps students in reviewing current, past, and future topics, in preparing better for a test, lab, or homework, and in selecting the next course in the program.

3.3 Course Assignments

The assignments for each course include three homework sets, four labs, report on a field trip, midterm and final exams, and a project paper that covers in depth one of the modern networking technologies. A student can gain extra points to his/her final grade as a result of fruitful participation in various class activities, such as "warm-up" exercises, (optional) project presentations, lab demonstrations of network modeling, team project leadership, and submission papers (on the course-related topics) to conferences or journals.

3.3.1 "Warm-up" Exercises

Every class is started with a brief discussion of an unusual non-trivial topic that is called a "warm-up" exercise. After these "warm-up" exercises, the instructor offers a discussion on the main topic and asks students for a feedback on lecture materials and their arguments on selecting a competitive strategy for the problem analysis and development. These discussions help students to focus on the main point of the class session and stay active in class. Here are a few examples of the "warm-up" exercises.

Exercise 1: What is the Last Digit of the Number 2597^{5927} *[*mod(10)*]?*

An introductory discussion of the theory of large numbers leads to the applied theory of encryption. This exercise helps in introducing encryption algorithms, such as the RSA Public-Key encryption algorithm [30]. At the same time, it illustrates a strong bond between mathematics and computer science. A student (even if he/she is not familiar with the theory of numbers) can solve the problem by a simple experimentation. Because we are interested in the last digit only, following the Newton's Binomial Theorem, it is absolutely enough to consider the last digit of a simpler number 7^{5927}. Doing experiments with powers of number 7, we find that the last digit can only be 7, 9, 3, or 1, and therefore, it is a cycle of *four* cases. The power, *5927* can be represented as *5927 = 4*1481+3*. Therefore, the last digit of 7^{5927} (and 2597^{5927}) is the same as the last digit of $7^3 = 343$, which is "*3*". Knowing two key parameters [e.g., the base (*10*) and the power (*5927*)], we can now restore all digits of the huge number.

Exercise 2: What is the Last Digit of the Number 2^{53} *[*mod(10)*] calculated by a simple computing program?*

Students are invited to study limitations on the size of the number values that can be represented through machine computations. Following the previous exercise, a student finds that the last digit of 2^{53} can be 2, 4, 8, or 6 only; and therefore, it is a cycle of *four* cases. The power, *53* can be represented as *53 = 4*13+1*, and the last digit of 2^{53} is the same as the last digit of 2^1, which is "*2*". Therefore, following this theoretical algorithm, the last digit of the number 2^{53} must be *2*. But trying the MS Excel™ spreadsheet calculations, a student finds that any number bigger than 2^{49} have the last "calculated" digit of "0" (in particular, 9007199254740990 for 2^{53}).

The students are asked to recall from the materials of their introductory courses in computer science [31] that data items of type *integer* are normally stored in memory by using two's complement notation and that this imposes a limit on the size of the values that can be represented. A student should

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consider this fact if he/she plans to use "traditional" calculations of integers for implementing the encryption algorithms.

Exercise 3: Graph Theory and Tic-Tie-Toe game

The Tic-Tie-Toe game analysis leads to exploring the theory of graphs and powerful applications of Structured Testing Methodology for the code study [15, 36]. A student usually makes the statement at the beginning of the 3 × 3 Tic-Tie-Toe game, that there are 3 × 3 = 9 different variants to start the game. After an additional analysis and discussion with the instructor, the student agrees that due to the rotational symmetry of the game fields there are actually only three different variants for starting the game: in the center, corner, and mid-side. This fact allows significantly reduce the number of possible game strategies (from nine to three), and introduce effectively the graph theory, which we apply later for studying the code complexity [36] and exploring the code testing strategies in the network system modeling [15].

3.3.2 Homework Assignments

There are three homework assignments (at least) for each course. The part of the first assignment requires students to describe installation procedures and plot a diagram for a virtual private connection from their home computers to the College network. They are also asked to briefly describe issues that should be resolved for establishing this connection. After this assignment, every student establishes the VPN connection between their office (home) computers and the College network system and utilizes remotely and securely the entire campus computing resources.

In one of the exercises from the second assignment students are asked to generate a bit-stream that represents the student's last name written in the ASCII 8-bit Coding Standard and encoded by using the Differential Manchester Digital Signal Format. Students study the advantages and disadvantages of implementing both synchronous and asynchronous transmission techniques for sending the encoded string through a network.

The third homework assignment is the set of exercises like the one described below [25]. A LAN has a data rate of $r = 4$ Mbps and a propagation delay between two stations at opposite ends of $d = 20$ μs. For what range of PDU sizes (S, measured in bits) does the stop-and-wait flow control give an efficiency of at least 50%, $E > 0.5$? (Neglect the transmission time for the ACK signal). The efficiency, E is defined as a ratio of the PDU transmission time (time for inserting the PDU onto the medium) to the total time the medium is occupied for this PDU. Unfortunately, only 60% of students have solved this problem correctly. Others have received incorrect result, because of neglecting both the transmission time and propagation time for the ACK signal. To help students better understand such kinds of communication mechanisms, we offer them several virtual labs [18, 22] that implement simulations of various networking systems and scenarios.

4 Field Trip to the College Information Technology Services Center

Prior to the virtual networking lab assignments, students are invited to the field trip to the college IT Services Center (similar to that one described in [10]), where they meet with the IT Services director, who demonstrates the state-of-the-art networking equipment and management software. He also describes services of the college Internet Service Provider, data communication media on campus, user profiles, network-load picks, educational software installed in the College Computer Labs, and how the students can access these resources remotely from their home computers via a Virtual Private Network (VPN).

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After the field trip, each student submits a report that contains both practical information about the on-campus networking facilities, hardware and software, security measures, and the detailed instructions of how to establish a VPN-tunnel link between their home computers and college computing resources.

5 Virtual OPNET™ Labs

Many classes have been designed as hands-on computer labs [41] that help students in understanding study cases and finding the ways of solving them. Usually a small college has no opportunity to offer a variety of physical networks to students and faculty for using them in the classrooms. As an option, they can use a unique application, the OPNET IT Guru™ Academic software package [22] that offers all the tools for virtual network model design, simulation, and analysis. OPNET software can simulate a wide variety of different networks, which are linked to each other through routers and switches. Students can work from their PCs independently or under the instructor's supervision to simulate different networks (ATM, Frame Relay, X.25, Fiber Optics, etc.) and study visually the impact of various factors (e.g., traffic load, bandwidth, data rate, etc.) on the network [18]. Providing means for analysis and modeling of network performance [23], OPNET IT Guru™ tool can also be used for studying data message flows, packet losses, link failures, bits errors, etc.

Following the methodology described by K. Brown and L. Christianson [24], L. Peterson and B. Davie [26], and R. Panko [40], twelve lab assignments have been designed and offered to students for exploring the Ethernet, Token Ring, Switched Local Area Networks (LANs), Frame Relay (FR), Asynchronous Transfer Mode (ATM), Routing Information Protocol (RIP), Open Shortest Path First (OSPF) protocol, Transmission Control Protocol (TCP), Queuing Disciplines, Resource Reservation Protocol (RSVP), Firewalls, and Virtual Private Networks (VPNs). Using this knowledge and skills, students develop their own lab projects [18] and include virtual lab techniques into their research projects related to various network application protocols, such as File Transfer Protocol (FTP), Simple Network Management Protocol (SNMP), and Simple Mail Transfer Protocol (SMTP) [14].

6 Examples of Students' Papers on Technology Overview

In many classes (e.g., CS553 Introduction to Networking Technologies, CS575 Advanced Local Area Networks, CS685 Network Management, CS690 System Simulation and Modeling, and CS699 Professional Seminar in Computer Science), the instructor encourages students to conduct research and write project papers on modern networking technologies. The assigned individual projects include all the components of feasibility study, analysis, synthesis, architectural design, application, and evaluation of selected networking systems. The students are motivated to select topics for projects that would be valuable for companies and the community. Usually, they demonstrate their project portfolios during the job interviews. Such demonstration of their actual professional skills helps students in finding a job immediately after the graduation.

Many students' projects are implemented in local companies and the community:

- Bruce Trull, "An Overview of Broadband over Power Lines," Fall 2005.
- Tom Borick, "Secure Wi-Fi Technologies for Enterprise LAN Network," Spring 2005.
- Jeff Corbit, "Gigabit Ethernet, QoS, and Multimedia Applications," Spring 2005.
- Xiaoling Zhu, "A New Chat System" (public domain software), Spring 2005.
- Yuen Kwok, "Developing a Web-based Hotel Booking System with Heterogeneous Databases," Spring 2004.

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- Vaishali Pujuri, "Speech Synthesis Using Java Speech API" (public domain software for persons with disabilities), Spring 2004.
- Christopher Baker, “Photo Editor for Evaluating and Transmitting Medical Images” (for The Catholic Medical Hospital, Manchester, NH), Fall 2003.
- Thomas Palmer, “HEART II System Monitor for Pocket PC-2002” (for regional medical hospitals), Fall 2003.
- Pradeepa Voruganti, “FTP Client Design,” Fall 2003.
- Cristian Cocheci, “A Recoder/Playback Testing Tool for Capturing User Interactions with Software GUIs” (public domain software), Fall 2002.
- Chunmei Chen, “Multi-Protocols Label Switching and MPLS Applications,” Spring 2002.
- Yuanping Chen, “Automatic Voice Response Bill Payment System” (public domain software), Spring 2002.
- Michael Bausha, “Broadband Connection: DSL vs. Cable Modem,” Fall 2001.
- David Norman, “Fibre Channel Technology for Storage Area Networks,” Fall 2001.
- Sankara Krishnaswamy, “Wireless Communication Methodologies and Wireless Application Protocol,” Fall 2001.
- Pei-Hsun Tsai, “ATM vs. Gigabit Ethernet for High Speed Local Area Networks,” Fall 2001.

Seniors and all graduate students have delivered publicly their presentations of individual and team projects in the classroom and seminars [20-21]. The instructor helps them in organizing the presentations and in developing professional skills of public speaking.

Working on the individual projects in the CS553A Introduction to Networking Technologies and CS575A Advanced Local Area Networks classes, students search information on modern networking technologies from the prime sources, such as the Request-For-Comments organization (a repository of the standards in networking industry [32]), IETF Secretariat [33], WiFi Alliance (an association that promotes secure solutions for wireless networking technologies [34]), Fibre Channel Industry Association (an international organization of manufacturers, developers, and end users of the Storage Area Networks [35]), and others.

Many graduate students, who are employed by local networking, computer and IT companies, select topics for individual projects that are based on their experience with the company. The network computer systems developed by the students under the instructor’s supervision are tested in the company's environment and receive a great support of their supervisors and managers. This fact helps the students in their job promotion.

7 Examples of Research Studies

The author’s articles and papers [4-11, 13-15] have a focus on interdisciplinary aspects of teaching the Computer Science classes and designing modern networking systems. The research in these publications includes both disciplinary and interdisciplinary perspectives that challenge the instructors to take a personal responsibility in teaching students according to their different backgrounds in Mathematics, Computer Science, Natural Sciences, and culture.

The special assignments have been designed for the CS690 System Simulation & Modeling course, which encourage the students to grasp understanding of what managers would expect from the results of simulating performances of various network systems and data farms. Working hard on his project, Martin Milkovich, a student in 2004-2005 classes, offered a new software tool, OMNeT++, for

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modeling and simulating performances of the digital video cluster firm. He selected a challenged topic, Digital Video Cluster Simulation, for his CS690 and CS699 research projects, and a few months later he delivered a presentation of his findings at the Winter-2005 International Conference on Simulation Methods held in Florida [16]. Nowadays, following his example, other students apply the OMNeT++ tool in their research studies of the clustered Storage Area Networks, wireless sensor networks, and distributed network systems.

The author supports his graduate students in their efforts of introducing the Computer System Analysis and Design Standards [36] to the networking industry, related software tools [37], and practices [15, 38] in the local networking companies. As a result of such efforts, David D. Norman, a student in 2001-2003 classes, has been promoted to the position of a Principle Software Engineer at IMPACT Science and Technology, Inc., located in Hollis, NH. He was a guest speaker at the Rivier College Mathematics & Computer Science Lecture Series on November 11, 2003 [21], where he shared his experience in software systems engineering and networking technologies with students and faculty.

The students are encouraged to submit summaries of their research projects to professional journals and magazines. Seven graduates (Gregory Dake, David Dwyer, Nimmi Gupta, Ajay Kumar [18], Martin Milkovich [19], David Snogles [17], and Bruce Trull) have submitted recently their manuscripts for publishing in the Rivier College Online Academic Journal. These activities develop a *strong bond* between students and faculty members that will last forever.

8 Conclusions

The author has described the goals, demand, design, implementation, and experience of running several Web-enhanced networking technology courses for seniors and graduate students. The experience has been in general a very positive one, while at the same time providing useful lessons learned. The author believes that this project-based and virtual-lab approach can be effectively applied to future courses of a similar nature in academia, and believes that the model can be extended to other engineering disciplines beyond the computing sciences.

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Dr. VLADIMIR V. RIABOV, Associate Professor of Computer Science at Rivier College, teaches Computing Concepts & Tools, Networking Technologies, Software Engineering, Object-Oriented System Design, and System Simulation and Modeling. He received a Ph.D. in Applied Mathematics and Physics from Moscow Institute of Physics and Technology and M.S. in Computer Information Systems from Southern New Hampshire University. Vladimir published about 100 articles in encyclopedias, handbooks, journals, and international and national conference proceedings, including *The Internet Encyclopedia*, *The Handbook of Information Technologies*, *Journal of Spacecraft and Rockets*, *Journal of Aircraft*, *Journal of Thermophysics and Heat Transfer*, *Proceedings of International Congress of Aeronautical Sciences*, *International Symposia on Rarefied Gas Dynamics*, *International Conference on Computer Science and Information Systems*, *Conferences of American Institute of Aeronautics and Astronautics*, and others. He is a member of ACM, AIAA, IEEE, and MAA.

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