Network-Based Education

Mladen A. Vouk
Department of Computer Science, North Carolina State University, Raleigh, USA

North Carolina State University has developed an advanced network-based education (NBE) system for support of distance teaching, training and learning, called Web Lecture System (WLS). The system helps construction and management of network-based lessons and courses. In this paper we outline some major issues related to successful network-based education (NBE), including the required technological and quality of service support, and provide an overview of the WLS.

1. Introduction

Advances in computer and communications technology have opened an unprecedented opportunity for satisfying many educational needs and bringing a wide variety of educational applications closer to a broad base of potential users. It is our experience that today end-users of educational and training services should, and do, expect not only provision of high quality educational and training material, but also smooth integration of this material and training with advanced computational and networking frameworks, and with the day-to-day operational environments and workflows within which they operate (e.g., industrial, government or academic settings). Education workflows are often as complex, and structured with intricate dependencies, as most complex scientific research or manufacturing workflows.

There have been many impressive achievements in the application of computer technology to education, and most informed observers would agree that there is much more to come. However, to date, most of these achievements can be classified as "point solutions" targeted at solving a particular problem within the academic arena; e.g., a set of courseware modules for teaching engineering statics, or a computer game designed to sharpen the spelling skills of a first grader. There are many reasons for that, some are technological, but some are related to system requirements and development issues. In the not too distant past, insertion of computer-related innovations into the educational process was a major undertaking, both technically and economically, usually requiring the setup and maintenance of a particular hardware and software environment specific to the individual educational tool or program.

The advent of the World Wide Web was a breakthrough in terms of defining a standard, albeit a somewhat primitive one, for information content independent of the underlying hardware and software delivery system. This simple decoupling of information content and delivery system has been largely responsible for the explosion of activity that we have witnessed on the Internet.

The next step, seamless and wide-spread integration of new computer and networking technology into everyday educational workflows and paradigms - similar to the "appliance-like" adoption of whiteboards, overhead projectors, and video technology - is still to come. We believe that this will be achieved only in systems that

a) provide appropriate and high quality content;

b) support appropriate user-profiles, functions, and user-oriented collaboration framework; and

c) dynamically adapt to user learning and other quality of service needs.

Very few educational systems were ever developed based on actual user-level quality of service considerations, and to the best of our knowledge, only one continuously assesses its own performance and offers that information to its users dynamically on a routine basis [Dix96].

1.1. Regional Training Center for Parallel Processing

As high-performance computing and networking, including parallel computing, begins to play an increasing role in all computer application areas, from scientific computing to communication routing, to accounting, potential users of this technology (e.g., researchers, industrial engineers, students) will all need access to better education and training on how to incorporate this new technology into their own domain. Hence, to further the use of parallel processing, extend the use of parallel computing facilities to more than just a small number of experts, and promote the use of parallel programming and high-performance computing and networking in general, North Carolina State University (NCSU) Department of Computer Science has established, with NSF and other support[1], a Regional Training Center for Parallel Processing (RTCPP). The goal of RTCPP infrastructure is to support end-user oriented quality-of-service (QoS) sensitive educational and training workflows, and to improve the quality of learning in a measurable way.

In Section 2 we discusses some issues that a network-based education (NBE) system needs to address to succeed, including the required QoS support. In Section 3 we briefly describe the NCSU Web Lecture System (WLS). WLS was originally developed to support RTCPP activities. Presentation of this paper includes a live demonstration of WLS.

2. Some Network-Based Education Issues

2.1. "Education Crisis"

It is widely recognized that we are in the midst of an "Education Crisis." The major issue is not computer-literacy, but literacy and training currency in general. For example:

- In many cases students are leaving high-school without acquiring the basic knowledge and skills in reading, writing, mathematics and sciences, in many cases due to lack of sufficient teaching resources;
- The number of students wishing to acquire higher education is on the rise, yet the "classical" approach to teaching requires resources far beyond their needs;
- The technology is moving so rapidly that in many fields, in order to stay competitive, workers need additional training every few years. This demand frequently outstrips the currently available educational resources.

The good news is that the advances in computer and communications technology allow us to at least alleviate the problem. However, while it is generally recognized that education can and should be one of the major benefactors of the recent explosive growth in multimedia and communication technologies, remarkably few fully-operational NBE systems have been developed. Only a small handful of these have made the difficult transition from the laboratory to the classroom.

In our experience, three major risks to success of such systems are

i) inappropriate functionality and instruction models;

ii) lack of continuous quantitative evaluation of student progress coupled with lack of student-system-student feedback; and

iii) inadequate system performance.

2.2. Education Workflows

We take a system view of education using the "workflow" concept [Bit73, Sin94, Rin95, Vou97]. This concept recognizes the educational process as a system which involves interactions among a variety of individuals including (but not necessarily limited to teachers, researchers, learners, advisors, and administrators) through a series of workflows that primarily involve access, creation, teaching or manipulation of the subject matter. These activities become particularly intense and difficult to

[1] This work is supported, in part, by the NSF awards ACS-9418960, ACS-9418606, and ACS-9696131, IBM Corp., Fujitsu Networking, MCNC and NCSU DURP funds.

manage and synchronize when one wishes to integrate them with research workflows that arise in rapidly changing fields, such as multimedia, advanced networking, and parallel computing. Understanding the educational workflows is the key to effective application of technology to the process. Only when advanced computer technology is correctly mapped to the educational process through the workflow model, can its fundamental benefits begin to approach full realization. The key to the understanding of the workflows is a clear understanding of the entities that create and sustain it.

2.3. Users

In a network-based education system, the most important system entity, and the principal quality driver and constraining influence is, of course, the **user**. NBE users can be classified into a number of categories. Four non-exclusive general user categories are of prime importance: **students, instructors, authors,** and **system developers**. Examples of other important general categories of users are parents of the students, employers of continuing and adult education students, and educational administrators. Special categories of special interest are K-12 users, community college users, university users, and adult education users. Functional and usability requirements derive, in most part, directly from the NBE user profile.

System developers are responsible for development and maintenance of the system framework. They develop and integrate system interfaces, administration and management software, communications and scheduling algorithms, authoring tools, courseware generation and material access algorithms and software, and so on. They must be experts in specialized areas such as AI, education, software and computer engineering, and communications. They require specialized tools for NBE system framework development, maintenance, testing and performance evaluation.

Authors are courseware developers. They are responsible for development of individual lessons that are integrated into courses by instructors. It is essential that authors be both pedagogical and content experts. Some of the functionalities that a NBE framework must provide for them are various editors, compilers, interpreters, authoring languages, tools, and capabilities to gather information about the use of their lessons and about any problems encountered with them, as well as courseware security (including protection of copyrights, protection from system crashes and losses, etc.). It is extremely important to note that the authors, for the most part, will not be system experts, and thus the authoring tools and interfaces must be easy-to-learn and easy-to-use and must allow the authors to concentrate on the lesson development rather than struggle with the system intricacies.

Instructors are curriculum developers and material selectors. They sample and combine existing lessons, customize courses and projects, update existing projects and courses, and develop new projects and courses. They also teach and tutor, i.e., they deliver the course material, assist students and oversee student projects. They have to be knowledgeable in the course material area, and they have to be experts in student needs and curriculum construction. The NBE system framework needs to support them when they evaluate student knowledge and progress, grade and compare student work, register students, query student records, write reports, interact and tutor electronically (including shared screen, whiteboards, and voice-based interaction), and give advice. Of course, the system must facilitate curriculum generation, as well as access to different information sources, and it must handle student-related information with special care in that it must preserve the student's right to privacy and yet provide the instructor and other educators with appropriate and needed student and course evaluation information.

Students and **trainees** are the most important users of the system. They require appropriately **reliable and timely** lesson delivery, easy-to-use interfaces, collaborative support in local and remote joint projects, instructor's help, information about their grades and/or progress in the courses, and so on. The distribution of student support tasks, across the network and across resources, will depend on the task complexity, desired schedules and resource constraints. The solutions should not rule out use of any network type (wire, optical, wireless) or access mode (high-speed and low-speed). However, at any point in time, students' work must be secure

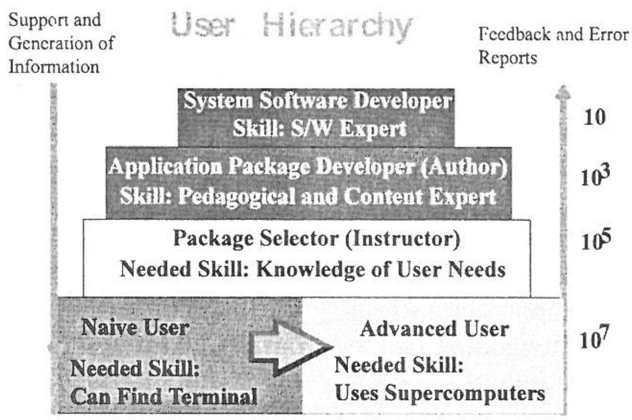

Fig. 1. General categories of user of a NBE system.

and protected from data losses and unauthorized access. Furthermore, the adult, part-time learner is becoming an important customer of higher education. To meet the needs of this population, we need to develop methods of educational delivery which effectively scale not only the barriers of space and time, but also of student diversity. The "class" of the future is likely to include students who are widely separated geographically, who are not able to "attend" lectures on a preset schedule, and who come with very different backgrounds and from very different walks of life. This presents new demands and challenges for the instructor, who must maintain the quality and integrity of the educational delivery given this diversity.

An illustration of the relationship among the four principal general user categories is shown in Figure 1. If we assume that a successful wide-area NBE system can be expected:

a) to support large numbers of users that range from very naive to very sophisticated;

b) to support construction and delivery of curricula to these users; for that, the system needs to provide support and tools for possibly thousands of instructors, teachers, professors and parents that serve the students;

c) to generate adequate content diversity, quality and range.

This may require many hundreds of authors.

Thus, the system architecture has to be scaleable and has to accommodate networking, computing and software facilities that can support many thousands of simultaneous users that can concurrently work and communicate with each other and receive adequate quality of service support. On the other hand, the system needs to be constructed in such as way that the entropy that accompanies all large systems does not make it unusable. This means facilities for centralized maintenance, master-storage, oversight, administration and evaluation by relatively few system operators, developers, administrators and educators. Furthermore, clear and direct lines of communication should be provided for user-generated feedback and error reporting, and rapid response to any problems in order to maintain adequate system reliability and capabilities.

2.4. Workflow Integration

As computing and networking technology expands, it encourages educators to construct complex distributed educational solutions that span the networks and, e.g., through Web-based interfaces, invite incorporation into still more complex systems that may include interactions with legislative, scientific and business flows. Education workflows represent the logical culmination of this trend. They can provide the necessary abstractions that enable effective usage of computational resources, and development of robust, open problem-solving environments that marshal educational, computing and networking resources. Since education workflows are expected to coexist, cooperate and meld with other user workflows, they must support compatible interfaces, and constraints such as funding, available human resources, state-of-the-art (but existing and **affordable**) technology, user QoS expectations, social issues, and

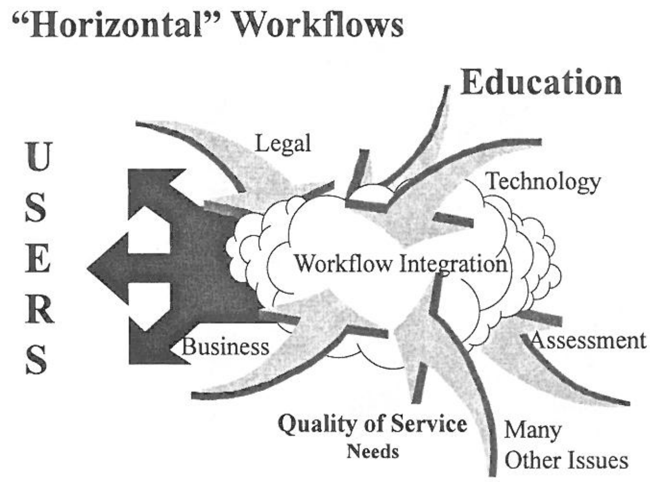

Fig. 2. Horizontal integration of education and other workflows.

so on. Figure 2 provides a general illustration of these expectations. We call this "horizontal" integration of the workflows at the level of end-users.

For example, many students from industry, that work during the day may prefer to incorporate the majority of their continuing education into their daily or weekly routine at times that suit them, e.g., evenings or weekends, because they cannot match their work-place processes with the traditional school, college or university teaching workflows. However, this particular challenge to "traditional" education workflows cannot be met without extensive technological and pedagogical support which allows:

a) decomposition of the synchronous teaching/learning cycle into a primarily asynchronous component (with a minor synchronous interactions), and

b) at the same time preserves and maximizes the quality of learning and the knowledge transfer rate that is normally associated with the "classical" synchronous teacher-student interaction.

Other functionalities are needed in the case of other types of horizontal integration.

Interactions and negotiations also have to take place between the end-user layer of an NBE environment and the underlying infrastructure (platforms, software, computer hardware, interconnecting networks). This assures the throughput, keystroke delays, jitter, and other services, that an NBE application or user expects. We call this "vertical" integration of education workflows with event, control and data flows that occur at infrastructure layers. The network- and platform-related flows and QoS capabilities of the information infrastructure (e.g., power of the user platform, network capacity, supercomputing facilities) have to be appropriately matched and interfaced with the needs of the user's educational and training workflows. This is illustrated in Figure 3.

The implication is that an NBE system has to provide some very sophisticated resource and dynamic QoS monitoring, provision and support algorithms, as well as interfaces to communication protocols that allow negotiation of extended QoS guarantees at the desktop level as well as the level of wide-area switching elements. For example, a good NBE solution supports content delivery at many different levels, including support for users that can only afford 14.4 or 28.8 kbaud telephone-modem connections, or only have stand-alone computing facilities (with CD-ROM).

2.5. Application of Workflow Technology

Application of the workflow technology to a specific course, requires information about the syllabus, participants (both faculty and students), schedules, and instructional facilities and technology, and development of the corresponding **operational profile** for the NBE system. Operational profile is the set of relative frequencies which tells us how often is a particular function or capability requested in practice. [Mus93]. Specifically, given a syllabus, schedule, and the student profiles, one would first categorize the students by qualifications and

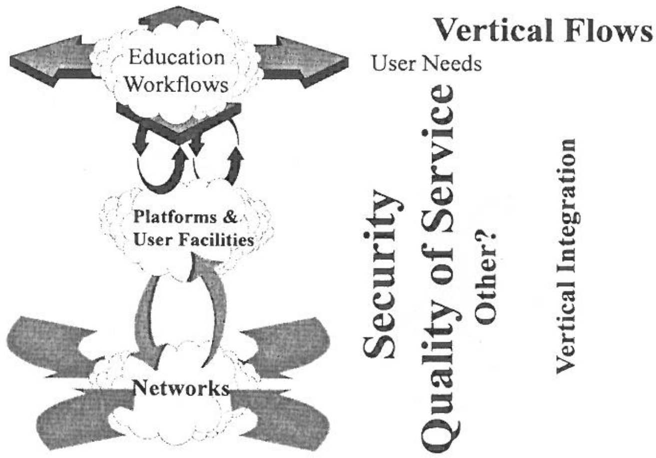

Fig. 3. Vertical integration of education workflows with infrastructure flows and capabilities.

learning styles, then one would produce a mapping between the syllabus topics and the student learning models. This would allow mapping of the needed content teaching approaches to content topics. This mapping may include the placement of feedback points, an estimate of the process feedback rates, location of testing points, and material reinforcement information. The final step would be to map these needs to NBE system functionalities, based on instructor/author qualifications and preferences, available resources, etc., to obtain an operational profile that needs to be supported during the course. The mappings and the operational profile allow us to recognize teaching alternatives and introduce adaptive or fault-tolerant teaching into the educational model.

2.6. Integration of Research Results

Examples of "fast changing areas" of research and education are multimedia, networking, and high-performance computing. The research in such areas is very intense and the "state-of-the-art" is changing very rapidly. Undergraduate courses related to these areas are liable to be "behind times" unless they are frequently "refreshed" with research results. There are several ways this can be done. For example, one could make copies of all the latest research papers and let the students read them. This approach is simple, but the style and difficulty of the papers may not be suitable for undergraduates. An alternative is that the instructor teaching the course prepares the material for class presentation. The most recent work of colleagues, peers, and area experts will generally be in a format of meeting presentations, lectures or at best research reports and papers. If the instructor is not the original researcher, the preparation time for integration and creative communication of material that is not in textbook format may be prohibitive. Another solution might be to invite the original author of the research to present it in the class. That has another set of problems associated with it. For example, travel, standardization of the lesson material and notes, and so on. Furthermore, effective and creative communication of research materials to students invariably requires access to state-of-the-art resources that are often very expensive and in short supply.

In general, two sets of issues arise:

- How to minimize the impact and cost of geographical dispersion of researchers, course authors, course instructors, students, and advanced instructional and laboratory facilities, but maximize knowledge transfer for the class or students under consideration; and
- How to appropriately but rapidly author, manage, re-use and disseminate research enriched courseware (e.g., standardized lecture objects, lessons).

The solution that we believe does work is the one that also includes workflow- and user-sensitive collaboration. Network-based collaboration and team work are the key to advances in modern society. A correctly constructed paradigm and NBE system will actively support experts who integrate contemporary research results into courseware, and it will enhance the communication and learning among students. At the same time, such an approach will speed-up and reduce the cost of the process.

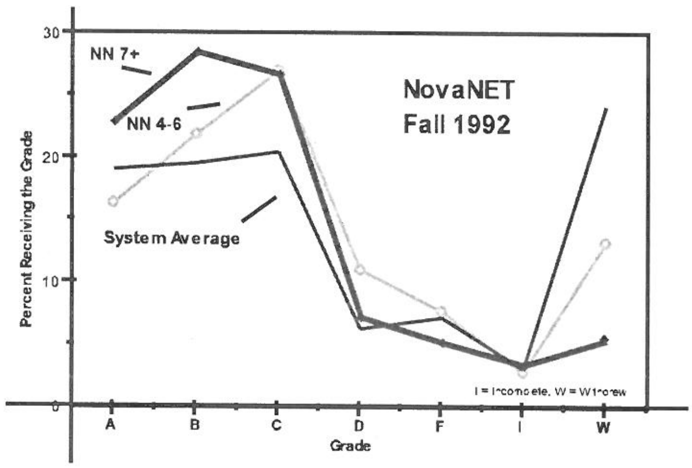

Fig. 4. Compared to system-wide average, NovaNET users who have completed 4 or more lessons, appear to be less likely to drop-out and more likely to achieve a grade of C or better.

2.7. Instruction

A good network-based learning environment must be interactive and auto-adaptive. By auto-adaptive, we mean that it has:

1) A method of interaction for query/response activity;

2) A means of measuring learning; and

3) A scheme to provide adaptive feedback that will define the pace and depth of the presented material based on the user-machine interaction, as well as an estimate of the knowledge transfer rate specific to a particular user.

Furthermore, when developing courseware modules for advanced computational methods and parallel processing, we must recognize that the subject matter is sufficiently complex and varied that it requires application of a judicious mixture of both "directed learning" and "exploratory learning" (or indirect instruction). In directed learning computer controls the flow of instruction, in indirect instruction the student participates in directing the learning activities. Both direct and indirect instruction can be self-paced or teacher-paced.

A directed learning lesson presents information, poses questions, waits for student's response, and then provides feedback to the response. Remediation is provided as needed. A typical example are tutorials. An advantage of directed instruction is that learning is efficient when proven instructional techniques are applied.

On the other hand, indirect (exploratory) instruction operates as follows. Rather than being told a rule or a principle, a learner explores relationships between relevant components and hopefully infers the rule as a consequence of his/her findings. Examples include NovaNET chemistry genetics and physics lessons called "Labs" [Bit73, Ste91]. An advantage of exploratory learning is that the student uses different learning strategies than he/she does in direct instructions. A learner may gain different insights and understanding from direct and indirect instruction. However, a disadvantage of exploratory learning is that a student may find out that his exploration (e.g., through a simulation) yields an incorrect result (e.g., a hypothetical patient dies), but may not know why this has happened. In fact, a student may fail to learn what was intended or may even derive some incorrect conclusions.

2.8. Assessment

We know that correctly implemented NBE improves learning and student grades. But without benchmarks and measurement of both student and system successes and failures, it is impossible to make any meaningful and scientific evaluation of either the new support technology (such as Web), or of the educational paradigms. Hence, the efficiency and effectiveness of network-based education must be measured through knowledge transfer and retention rates and other related metrics (e.g., increases in SAT scores, graduation rates, etc.).

For example, our experiences with NovaNET show that NBE can provide considerable benefits and learning gains [Bit73, Ste91, Dix98]. Figures 4 and 5 illustrate the effectiveness of NovaNET use in the Chicago area for a sample of about 10,000 students (average over mathematics, biology, English and reading). We see that NovaNET students who have completed seven or more computer-based lessons show significant improvement in their grades over the system average. To achieve this, NovaNET not only provides dynamic adaptation to student needs, but it also automatically collects relevant student and courseware data that help in the assessment of student progress and system efficiency. Any NBE support framework should do the same.

The interaction of a student with the educational material must be evaluated constantly by the acceptance of a broad range of student responses and flexible judging. Based on that, NBE needs to customize its computer-human interface, presentation modes, and content to match student background knowledge, knowledge absorption rate and networking resources. Successful interaction of students with the lesson material, under the constraint of limited networking and computing resources, requires sophisticated control of the computing and network services, i.e., control over the end-user quality of service.

2.9. Quality of Service

As mentioned earlier, one of the key issues is the quality of educational service that an **end-user** (student) sees. There are two major components: **quality of service** as provided by the technological framework (including educational paradigm support and networks), and the **quality of content**.

Traditional (network-related) QoS is defined by a number of measures. These include keystroke delays, probability of loss of data, jitter, and throughput. In the context of end-user-oriented workflows, we broaden the classical definition of QoS to also include measurable end-user quality characteristics such as system reliability and availability, performance, algorithmic scaleability, effectiveness, quality of lessons, quality of user-system interactions, semantic interoperability, and so on.

For example, **interoperability** parameters will alleviate problems that might arise between the various local-area and wide-area network guarantee mechanisms, and with the interoperability among its distributed components. In fact, in order to achieve end-user QoS guarantees, it is necessary that all interacting end-to-end entities have agreement upon the interfaces for QoS specification, for exchange of information regarding QoS requests and provisions, and for evaluation of QoS performance.

Furthermore, a NBE system should have resource adaptation capabilities that minimize the impact of resource limitations on the user. For example, the system would recognize limitations of a user resource, such as lack of audio capabilities or video bandwidth limitations, and would automatically downgrade the information transfer mode to display the textual transcript of the audio record, or display a

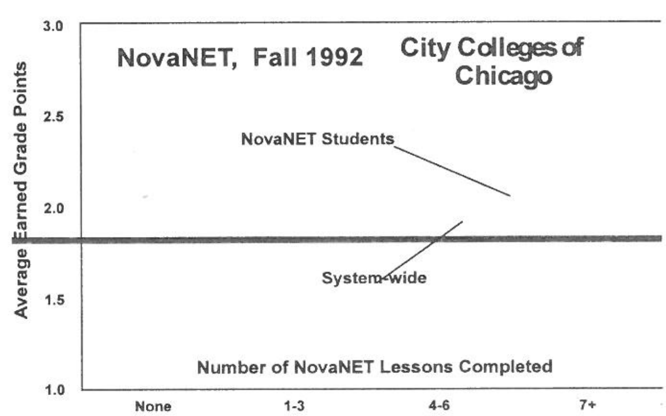

Fig. 5. Compared to system-wide average, NovaNET users who have completed 7 or more lessons appear to have high GPA scores.

downgraded video stream. Similarly the system might recognize user knowledge or experience profile and adapt its interfaces, and/or the amount and level of interaction (advice) and material it offers to the user, to suit.

QoS capabilities of a system used to deliver education will dictate the mix of the modes in which the education can be delivered. In advanced networking environments the most important issues will be i) guaranteeing end-user QoS for the varying mixes of transmitted voice, video, image and data needed to most efficiently deliver the knowledge, ii) providing appropriate application level interfaces (API's) that enable NBE systems to tap into those services, and iii) guaranteeing quality of learning through appropriate knowledge transfer and retention assessment and feedback.

While some QoS parameters, appropriate for an educational system, are well known, definition of the full QoS spectrum, development of adequate QoS control mechanisms and algorithms, and modeling and prediction of QoS properties of different topologies and configurations is still an open research and development issue. For example, it is desirable to develop a communication control architecture and communication primitives which efficiently support different types of networked classroom interpersonal interactions. Communication control in the networked classroom must support synchronous and asynchronous collaborative activities, as well as a mixture of underlying hardware and software technologies, such as students sitting in front of PCs, teleconferencing equipped classrooms, multimedia database servers, etc. Further, the communication system should easily allow differing levels of privacy, security and distributed collaborative floor management techniques. Finally, the communication architecture must be interoperable with existing and projected network technologies.

In the following sub-sections we briefly visit some of the end-to-end system quality and QoS parameters that we believe are essential for successful operation of a NBE system.

2.9.1. Reliability and Availability

In addition to adequate system functionality and usability, a successful scientific workflow support system must have adequate reliability and availability, or a broad base of users will simply not use it. Availability is defined as the probability that a system will be available at any random time during its operational life. This implies appropriate system reliability and recovery rates [Jon96, Dix96]. What are they?

If we assume that a typical NBE user will be at least as discriminating and demanding as university students and educators that use NovaNET, we can set a lower bound on the minimally acceptable overall system reliability and availability. If we assume that a network-based system will be limited by the reliability of its network links, we can use the information on the field quality of Internet switching elements, e.g., [Jon96], to establish another type of bound. Of course, this assumes that numerical components of the system, individually and in combination, have sufficiently high reliability that they are not the limiting factor. In general, networks and user interfaces may play an equally important role. For example, we estimate that (before error correction) acceptable network-level packet loss rate should not exceed 0.02 to 0.1 for voice and audio interactions, 10^{-9} to 10^{-5} for images, zero to 10-5 for data, and 10^{-10} to 10^{-8} for full-motion MPEG video.

NovaNET system measurements indicate that, once a user starts one hour of work (e.g., a lesson), to maintain reasonable user satisfaction, the probability of getting through that hour without any problems should be above 0.95 [Bit73, Avn93]. We expect that a good NBE environment would have reliability and availability characteristics that at least match above figures. On the other hand, according to Bellcore [Bel89], public network switching elements are expected to assure unavailability that does not exceed about 10^{-5} (about 3 min. of downtime per year). Therefore, it is reasonable to require that individual NBE system elements provide reliability and error control (including exception handling, fault-tolerance, and graceful error trapping) at least at that level, and that the overall NBE system reliability during its posted user access hours be at least 0.95 (this includes everything: network outages, violation of end-to-end response times, NBE system and content software failures due to algorithmic or other problems, and so on).

Network	Traffic Load	Probability that Response Time is		
		Good	Acceptable	Poor*
NCSU Campus	Low	0.9963	0.0020	0.0017
	Medium	0.9889	0.0054	0.0057
	High	0.9566	0.0356	0.0078
Internet	Low	0.9682	0.0176	0.0142
	Medium	0.9502	0.0130	0.0368
	High	0.7187	0.0458	0.2355

(*) Includes lost packets.

Table 1. Campus and Internet response times under different traffic loads.

2.9.2. End-User Bandwidth Matching

One of the most important QoS drivers is the quality of the computer-human interface (CHI). A user response to an NBE, and user's capability to start and understand the interactions and absorb results, is a very strong function of its CHI. To achieve effective information transfer rates[2], we may need to use different sets of "symbols" and presentation rates - from simple characters (at several thousand bits per second), to sophisticated high-definition animations and full-motion movies (at many megabits per second). The exact mix and density of the "symbols," functions, and the content of delivery modes that is most efficient, remains a research issue. However, it is clear that a "quality" NBE environment needs to dynamically customize its CHI, its presentation and communication modes, and the amount and level of the delivered material to match user expertise, user knowledge absorption rate, and the available computing and networking resources. Hence, NBE **throughput** requirements may vary widely. Each mode of operation of a NBE environment has certain throughput requirements. In some cases the bandwidth needs to be provided synchronously (user waits for output), and in some cases asynchronously (batch mode), both with varying delay requirements. The principal driver in deciding what is appropriate is the education and problem solving workflow.

It usually takes one of the two forms:

- "TV-model" format; This is a high average bandwidth synchronous (real-time) full-motion audio/video interaction that can be found in video-conferencing, distance-teaching and video-based collaborative work, or in a large-scale real-time data acquisition effort. These exchanges can require as much as 6 to 45 megabits per second (Mbps) per session, depending on the compression mode used and the desired quality of images. Since a NBE system is expected to serve thousands of students concurrently, it is not difficult to construct situations where OC3 or even OC12 bandwidth may not be sufficient if all users interact in this expensive mode.
- "Data-model" format; This is a low to medium average bandwidth synchronous (real-time) interaction with asynchronous data transfers. In this format one expects judicious use of hypertext, animation, graphics, voice and text to adaptively deliver the material. The synchronous interactions in this format may be very bursty. The average required throughput may be quite low, in the range 1000 to 20,000 bits per second, peaks can be as high as 100 Kbits/s to 2 Mbits/s. Thus, real-time bandwidth-on-demand is a network feature that can greatly enhance this mode of interaction [Rin95]. Asynchronous transfers may require an even larger bandwidth range. Although in this mode the user will not wait for the response (e.g., batch job submissions to supercomputers, transfers of non-real-time visualization data), bandwidth requirements will still be lower-bounded by the overall scheduling requirements of the interaction.

[2] Research shows that humans cannot extract (reason about, learn) new information at the rate faster than about 20 bits/second (i.e., differentiate among about 1,000,000 "symbols" each second) [e.g., Str67].

In general, in a good large-scale NBE system framework "bandwidth-greedy" material is distributed in a way that conserves bandwidth and allows support of a large number of simultaneous users. The distribution of tasks, across the network and across resources, will depend on the task complexity, desired schedules and resource constraints. The solutions should not rule out use of any network type (wire, optical, wireless) or access mode (high-speed and low-speed).

2.9.3. Delays

End-to-end response **delay** can also be a big problem. Studies show that synchronous end-to-end (round-trip) delays that consistently exceed about 250 ms are often unacceptable from the user point of view when the interaction is conducted in the key-stroke-by-key-stroke mode [Bit73; Kau95, Dix98]. Furthermore, the video, voice and animation jitter should be less than about 10 ms, and for some specific coding approaches such as MPEG, less than 1 ms. Our measurements indicate that, except over limited areas, current incarnation of the Internet is probably not an adequate medium for key-by-key interactions. An alternative to real-time interaction on the key-by-key basis is for NBE to operate in semi-batch mode where the user interface and interactions are designed in such as way that a user expects some delays (not exceeding few tens of seconds), and does not consider long responses as system failures.

For example, we have measured network delays on the North Carolina State University (NCSU) campus intranet, in the NC Research Triangle (about 40 miles per side) wide-area net, and over the Internet stretch between NCSU and University of Illinois at Urbana-Champaign (UIUC) [Kau95, Dix98]. Table 1 illustrates the 1995 results, more recent results are not any better. The table shows the probability of response time for on-campus network and Internet under different loads. Assuming that an NBE application has response time of about 100 msec or better [Bal96, Dix98], the network response times under 100 msec are considered good, response times between 100 and 150 milliseconds are considered *acceptable*, and response times over 150 msec are considered *poor*. The results show that a well designed campus network (or intranet) can adequately support modern NBE, but problems grow rapidly beyond campus bounds. For instance, the NCSU-UIUC Internet link was totally inadequate for interactive work during high traffic time slots (e.g., midday), and was at best marginal in medium to low traffic conditions. Adequate long-distance throughput over Internet is another problem.

Obviously, a network that provides delay, jitter and throughput guarantees, can make a big difference in providing real NBE.

2.10. Security

There are also a number of issues related to security and privacy. They range from almost trivial, but very serious issues, of electronic cheating and copying of homeworks, to more sophisticated issues such as letting the student know his/her grades and standing in the class without revealing that information to wrong person. Many of these issues have already been examined [Ste91], but many are still unresolved, and many more will emerge as the Web and high-performance networks become more prevalent. The NBE system primitives and communication architecture need to be enhanced to support floor management or "baton-passing", voting, security and privacy in the networked classroom.

For instance, during a distributed synchronous problem-solving investigation a teacher may wish to pause and have a private conversation with a student without ending the lecture. This might be accomplished through the use of NBE group management primitives by encrypting the audio communication channel between the teacher and the student, without disturbing or modifying the rest of the group's connection.

3. Web Lecture System (WLS)

Web Lecture System was developed by the RTCPP for training in the area of parallel processing [Kle96]. Subsequently, the WLS use was extended to other areas where rapid transfer of research results into training and education is of the essence. WLS supports construction, editing, and management of Web-based presentations, and synchronous and asynchronous capture and delivery of classes and lessons.

Fig. 6. http://renoir.csc.ncsu.edu/WLS

Using existing technology, such as Web browsers, HTTP servers, HTML documents, CGI programs, Javascript, Java Applets, and RealAudioT, we have developed a method for automatically generating and serving low-bandwidth and high-bandwidth Web-based multimedia presentations based on live versions of the same presentations. The presentations consist of HTML documents with streaming synchronized audio and video. The video can be of the low-bandwidth variety or it can be MPEG-2 or some other higher-bandwidth method. Low-bandwidth WLS lesson can be received over ordinary modems and telephone lines.

WLS can be downloaded from its main site, Figure 6.

WLS contains an on-line editor that allows instructors to prepare slides for delivery. However, for development of Web pages and animations that are used for class presentation, we encourage use of commercial HTML and Web-site editors and environments such as HomePage, PageMill, FrontPage and similar, or tools such as PowerPoint. WLS can work with outputs from all these tools. In operation, WLS captures audio/video and timing data during live presentations and automatically creates a web-deliverable version of the presentation. All of the details of the underlying system are hidden from the users, both instructors and students. WLS allows users to view a presentation using a standard Web browser, such as Netscape, and listen to the accompanying streams via a RealSystem player. The system also has the ability to deliver live presentations with student interaction.

WLS is currently installed at several sites in North Carolina and US. It is in regular use at RTCPP and by some NCSU on-line courses [WLS98]. Public domain version of is available from the main site, see Figure 6.

3.1. Development Directions - Collaborative Lecture System

Collaboration, combined with workflow, user-orientation and modern networking and computing technology, is the key to successful cost-effective integration of research into undergraduate courses. Potential collaborative activities include:

- Collaboration among authors, joint courseware development. Experts can contribute to those parts of a course that are in their domain of expertise. The collaborative effort can minimizes the courseware production provided **courseware organization** and lesson formats are standardized to facilitate integration and re-use of the material.
- Sharing of special facilities and simulations. Expensive state-of-the-art facilities of one institution can be made accessible to another institution via a **virtual laboratory**. A student can remotely access the targeted facilities through Internet and control all relevant parameters when conducting a hands-on activity. This can greatly increase the opportunities for students who might have limited facilities in their local institutions.
- Collaboration among, and with, learners can significantly enhance the learning experiences. One way to encourage such collaboration is to design team projects for the

courses offered. Students who are physically apart should be allowed to perform joint work. This requires **groupware** that facilitates file sharing, collaboration, discussion among distant students, and so on.

We plan to develop an advanced learning framework which we call "Collaborative Lecture System (CLS)." The system will be Web-based and will be built on top of the Web Lecture Systems, since WLS is operational, and it can already perform many of the envisioned collaborative functions. Nevertheless, to fully meet the collaboration requirement and goals of modern education, WLS will need to be enhanced. This will require some research in the areas of collaborative technology (e.g., development of advanced virtual laboratories, groupware, and courseware organization), quality of service, and learning paradigms. Some more elaborate issues of CLS are outlined in the following paragraphs.

Virtual Laboratory (VL). This idea dates back to the early days of NBE. Examples of "*learning-by-doing*" are computer-based laboratories that many learning environments provide. A classical example is the full-interaction "distillation experiment" implemented in PLATO [Ste91]. Web-resident examples abound as well. From the "Web-Telescope (Mt. Palomar), to collaborative environments such as IRI [Mal97] and TANGO (http://trurl.npac.sy.edu/tango/), to several remote electron-microscope labs, and similar Internet 2 applications. We plan to make full use of the VL concept in CLS since a major focus of our effort will be to stimulate hands-on and constructivist learning. Rather than merely presenting abstract, decontextualized information to students, the system will facilitate the acquisition of scientific principles by enabling students to design and troubleshoot complex devices and networks of devices. Recent advances in visualization technology enable us to create expansive and intricate synthetic environments that are ideal for this learning-by-doing paradigm. Equipment will be accessed through virtual laboratories to eliminate the geographical constraints.

NC State University will provide Virtual Laboratory servers that will allow access to NC State University state-of-the-art high-performance Internet 2 network and equipment. These servers will act as an interface, experimental design engine, data-collection and storage facility, set-up facility, and resource reservation arbiter.

A typical end-user station within an instructional facility would consist of a computer with a WWW Browser and streaming media support, and an extra terminal, TV or projection set that provides the high-bandwidth (3 to 10 Mbps) video link among the virtual laboratory facilities. A typical home or low-bandwidth end-station would be a PC, Macintosh or Unix-based computer with WWW and streaming audio/video support.

Groupware. Students taking classes at a distance need collaboration. PLATO and NovaNET were the first multimedia learning environments that supported extensive interaction among students as well as communication between the tutors and the students through a facility that lets one or more of the collaborators "watch" and interact with the screen of another collaborator [Ste91]. There is currently a host of commercial tools that provide similar or more extensive facilities. These range from teleconferencing, to whiteboard sharing to "chat-rooms." Examples are full versions of Netscape and Microsoft WWW browsers, the MBONE toolset [e.g., McC95], numerous "video-over-IP" ventures, Microsoft's NetMeeting, and so on. Groupware for collaborative project development needs to also consider synchronous and asynchronous group document control and maintenance. The CLS system will include the groupware that integrates shared document management and teleconferencing to support the collaborative activities among learners.

Courseware Organization and Storage. The organization of the course material can be crucial to the effect of the instruction. Proper organization should consider issues such as the integration of course contents developed by multiple instructors (re-use), proper break of presentation flow to allow insertion of activities on-the-fly, convenient random accesses, etc. WLS materials are organized into classes. Each class owns sets of slides. A slide can be either a local HTML page, or a URL. Lessons can be constructed out of any of the slides that belong to the course, or if URLs are used, to anyone, in any order and as many times as needed. The data-base is "home-grown," but we are in the process of moving to an object-oriented data-base. Since audio, video and text/graphic data are typically stored on different servers, the data-base has to be distributed.

The CLS course organization will be more oriented towards support of learning objects and their meta representations. It can be represented by a hierarchical graph, with topics and subtopics being represented by nodes and directed links associating subtopics to topics. For a given node (topic), summary and keywords are attached as attributes to the node to facilitate search and topic integration. Examples and case-studies are linked as subtopics to a topic. Text, viewgraphs, sounds, graphics, animations, and/or video are independently associated with a node to facilitate individualized storage, playback and adaptation that conforms with end-users media and networking preferences and/or constraints. Information about synchronization and about conversion options between high-bandwidth formats and low-bandwidth formats is also associated with the node (e.g., the same information may be stored as video+voice+streaming text, voice only, or streaming text only). A search engine will search for specific topics and keywords. One additional piece of information that will be attached to the learning objects is the quality of service that they expect (e.g., this lesson, or this "slide" needs to run with round-trip response times less than 100 ms, it needs throughput of 2 Mbps, and the probability of failure of the system to deliver the picture must be less than 1%). Other lesson object attributes, methods, and organizational characteristics will be added as necessary.

WLS will be transformed gradually into CLS. The CLS project will start in the Fall 1998. We expect to have the first integrated version of CLS available in the Fall 1999, and a public domain version in the Fall 2000.

References

[1] ALPERT, D. AND D. L. BITZER, "Advances in Computer-based Education," *Science*, 167, 1582–1590, March, 1970.

[2] R. A. AVNER, Measuring Reliability of Networked Educational Computer Systems Internal CERL Evaluation Report, UIUC, Illinois, August 1993

[3] R. BALAY AND M. A. VOUK, " A Lightweight Software Bus for Prototyping Problem Solving Environments", in Proc of the Eleventh International Conference on Systems Engineering, Las Vegas, pp. 626–630, 1996.

[4] BELLCORE, *Network Switching Element Outage Performance Monitoring Procedures*, SR-TSY-000963, Issue 1, April 1989.

[5] BITZER, M. D. and Bitzer, D. L. "(1973) Teaching nursing by computer: an evaluation study," *Computers in Biology and Medicine*, **3**, 187–204.

[6] DIXIT P., M. A. VOUK, D. L. BITZER AND C. ALIX, "Availability of NovaNET - A Wide-Area Network-Based Education System," *Proceedings ISSRE'96*, IEEE CS Press, pp. 213–218, October 1996.

[7] DIXIT, P., "Quality of Service Modeling ofr Wide Area Network-Based Systems," Ph.D. Thesis, North Carolina State University, May 1998.

[8] L. M. JONES, D. KANE, B. A. SHERWOOD, AND R. A. AVNER, "A Final-Exam Comparison Involving Computer-Based Instruction," *Am. J. Phys*, Vol. 51 (6), pp. 533–538, 1983.

[9] JONES W. AND VOUK M. A., (1996) Software Reliability Field Data Analysis, in *Handbook of Software Reliability Engineering* (ed. M. Lyu), McGraw Hill, pp. 439–89.

[10] P. K. KAUER, An Analysis of North Carolina State University's Network Performance, M. S. Thesis, Department of Computer Science, NCSU, 1995.

[11] R. L. KLEVANS AND M. A. VOUK, " Automatically Generated Multimedia Presentations ", WebNet 96, San Francisco, CA, Oct. 16–20, 1996.

[12] KURT MALY, HUSSEIN ABDEL–WAHAB, C. MICHAEL OVERSTREET, J. CHRISTIAN WILD, AJAY K. GUPTA, ALAA YOUSSEF, EMILIA STOICA, EHAB S. AL–SHAER, Interactive Distance Learning over Intranets,IEEE Internet Computing, Jan–Feb 1997, pp. 60–71 (URL: www.cs.odu.edu/ tele/iri)

[13] S. MCCANNE AND V. JACOBSON, "vic: A Flexible Framework for Packet Video," *ACM Multimedia*, Nov. 1995, California, 511–522.

[14] J. D. MUSA, "Operational Profiles in Software-Reliability Engineering," IEEE Software, Vol. 10 (2), pp. 14–32, March 1993.

[15] NovaNET Total System Reliability Reports (online, since 1985).

[16] NovaNET is owned and operated by University Communications Inc.

[17] R. C. OVERBAUGH, "Research-Based Guidelines for Computer-Based Instruction Development," *J. Res. on Computing Education*, Vol. 27 (1), pp. 29–47, 1994.

[18] RINDOS, A., VOUK, M., WOOLET, S., HINES, J. AND LESTER J., (1995) ATM Technology Enabling Educational Applications Across the North Carolina Information Highway, *in Proc. TELECOM '95 FORUM Technology Summit*, ITU, Geneva, pp. 519–22.

[19] SINGH, M. AND HUHNS, M., (1994) Automating Workflows for Service Provisioning: Integrating AI and Database Technologies, *IEEE Expert*, **9**, 19–23.

[20] STEINBERG, ESTER R., *Computer-Assisted Instruction - synthesis of Theory, Pratice and TechnologyI*, Lawrence Erlbaum Associates, Hollsdale, N. J., 1991.

[21] STROUD J. M., (1967) The Fine Structure of Psychological Time., *Annals of the New York Academy of Sciences*, **138** (Art. 2), 623–31.

[22] M. A. VOUK, AND M. P. SINGH, "Quality of Service and Scientific Workflows," in *The Quality of Numerical Software: Assessment and Enhancements*, editor: R. Boisvert, Chapman & Hall, pp. 77–89 , 1997.

[23] http://renoir.csc.ncsu.edu/WLS, and http://courses.ncsu.edu.

Received: June, 1999
Accepted: June, 1999

Contact address:
Mladen A. Vouk
Department of Computer Science
North Carolina State University
Raleigh, NC 27695
USA

MLADEN A. VOUK received B.Sc. and Ph.D. degrees from the King's College, University of London, U.K. He is currently a Professor of Computer Science at the N.C. State University, Raleigh, N.C., U.S.A.

Dr. Vouk has extensive experience in both commercial software production and academic computing. He is the author, or co-author, of over 130 publications. His research and development interests include software engineering (software process and risk management, software testing, software reliability and fault-tolerance), scientific computing (development of numerical software and scientific software-based systems, parallel computing, scientific workflows), computer-based education (network-based education, distance learning, computer-assisted education workflows), and high-speed networks (end-user quality of service, forward error correction in high-speed networks, empirical evaluation of ATM-based high-speed networking solutions).

Dr. Vouk is a member, and ex-chair, of the IFIP Working Group 2.5 on Numerical Software. He is a senior member of IEEE, member of IEEE Reliability, Communications and Computer Societies, and member of IEEE TC on Software Engineering, ACM, ASQC, and Sigma Xi. He is an associate editor of IEEE Transactions on Reliability.