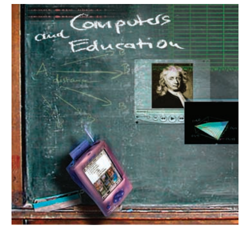
Project Numina: Enhancing Student Learning with Handheld Computers



Despite recent technological advances, the promise of the virtual classroom with anywhere, anytime access and rich data sharing remains largely unfulfilled. To address this need, Project Numina researchers are developing a mobile learning environment that fosters collaboration among students and between students and instructors.

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The widespread emergence of wireless networks and the rapid adoption of handheld computing devices have made mobile computing a reality. Hotspots are now commonly found at coffee shops, bookstores, airports, hotels, and other public spaces. In line with this trend, a growing number of college campuses are also becoming "unwired." This new infrastructure is enabling the development of a whole new generation of educational applications and associated pedagogical approaches to teaching and learning.

A convergence of technologies is giving small computing platforms, such as the pocket PC, the ability to support telecommunications, audio and video applications, mathematical computations, word processing, electronic spreadsheets, and standard PDA functions. Wrapped into a single device, the handheld can replace all of the traditional electronic hardware students commonly carry in their backpacks such as a cell phone, MP3 player, and calculator. Laptops and tablet PCs are also more popular than ever on campus.[1,2]

College students across the US are increasingly making extensive use of mobile computing devices that they carry with them at all times. As this technology becomes more accessible, colleges and universities will seek new ways to integrate it in the classroom.[3] Unfortunately, few high-quality educational applications are currently available for handhelds, especially in mathematics and science.

A handful of US institutions, including Stanford University, Des Moines Area Community College, and California State University-Monterey Bay now require such devices in some courses, while hundreds of others are testing their feasibility in pilot programs.[4,5] More than 77 percent of US colleges and universities report some use of wireless networks, with many providing seamless network access to their physical boundaries.[6]

In 1999, the University of North Carolina Wilmington began rolling out its campuswide wireless network infrastructure. At the same time, Project Numina (http://aa.uncw.edu/numina) was formed to test the use of mobile devices in instruction. Over the years, an interdisciplinary team of UNCW researchers in chemistry, computer science, and mathematics has experimented with a wide range of handheld devices and software applications for use primarily in undergraduate classrooms.

Our extensive experience with both commercially available and homegrown software suggests that using handhelds engages students more fully in learning and may improve understanding of mathematical and scientific concepts. On the other hand, we have also identified many shortcomings of handheld technology.

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Table 1. Handheld devices used in Project Numina.

Year purchased	Device	Operating system	Processor speed	RAM/ROM	Purchase price
1999	HP Jornada 690	Windows CE Handheld PC Professional Edition v3.01	133 MHz	32/32 Mbytes	$749
2000	HP Jornada 720	Windows Handheld PC 2000	206 MHz	32/32 Mbytes	$749
2002	HP Jornada 568	Windows Pocket PC 2002	206 MHz	64/32 Mbytes	$549
2003	Dell Axim X5	Windows Pocket PC 2002	400 MHz	64/32 Mbytes	$450
2004	HP iPAQ 2215	Windows Mobile 2003	400 MHz	64/32 Mbytes	$499
2005	Dell Axim X50v	Windows Mobile 2003 Second Edition	624 MHz	64/128 Mbytes	$425

To address these deficiencies, we are developing a mobile learning environment designed to foster collaboration among students, and between students and faculty, in a virtual learning community.

PROJECT BACKGROUND

Although UNCW has been widely using instructional technology for nearly 15 years, it has had little impact on some important areas. For example, the student role in class remains generally passive, tests do not contain multimedia components, and computers are not readily available for calculations and modeling in large classrooms.

We postulated that handhelds' mobility and touch-screen interactivity made them ideal for classroom and laboratory use. In addition, some current-generation handhelds are powerful enough to run applications, including molecular modeling and numerical analysis, that only a few years ago required a supercomputer.

Project Numina focuses on creating, testing, and evaluating handheld computing applications for college-level science and mathematics students and instructors. Table 1 lists the devices used throughout the project's history in both large classroom (125-seat auditorium) and small laboratory settings.

With funding from Pearson Education and UNCW, the Project Numina research team initially acquired 100 Hewlett-Packard Jornada 690/720 series handheld computers and installed IEEE 802.11b wireless networks in the chemistry, mathematics, and computer science buildings. In 1999, such networks were still in their infancy and costs were high—for example, a single Cisco Aironet 340 access point cost $980.

Using these devices, the team developed various novel applications including preliminary versions of a Web-based interactive student response system, graphing software for use with Pocket Excel (GraphData), and instructional materials built around the use of Pocket HyperChem, a molecular modeling program developed by Hypercube for handhelds. Other student applications included Microsoft Pocket Word, Pocket Excel, and Internet Explorer; an introductory chemistry eBook; and a few DOS-based statistical applications.[7]

In early 2001, the pocket PC began to supplant the handheld PC in the wake of the Palm Pilot's success. Although happy with the somewhat larger HPC, we soon realized that the market shift to the PPC was too important to ignore. In April of that year, we obtained an internal seed grant to purchase 24 PPCs and began studying how to employ these new devices for instruction. Figure 1 shows a PPC with data acquisition equipment and keyboard for use in science labs at UNCW.

HANDHELD APPLICATIONS

Although the hardware has changed during Project Numina, the classroom implementation and applications have remained consistent except for software upgrades and lessons learned. In a typical scenario, students arrive at a lecture or lab and take a machine from a charging cart. They usually receive their own device but at times may share one while working in groups. After completing their lesson, the students return the machines to the charging cart before leaving the classroom or lab.

Student response system

One of Project Numina's most popular applications is the student response system (SRS).[7]

Figure 1. Project Numina hardware. UNCW students use a pocket PC, such as this Dell Axim X5, with temperature probe and CompactFlash data logger, in science labs.

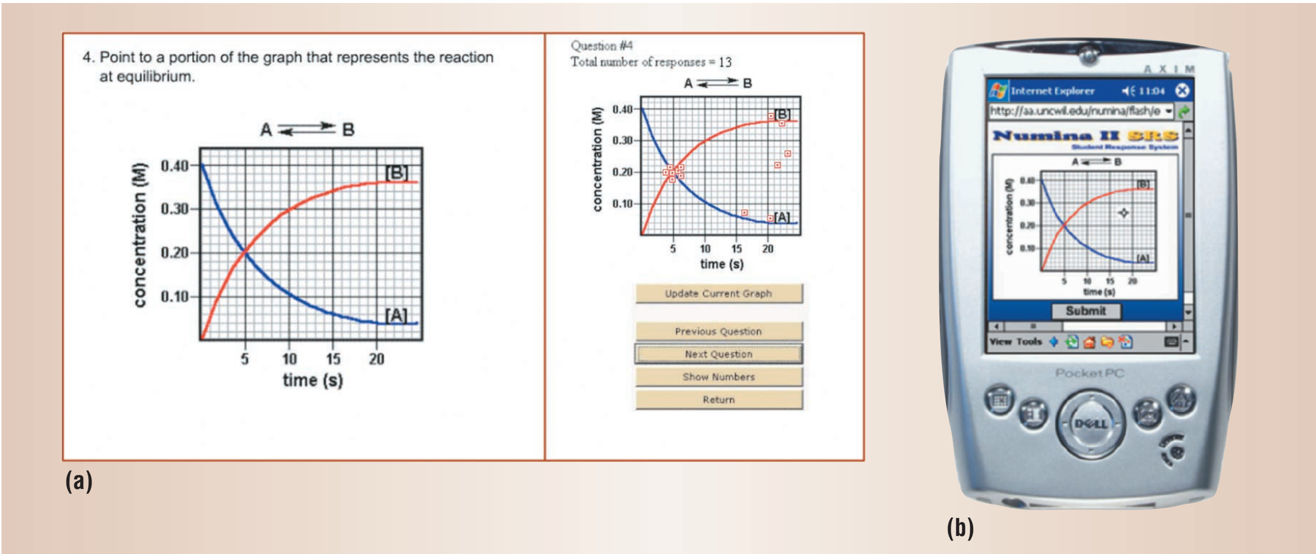

Figure 2. Project Numina student response system: (a) Classroom view and (b) student view. Students point to a graph region on their touch screen, and the system displays the graph with all of the students' points on it.

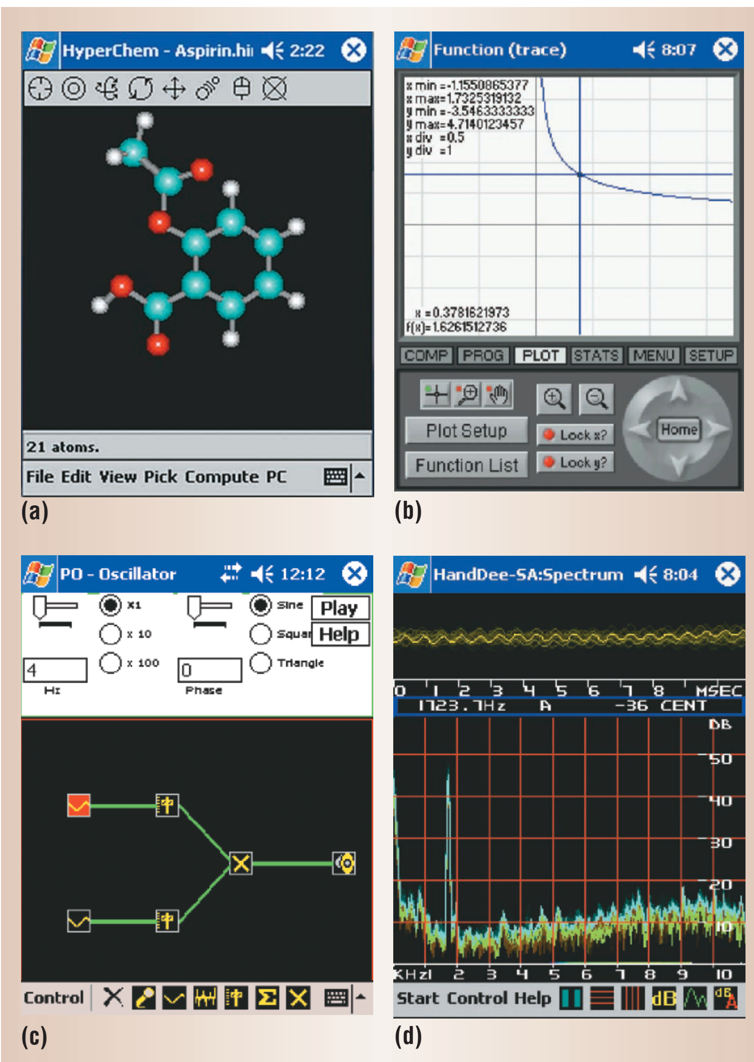

Figure 3. Sample mathematical and scientific applications for PPCs: (a) Pocket HyperChem; (b) RDcalc; (c) Pocket Oscillator; and (d) HandDee Spectrum Analyzer.

Students use handheld computers to respond to the instructor's questions, and the SRS stores these responses in a remote database and collectively displays them at the front of the classroom. SRS is a server-side Web application implemented as an active server page. It is completely Web-based and therefore requires no special software on the client side other than a Web browser.

The instructor poses a question in a multiple-choice, true-false, or yes-no format and directs students to a Web site that generates a Web form on their computer screens through which they submit their responses. Multiple question-and-answer scenarios are possible. A back-end database stores only responses to questions, not information about the student, so responses are anonymous.

In contrast to the typical 2-3 percent response rate in a traditional classroom setting, nearly all students using SRS answer the instructor's questions. This suggests that students are more comfortable responding to a question when they see others doing the same and when their responses are anonymous.

Another benefit of SRS is that instructors can see immediately how well students comprehend a specific topic they have presented. This real-time feedback enables instructors to make just-in-time decisions on instructional content to better meet learners' needs.

Unlike today's popular infrared and radio-based "clicker" technologies,[8] SRS can exploit the PPC's ability to run Macromedia Flash applications. This allows SRS to provide more interactive and interesting response types. For example, Figure 2 shows a Macromedia Flash application in which students presented with a graph point to a region on their touch screen, and the system displays the graph with all of the students' points on it.

Mathematical and scientific applications

In 2002, Project Numina researchers began investigating the practicality of using handhelds for mathematics and scientific instruction. At the time, few such applications existed for these devices, but several have appeared in recent years. The most useful are designed for Windows-based PPCs, although a few are available for the Palm OS and Linux-based PDAs such as the Sharp Zaurus.

Figure 3 shows screenshots from four mathematical and scientific applications used at UNCW: Pocket HyperChem (www.hyper.com/products/PocketPC), RDcalc (http://ravend.com), Pocket Oscillator (http://bofinit.com), and HandDee Spectrum Analyzer (www.phonature.com:8092/home/products_mpApp_HandDeeSA.htm).

To illustrate the growing range of PPC software available today, Table 2 provides a selection of mathematical applications, which range from calculators to spreadsheets to graphing utilities (a more comprehensive listing is available at http://people.uncw.edu/hermanr/TechFiles/PPCMathSite.htm). It is worth noting, however, that many of the more esoteric applications ported to PPCs have installation and programming requirements beyond the average student's expertise.

Project Numina members have also experimented with using handhelds as data-gathering devices in mathematics and science classes. For example, one study required students to collect spring and beam oscillation data on an HP Jornada 720 using a Data Harvest interface with distance probes and then analyze the data to solve a governing differential equation.[9,10]

Table 2. Pocket PC mathematics applications.

Category	Applications
Calculators	HP 15C, Math Tablet, MRI Graphing Calculator, PDAcalc (classic and matrix), Pocket Atlantis, RDcalc, TI59ce
Computer algebra systems	Euclid, Formulae 1, Giac/Xcas—qdCAS, JACAL, Math Xpander, Maxima
Data acquisition and analysis	Data Harvest
Editors	LaTeX
Graphing	Autograph, Gnuplot, GraphData, PDAGraphiX, SpaceTime, Vinny Graph
Miscellaneous	Mandelbrot Explorer, Lisa, logic applications, PocketFract, RPS/Fract, Rubik's Cube applications, SLAE Solver
Multimedia	HandDee Spectrum Analyzer, Pocket Oscillator, Pocket RTA, Pocket TV Browser, PocketDivX, Windows Media Player
Programming	CEPython with mathematics packages, Common Lisp, Embedded Visual Basic, GnuPG, Macromedia Flash, Math.NET, NSBasic, Pari/GP, Pocket C, Pocket Scheme, PocketGCC, SCM Scheme
Spreadsheets	Pocket Excel, PTab

STUDY RESULTS

Project Numina has conducted numerous studies related to the use of handheld computers in the classroom. One in-house study of the SRS found that, in addition to consistently achieving a near 100 percent participation rate during question sessions, the system increases classroom discussion and reduces off-task behavior. In addition, equipment distribution and setup costs little instructional time.

Another in-house study examined whether Pocket HyperChem's interactive capabilities contributed to student learning. Students use the software in chemistry classes to build 3D models of molecules, optimize their geometries, and measure bond lengths, bond angles, and other physical properties. We found that students who could rotate molecules on a PPC during classroom activities scored significantly higher on related quiz questions than those who viewed the molecules online without rotation capability. We also used Pocket HyperChem to design multimedia-based molecular modeling questions that required students to perform computations in near-real time on chemistry exams.

In 2001, we conducted an in-depth study of the effectiveness of handheld computers and other high-tech tools in a general chemistry laboratory.[11] Students used Pocket Word to answer pre- and postlab questions, submitting their work via a File Transfer Protocol (Scotty FTP) application as well as an early version of the SRS to answer questions the instructor posed. They also had access to other PPC applications such as Pocket Excel, GraphData, Pocket Internet Explorer, a scientific calculator, Pocket HyperChem, an e-textbook, and an interactive periodic table.

The study revealed that PPC hardware limitations—including minimal I/O options, small screen size, and short battery life—as well as software restrictions made such an intense application of handheld technologies in the classroom cumbersome. For example, students could not reliably print to a local network printer, had trouble moving between multiple open applications, could share documents with lab partners only via e-mail, and could not copy and paste Pocket Excel tables into Pocket Word. The data acquisition software also limited what students could collect and share.

Electronic submission of work also posed numerous challenges for instructors, including how to store, access, grade, and return files to the students. Moreover, FTP work submission was not easily

Learning Communities

Learning communities gained attention in the US after the publication of *Involvement in Learning: Realizing the Potential of Higher Education,* by the National Institute of Education's Study Group on the Conditions of Excellence in Higher Education, in 1984.

The report's authors argued that active engagement in the learning process enhances learning and leads to two fundamental principles:

- The amount of student learning and personal development associated with any educational program is directly proportional to the quality and quantity of student involvement.
- The effectiveness of any educational policy or practice is directly related to the capacity of that policy or practice to increase student involvement in learning.

Unfortunately, traditional learning communities rely solely on direct physical interactions among students, as well as between students and faculty. This requires students to live together in designated residence halls, and they must be available to attend group seminars, study sessions, and meetings at specific times and locations.

By supporting a virtual learning community, Project Numina's mobile learning environment aims to address these time and space limitations.

scalable to multiple instructors, teaching assistants, and class sections.

MOBILE LEARNING ENVIRONMENT

These study results prompted Project Numina team members to explore ways to more efficiently implement handheld technologies in classrooms and laboratories and ultimately make anytime, anywhere mobile computing a reality on university and college campuses.

Integrated computing services

Supporting truly collaborative learning requires a software infrastructure that seamlessly integrates wired and wireless computing services. Currently, computing services can be broadly categorized as either disaggregated or aggregated.

Disaggregated services include individual protocols, portals, or applications such as FTP, e-mail, the Web, chat, instant messaging, Telnet, and Excel and Word. Above this layer of services are *aggregated* services—multiple-service protocols that typically require a common login, such as Campus Pipeline (www.campuspipeline.com); e-learning systems such as WebCT (www.webct.com), Blackboard (www.blackboard.com), and IBM Lotus Learning Space (www.lotus.com/lotus/offering3.nsf/wdocs/learningspacehome); and real-time collaboration applications such as Microsoft NetMeeting (www.microsoft.com/windows/netmeeting), FirstClass (www.softarc.com), and myStanford (http://my.stanford.edu).

We propose to add atop the aggregated services layer a new *integrated services* layer to support multiway communications, teamwork, rich data sharing, and personalized application-level access controls. The lack of such a layer limits the integration of current educational applications. Our preliminary studies demonstrate that the addition of integrated services has great potential.

Mobile learning environment objectives

Drawing on the concept of integrated services, Project Numina researchers are developing a Web-based *mobile learning environment* that will for the first time enable students and faculty to collaborate at any time or in any location, using the most effective educational tools available.

In this way, the MLE will support a 24/7 *virtual learning community* that is flexible, easy to use, and conducive to all types of communication including personal interaction, presentations, group tutoring, seminars, workshops, study groups, and lectures. The "Learning Communities" sidebar describes the pedagogical value of learning communities and limitations of traditional approaches.

Figure 4 illustrates the MLE software architecture, which has five key objectives.

Support for multiple devices and platforms. The MLE will provide an easy-to-use environment for multiple devices and platforms. Students and faculty will have access to numerous devices including tablet and pocket PCs, notebooks, desktop computers, and smart phones running on Mac OS, Linux, and Windows and connected by both wireless and wired networks.

Client-side runtime model. The MLE will be built on a widely available, high-performance, client-side runtime model. Existing Web applications are built upon a legacy HTML model with significant performance limitations. Macromedia Flash MX and other next-generation technologies provide the ideal power and extensibility for building this type of system. An industry leader in providing Web-based, interactive-application development tools, Macromedia estimates that its Flash Player is installed on nearly 98 percent of all computers connected to the Internet.

Comprehensive component integration. The MLE will offer a powerful object-oriented model for applications and events that integrates multiway communications, personalized access, collaborative learning, and location-based services in a way that educators of varying skill levels can use. This will create a synergy impossible to achieve with existing commercial applications.

Rich data sharing. The MLE will enhance data interchange through the use of Web services cre-

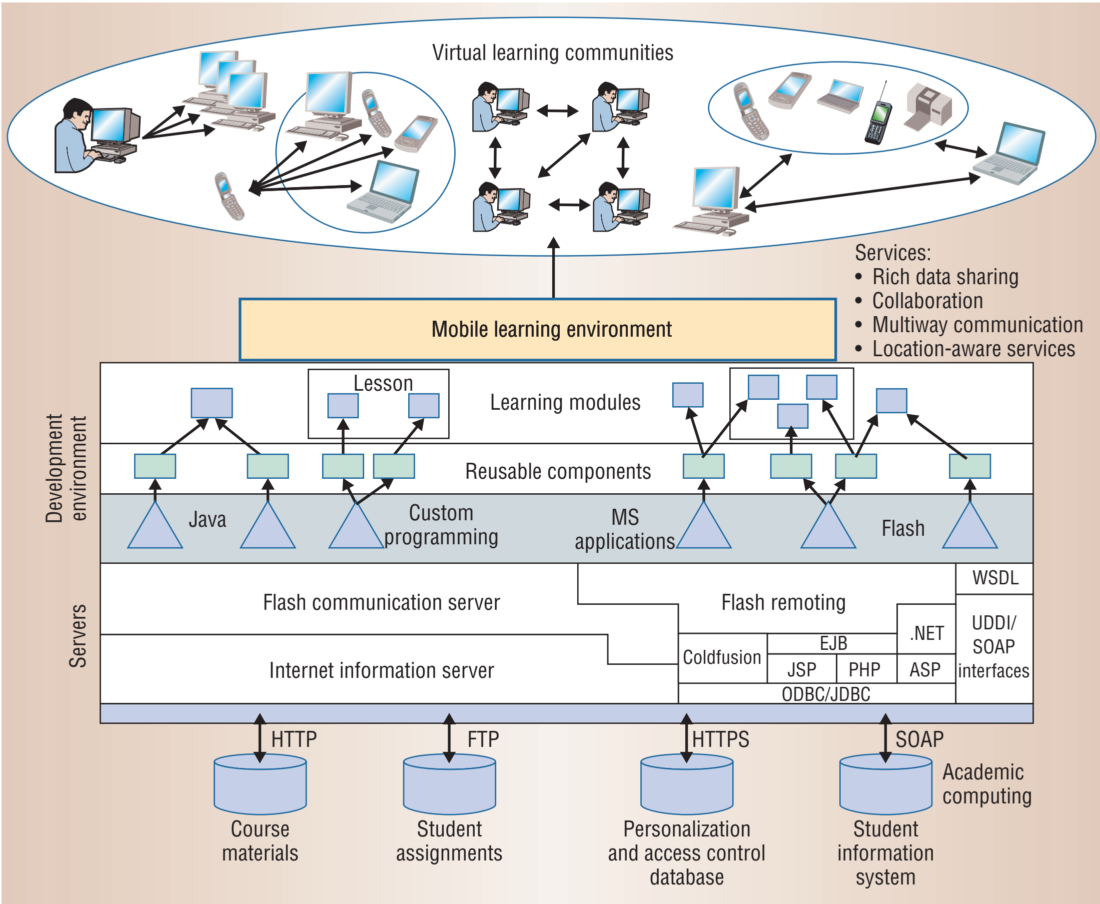

Figure 4. Mobile learning environment software architecture. The MLE seeks to support a 24/7 virtual learning community that seamlessly integrates wired and wireless services.

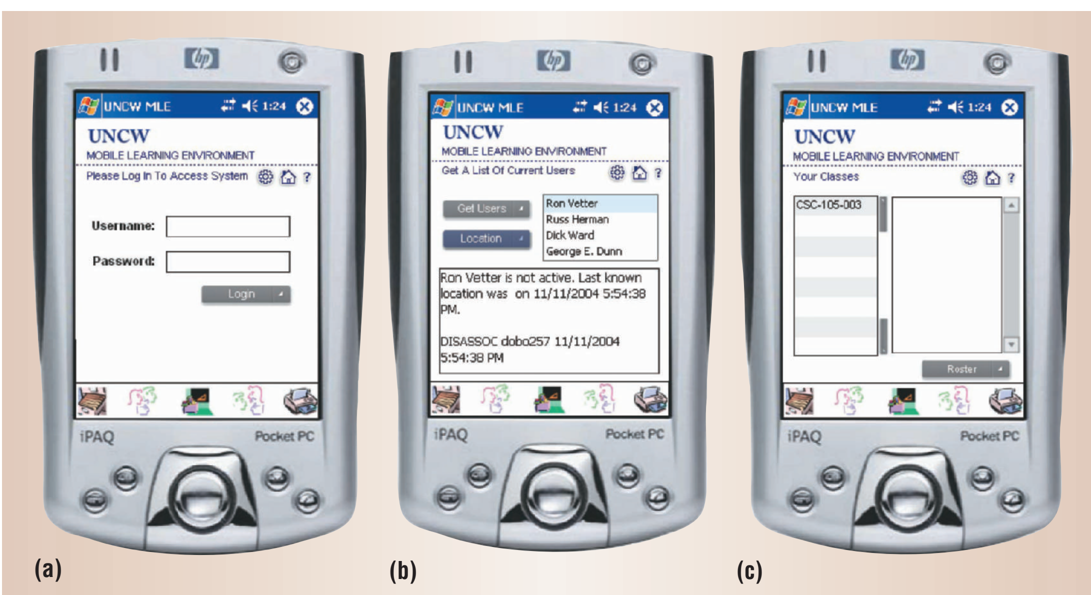

Figure 5. MLE screenshots: (a) Login screen, (b) People Finder service, and (c) Classroom Roster service.

ated with XML, SOAP, the Web Services Description Language, and the universal description, discovery, and integration protocol. The MLE currently uses XML messages to dynamically retrieve data within the Flash application. The server-side application logic is based on standard Microsoft Internet Information Services Web server technologies. The server-side applications themselves are active server pages that can send and receive XML-formatted messages to client-based flash applications.

Component reusability. Finally, the MLE hopes to shorten the development cycle, maintain a consistent and easy-to-use interface, and increase reliability through the use of reusable components.

Sample MLE applications

Figure 5 provides iPAQ PPC screenshots of the MLE login screen and two service applications we have completed. People Finder lets users determine the location of another user connected to the wireless network. Classroom Roster allows faculty and students in a common course to easily contact and communicate with one another, demonstrating MLE's ability to tie into back-end university student information systems.

At the bottom of the screen is a set of icons that the user can activate to bring up menus for carrying out various functions. For example, *File transfer* sends files from the local device to other devices or to any device from the remote server. *People* locates users logged into the system. *Classroom and course* launches various communications options including text, audio, video, and whiteboard and supports one-to-many, many-to-one, and one-to-one communication. *Services* supports printing, location-aware services, software updates, alert services, user-profile editing, and MLE version and copyright information.

Despite the technological revolution in information access and communication, the promise of the virtual classroom remains largely unfulfilled. While many faculty employ technology in their teaching, few courses offer more than online syllabi, study sheets, group discussion boards, and e-mail. Hardware and software constraints continue to limit more sophisticated strategies such as virtual help sessions or electronically graded homework, and few instructors are willing to introduce more than one of these technologies in any given class.

Existing learning systems do not provide rich data sharing and location-aware services, and multiway communication is usually limited to text. Moreover, the information these products store cannot be easily integrated with the data on the instructor's computer. Finally, the systems are not designed for mobile devices, the most promising technology for anytime, anywhere learning.

Project Numina's mobile learning environment attempts to address these deficiencies by supporting virtual learning communities. Its modular construction and reliance on readily available commercial software should make the MLE relatively easy to implement at other institutions. Several additional software applications are under development, and future plans call for integrating the MLE more fully with core campus data services to build more useful value-added educational offerings. ■

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