

Approaches That Work: How Authentic Learning Is Transforming Higher Education

By Marilyn M. Lombardi

Edited by Diana G. Oblinger

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Abstract

Authentic learning aligns well with the needs of today's participatory learners. The challenge is to channel their online and collaborative abilities and interests into academic pursuits, helping them develop the higher-order thinking skills they may not acquire on their own. This second paper in the EDUCAUSE Learning Initiative's authentic learning series presents case studies on how institutions have used technology to foster authentic learning and thus better meet learners' needs.

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The first white paper in ELI's 2007 series on authentic learning, "Authentic Learning for the 21st Century",¹ introduced readers to the basic elements of an authentic learning experience:

- Instructors are encouraged to design activities for their students that match as nearly as possible the real-world tasks of professionals in the field.
- The challenges students are asked to undertake should be complex, ambiguous, and multifaceted in nature, requiring sustained investigation.
- Reflection, self-assessment, and performance review are fully integrated into the exercise. The real-world challenge comes with its own criteria for success. Students are held accountable for achieving the milestones that practitioners would have to meet under genuine working conditions.
- Teamwork is as essential to the authentic learning experience as it is likely to be in modern workplace settings. Groups of students have to draw on multiple sources and negotiate among multiple perspectives—including those of the stakeholders (business partners, clients, customers, citizens) who will be impacted by their performance.
- An authentic learning exercise highlights a student's capacity to affect the world beyond the classroom and to make contributions that are valued by peers, mentors, and prospective employers.

An authentic learning activity is designed to draw on the existing talents and experiences of students, building their confidence through participation and helping them see the connection between personal aptitude and professional practice. The activity is matched to the needs of the new "participatory learner," one whose expectations for active, hands-on involvement in learning have been raised by the proliferation of creative opportunities available through Web 2.0 applications. Increasingly adept at creating new-media content and evaluating the content of others through blogs, wikis, and social networking sites, incoming college students are accustomed to working collaboratively and shaping the direction of online communities forged from personal interests.

Educators can channel these creative and collaborative energies into discipline-specific pursuits and help learners develop the higher-order thinking skills they are least likely to acquire on their own. Within the context of real-world challenges, an effective authentic learning exercise will provide guided opportunities for students to practice the "portable" skills that will serve them well in any professional context:²

- Distinguishing reliable from unreliable information (judgment)
- Following longer arguments across multiple modalities (synthesis)
- Discovering and sharing relevant information in a credible manner (research)
- Learning an abstract concept by applying it appropriately in real-world contexts (practice)
- Generating alternative solutions that work across disciplinary and cultural boundaries (negotiation).

This second paper in the authentic learning series focuses on a set of authentic learning case studies. In each of these cases, technology plays the same role in the classroom as it would in the modern laboratory, clinic, or corporation, both as a necessary support and as a catalyst for innovation.

Types of Authentic Learning Activities

Table 1 classifies commonly employed authentic learning activities by their desired learning outcomes, the technologies that may be used to support them, and the case study that best illustrates their potential.

Table 1. A Classification of Activity Types

Type of Authentic Activity	Desired Learning Outcome	Technology Requirements	Exemplary Cases
Student-created media	Students work in teams to replicate real-world, cross-disciplinary research processes and produce a credible presentation of their findings in the appropriate media format.	Appropriate media production tools	<i>Rising Up</i> (University of Virginia)
Working with data	Students generate credible analyses of primary historical documents or up-to-date scientific data and share their findings with the larger community of practice.	Internet-based access to a rich wiki-like database on a particular subject	The History Engine (University of Virginia)
Using remote instruments and high-end scientific simulation tools	Students are able to control specialized, discipline-specific instruments (astronomical tools, spectrometers, electronics equipment, and the like) or run live simulations using high-performance computational resources.	For access to remote instruments, a browser-based interface that allows users to control the relevant functions of the instrument For running live simulations, a Web-based portal providing access to distributed high-performance computing resources	iLab (MIT) nanoHUB Gateway (Purdue)
Investigative case-based learning	Students situate their learning in authentic contexts, tackle ambiguity, hone their decision-making skills, acknowledge multiple perspectives, and practice the type of negotiation required of them as professionals.	Online access to field-tested case studies, real-world datasets, analytic tools, and instructional support	BioQUEST (Beloit College)

Student-Created Media

Case Study: The University of Virginia

Rising Up: Student historians and filmmakers produce televised documentary on local civil rights activism.

What is it?

The story of how 20 University of Virginia (UVA) fourth-year undergraduates came together to make history—in more ways than one—captures the spirit of authentic learning. Historian William G. Thomas III, now John and Catherine Angle Chair in the Humanities and professor of history at the University of Nebraska–Lincoln, and filmmaker Bill Reifenberger, a lecturer in UVA's Advanced Media Studies, recruited students for a combined course entitled Document the Civil Rights Era, which they team taught in the spring of 2005. In just 16 weeks, this group of advanced history students and media-studies majors created a one-hour, broadcast-quality video documentary called *Rising Up*. The film is set to air on WCVE, the PBS affiliate in Richmond, Virginia, in fall 2007 and is likely to be televised nationally on PBS in 2008.

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Collaborating in four-person production teams, students mined digital archives; investigated leads; tracked down eyewitnesses; filmed interviews with local citizens and state senators; and scripted, edited, scored, and produced this genuine work of historical research and analysis, with an interpretive slant all its own. This civil rights documentary shifts the focus away from the Deep South toward recovering the contributions of ordinary Virginians who never gained the celebrity of Martin Luther King, Jr., Rosa Parks, or others. Speaking to the concerns of their own generation, the UVA students emphasized the impact of individuals and explored what motivates certain people to alter local realities, becoming activists where they live and work. From tracking down prospective interviewees to securing copyrights for the use of archival materials, students learned what it means to *be* a working historian, journalist, documentary filmmaker, and production manager in the participatory, digital age.

What problem did it solve?

Since the end of World War II, television news crews have often been the first to capture American history in the making—a fact that makes film footage, particularly footage shot by local news stations, an invaluable and frequently endangered material resource for working historians. Undergraduate “historians-in-the-making” who seek to specialize in modern history will need to be as conversant with film archives as their medievalist counterparts are with the library’s rare-book room.

How did they do it?

When Will Thomas first proposed what he called his “dream project,” he had just been awarded the Virginia Alumni Association’s Ernest C. Mead Endowment Award for exemplary classroom teaching and student engagement. The endowment agreed to fund his proposal to the tune of \$2,000, hardly a windfall given the ambition of his educational initiative but sufficient for his purposes. The essential ingredients for this authentic learning experience—the elements that would ensure its viability—were clearly defined from the outset:

- **Real-world relevance:** Thomas designed a project that would make the most of his own experience, resources, and connections as a working historian. Not only would students be able to use his own digital archives as the seedbed for their documentary, but Thomas was also in the professional position to contact the president of the local PBS affiliate and enlist his expert services as a genuine stakeholder in the project. Having already worked with Thomas on a documentary about Virginia history, the station president would be willing to evaluate the student work and consider televising it.
- **Ill-defined challenges:** While Thomas and Reifenberger, serving as coexecutive producers, guided and facilitated student decision making along the way, it was clear from the start that the students themselves would be responsible for shaping the one-hour documentary. It was decided by mutual consent that the film would consist of five 10-minute segments, each exploring a particular event or theme in the history of civil rights activism in Virginia. Produced by a team of three to four students, each segment had its own storyline, footage, graphics, and musical score. The task of ensuring continuity across these five minidocumentaries fell to the class as a whole, which agreed on a visual vocabulary, a common “look” or strategy for lighting, and accompanying graphics.
- **Sustained investigation, using multiple sources:** Without its direct connection to Thomas’s own historical scholarship, this initiative in authentic learning might never have gotten off the ground. For several years, Thomas has been amassing and digitizing an archive of television news footage from the period, including coverage of school desegregation, public meetings, citizen interviews, and local debates over civil rights

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matters. His project, Television News of the Civil Rights Era, is housed on the UVA campus in the Virginia Center for Digital History (<http://www.vcdh.virginia.edu/>), which he cofounded in 1998 with fellow historian Edward L. Ayers. Streamed over the Web, the digitized content is now available to scholars, teachers, and students worldwide. The class that produced *Rising Up* was able to mine this digitized footage, which provided the necessary starting point for their own historical research.

- **Multiple perspectives:** The students moved beyond Thomas's seedbed to shoot additional footage and track down other perspectives. The students responsible for telling the story of the 1960 sit-in at Thalhimers Department Store in downtown Richmond (modeled after the well-known Greensboro, North Carolina, protest), managed to track down and film interviews with two of the 34 activists arrested at the scene, including one of the Virginia Union University students who staged the sit-in. But it did not seem right to supplement this critical interview footage with still images when the story focused on the power of individual action. The team's editor decided to trawl through online resources searching for any footage that captured the look and feel of Richmond at the time. His dogged determination was rewarded when he stumbled on extraordinary footage showing a group of black students, his interview subject among them, as they took their seats at the counter of Thalhimers' "whites only" restaurant and were promptly arrested for trespassing.
- **Cross-disciplinary student teams:** The students formed what Reifenberger calls a "dream team" because of their varied talents and expertise. They came from different tracks—history majors who knew how to judge the reliability of sources, and media studies students who had done camera and postproduction work in the past. An English major served as production manager, coordinating the entire project. An anthropology major with filmmaking experience took on directing and editing duties. When a necessary skill set was not represented in the group, the classmates recruited friends and acquaintances, including a talented student composer who wrote the film's musical interludes and a fourth-year student and soloist from the Black Voices Gospel Choir who provided the voice-over narration.
- **Faculty mentors modeling professional practices:** Instructors played a facilitative role over the course of the semester. When students were faced with the prospect of shooting an interview with a sitting state senator, Thomas and Reifenberger calmed their nerves by coaching them through what it meant to be a professional, including how to anticipate the range of possible responses in an interview and react properly to the unexpected.
- **Integrated assessment:** Timetables and milestones were as important to this student production as they would have been in a professional setting. Each team was expected to complete its interviews, its graphics, its script, and the visual assembly of its material at designated junctures. As each milestone was achieved, the teams were asked to present their work, with individual students responsible for different aspects of the group presentation. If a student had not been pulling his or her weight, the slippage would be obvious to classmates and instructors alike.
- **Confronting the complexities and ambiguities of real-world professional practice:** Not only did these classmates find themselves collaborating with students they would never have known otherwise, but as white students interviewing African-American activists, they were given ample opportunity to reflect on the continuing impact of the civil rights movement on their own lives and the lives of their interview subjects. Historians and social scientists are particularly sensitive to the authority of lived experience and the

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ambiguity of their own position as observers, a lesson these undergraduates began to grapple with over the course of this authentic learning experience.

Working with Data

Case Study: University of Virginia

The History Engine: Students use primary and secondary sources to create records of 19th-century life in the South and contribute these episodes to the Southern History Database.

What is it?

The History Engine (<http://www.vcdh.virginia.edu/he/>) is an online tool that compiles student research into a single comprehensive and searchable database that offers a wide-ranging portrait of life in the 19th-century American South. The History Engine is a project of the Virginia Center for Digital History at the University of Virginia, a center founded by historian Edward L. Ayers, now president of the University of Richmond, and William G. Thomas III, now John and Catherine Angle Chair in the Humanities and professor of history at the University of Nebraska–Lincoln. In the fall of 2006, Ayers taught the first class that used the online tool as the centerpiece of an authentic learning experience for UVA undergraduate history students: *Rise and Fall of the Slave South*. Still taught at UVA, the course is designed to immerse students in a single, sustained investigation. The course asks learners to behave as professional historians would when faced with an intriguing challenge.

Using the History Engine as their primary research tool, students work in teams to investigate an assigned geographical region and a limited time frame. For instance, one student team might concentrate on Abermarle County, Virginia, in the 1860s. Each team member is expected to produce 10 “episodes”—brief narratives that describe and analyze a recorded event or experience from that time and place, whether public (such as a passing newspaper account of a yellow fever epidemic) or private (such as a father’s letter to his son about the family farm). The student’s task is to select episodes that resonate with larger meaning and to draw out the connections between these single threads and the broader patterns and processes at work in the South between 1820 and 1900. In effect, learners replicate the thought processes of the working historian. At the same time, they make their own contributions to the scholarly enterprise. Each time this course is taught, the History Engine database is richer by at least 2,000 student-generated entries.

What problem does it solve?

This semester-long authentic learning experience compels the novice researcher to think like a practicing historian. The structure of the course requires undergraduates to ask themselves how it is that a working scholar knows what to focus on. How does she identify a salient detail in the archives? What makes certain bits of information stand out from the rest, suggesting deeper levels of meaning? How can seemingly minor incidents accumulate to form significant patterns over time? When a student learns to hear the regional and national reverberations in a father’s letter to his son about the family farm or in a passing reference in a newspaper to a yellow fever epidemic, that student has taken the first step toward becoming a critical thinker.

How did they do it?

At the start of the course, students are asked to explore secondary sources—books written by professional historians. These preliminary readings alert students to the major themes of the period, as defined by the professional community of practice. The astute learner will also pick up on the way the scholarly culture frames its internal debates and adjudicates its

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interpretive conflicts. Although they draw on this background information when they connect the incident to its larger implications, students are expected to base their own episodes primarily on original readings of primary sources (newspapers, diaries, letters, plantation records) found online and in the university's Special Collections—sources which they are cautioned to cite properly in their entries. Finally, the students are expected to produce a synthesizing paper that places their episodes and those of their research teammates into the larger context of the team's assigned region, while offering them the chance to reflect on the process they followed and distill what they have learned over the semester.

While a wiki-like community spirit attaches itself to the project, the History Engine retains a relatively closed editorial structure. The site may be open to public view, but only registered users may contribute to the database. Instructors vet student entries for accuracy, and posted entries cannot be modified by students once they have completed the course. These editorial policies reflect the current struggles within the scholarly community sparked by the popularity of Wikipedia and centered on the question of reliable information. Underscoring the importance of reliable sources, course assignments insist that students spend more time exploring non-digital primary sources in rare-book rooms and special collections than consulting online authorities.

With funding from the Andrew W. Mellon Foundation, the Southern History Database (<http://www.vcdh.virginia.edu/SHD/>) is being developed into a more generalized teaching tool no longer exclusively wedded to the 19th-century American South. In future, a mapping tool will be integrated into the History Engine so that users searching by the keyword "cotton," for instance, will be able to see the geographical dispersion of cotton-related episodes across the South. Currently, Mellon's National Institute for Technology and Liberal Education, in association with the Virginia Center for Digital History, is funding a pilot teaching project and series of workshops, bringing together six Southern History instructors from participating colleges and universities, to test the History Engine as a teaching and learning tool and prepare to implement it at their institutions.

Remote Instruments and Simulation Tools

Case Study: MIT

iLabs: MIT builds a community of Internet-accessible laboratories for hands-on learning experiences.

What is it?

For engineering and science students worldwide who do not have direct access to the rare and expensive equipment required for 21st-century research in their fields, online laboratories at MIT (iLabs) offer a Web-enabled alternative. From their own computers at any time of the day or night, students can use these remote lab setups to conduct experiments, working remotely with instruments housed at MIT. More than 4,500 students from universities around the globe—from countries including Sweden, the United Kingdom, Greece, Italy, Egypt, Taiwan, China, Uganda, Tanzania, and Nigeria—have used the iLabs (<http://icampus.mit.edu/projects/iLabs.shtml>) to complete course assignments with curriculum materials that combine remote experiments and OpenCourseWare content.

The iLab Project began in 1998 when MIT Professor Jesús del Alamo (Department of Electrical Engineering and Computer Science) grew frustrated teaching microelectronics in large-enrollment classes where students had no opportunity to conduct experiments and make measurements. A conventional lab equipped with the proper instrument would only be

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able to support three student experiments each hour, with each student taking 20 minutes to set up each experiment. Since these experiments only took 10 seconds to run, del Alamo reasoned that hundreds of students—at MIT or elsewhere—could conduct experiments in that same hour's time if they could set up the experiments from a remote location at their leisure.

Enlisting the help of Steven Lerman, director of MIT's Center for Educational Computing Initiatives and a professor of civil and environmental engineering, del Alamo set about devising a way for equipment in his lab to be made available to students online. Remote labs were nothing new in engineering circles when Lerman and del Alamo conceived of the iLab Project. The unique aspect of their endeavor would be the emphasis on serving students beyond MIT. Unlike conventional labs that are privately owned and operated by each institution, the iLabs resources were meant to be shared with students from other universities.

The first-generation MIT iLabs, including del Alamo's microelectronics test station, were allowed to develop independently from one another. They took their own approaches to the routine management tasks involved in registering each student user, scheduling their sessions with the online lab, and storing or retrieving experiment results. Lab owners were responsible for managing the lab itself and authentication, security, data storage, and user accounts. In addition, students needed multiple accounts to access multiple labs. This placed an enormous administrative burden on the lab owners and faculty members who agreed to share their equipment. Lab owners were responsible for their own experiments, classes, and students, and obligated as well to administer the accounts and manage the experiment results of student users from other universities. Moreover, the matter of storing and archiving or otherwise disposing of results from student experiments was complicated by the fact that different courses, disciplines, and institutions had different policies on these and other issues.

Backed by funding from Microsoft Research, the two MIT professors along with Chief Architect Judson Harward designed a new, unified approach to provisioning remote lab resources. The resulting iLabs Shared Architecture is a common software suite for supporting experiments from all disciplines. It provides faculty with the creative leeway they needed to design and implement the discipline-specific aspects of their class assignments and releases the MIT lab owner of administrative responsibility for user account management and data storage. The architecture provides common services for the three primary types of online experiments: (1) batched experiments, of the kind that use MIT's Microelectronics iLab, where the student specifies the entire course of the experiment before the experiment begins; (2) interactive experiments, of the kind that use MIT's online Heat Exchanger, where the student controls one or more aspects of the experiment during its execution; and (3) sensor experiments, of the kind that use MIT's online photovoltaic station, where the student monitors or analyzes real-time data streams without influencing the phenomena being measured.³

The educational goals of the broader MIT iLab Project, however, were never limited to offering students at other institutions access to MIT resources and assets. By releasing its shared architecture and common services, MIT hopes to fuel a shareable lab movement, resulting in a federated community of remote labs for enhancing science and engineering instruction the world over. The MIT software toolkit is designed to help other institutions support and manage the activities of large numbers of students as they run complex experiments from remote locations in real time. The software makes it fast and easy for other colleges and universities to follow MIT's lead, developing and managing their own online labs efficiently and sharing their resources with others.

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What problem does it solve?

Hands-on laboratory experience has always been a critical part of engineering and science education, but it is becoming even more important for students to gain access to the kinds of state-of-the-art equipment commonly found in the real world. The costs and logistics involved, however, have often prevented engineering and science departments from offering students certain hands-on laboratory experiences. Even students attending universities with the funding, space, safety measures, and support structures in place to purchase and support expensive equipment of this kind may find themselves competing with their peers for access to the same rare resource.

From a pedagogical standpoint, the iLab is not a replacement for conventional laboratories but can be a valuable adjunct to classroom-based courses without a lab component. For example, online lab users studying how to engineer an earthquake-proof building can use the MIT shake table to observe the impact of ground vibration on model building structures. Not only do these online labs offer quick and easy access to data, but they also ensure that the devices themselves are safe to use (and won't blow up in a learner's face). While their hands might not be on the actual instrument, students do gain valuable insight from working remotely with real equipment—insights that the most carefully constructed simulation could not provide. Real equipment, after all, usually provides authentic surprises (or “non-idealities” in engineering parlance).⁴

From an institutional perspective, the online laboratory concept promises to alleviate some of the financial stress on colleges and universities struggling to provide large numbers of undergraduates with the access they need to safe, well-equipped conventional laboratories.

How did they do it?

Beginning with Microelectronics (launched in 1998), MIT built a succession of iLabs that harnessed networking technologies in the service of authentic learning. Now used by over 500 MIT undergraduates every year in three different courses, the Microelectronics iLab for measuring the current/voltage characteristics of transistors and other devices was so successful that it paved the way for other MIT remote laboratories in a broad range of engineering disciplines, including chemical (polymer crystallization), civil (seismic simulation), and electrical (semiconductor characterization).

The variety of uses to which a single remote laboratory may be put is apparent in the example of the Heat Exchanger iLab.⁵ At MIT alone, this iLab has been used for a number of different purposes: (1) a Transport Processes class uses it to demonstrate the principles of heat transfer through hands-on experimentation; (2) students enrolled in Process Dynamics and Control practice tuning equipment in real time and gain a general understanding of how a real piece of equipment may be translated into abstract diagrams and equations; and (3) chemical engineering undergraduates gain valuable experience in data collection, analysis, and presentation and in writing technical reports.

The mechanics of conducting experiments from remote locations is easy enough. In the Heat Exchanger iLab, for example, course instructors commonly preregister their students, who will log on to the Web site to view their team assignments and schedule a time for performing their team experiment. At the scheduled time, students click a Perform Experiment link on the navigation bar to display the appropriate experiment in a new window consisting of a Java chat interface, a Web camera feed, and a LabVIEW experiment interface.

Teamwork is essential for many of the iLab assignments. Team members at different remote sites may connect at the same time, using the chat interface to communicate with one

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another and coordinate their actions. This is vitally important since only one person can interact with the equipment at any given time. The Web camera feed from the MIT lab gives students the ability to see and hear the equipment being used in the experiment (albeit with a 7-second delay in the feed). Team members are instructed to select Request Control from the menu on the LabVIEW interface when they want to take charge. Students control the experimental parameters through the LabVIEW interface by simply turning the knob, clicking the button/switch, or typing the desired value into the value window for that parameter. To save data from their experiment, student teams use a Record Data button, which automatically samples data every second and saves it to a file that can be downloaded from the Web site after the experiment and viewed as a spreadsheet.

Thanks to the iLabs “service broker” software, it is commonplace for someone wandering MIT’s Building 1 at 4:00 a.m. to hear strange rumblings coming from the shake table lab, despite the fact that no one is in there. A student 5,000 miles away at Obafemi Awolowo University, in Nigeria, may be using the equipment to simulate an earthquake. Obafemi Awolowo is one of an increasing number of universities that have installed the MIT service broker on its own servers. The African institution can then validate its students and archive their results without putting undue burden on the MIT lab owner, who is far more willing to share expensive equipment when he is no longer burdened with authenticating and managing the user accounts of students at other universities.

Of course, this is not to say that all hurdles to participation have been overcome. Inadequate access to networked computers makes it particularly difficult for universities on the East Coast of Africa to take advantage of iLabs. Nevertheless, with a grant from the Carnegie Corporation of New York, Lerman and his team are moving forward both to accommodate the needs of developing countries and to serve those students with adequate access to networked computers who want to modify their experiments while they are being executed.

Case Study: Purdue University

nanoHUB Gateway: Students gain remote access to high-performance scientific tools for research, demonstration, and collaboration in the field of nanotechnology.

What is it?

The nanoHUB Web portal (<http://www.nanohub.org/>) is an online simulation laboratory and knowledge repository that allows students to engage in authentic experiments using the same tools and services as professionals in the field. Nanoscientists study the behavior of matter at the atomic, molecular, and macromolecular levels—a pursuit that is absolutely dependent upon access to specialized tools and services. In order to create useful and functional new materials, devices, and systems at the nanoscale (25,000 times smaller than the width of a human hair), researchers rely on computer simulations to predict their phantom behaviors along with special scanning and probing microscopes to move atoms around on a surface and fabricate new structures. The nanoHUB places these rare resources—simulation software and explanatory materials—at the disposal of undergraduates and veteran researchers alike, making them freely available and providing the cyberinfrastructure needed to run complex experiments with ease.

Launched in 2001 and supported by the National Science Foundation (NSF), the nanoHUB Web site is an effort on the part of multiple universities to serve the simulation, visualization, and high-performance computing needs of learners, educators, and researchers in this technology-intensive field. Drawing on the supercomputing and data-storage power of the national TeraGrid, this Web portal features more than 50 high-performance, interactive tools

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that let users input their own data and parameters to run complex experiments from their desktops. Much as the MIT iLabs Shared Architecture lowers the barrier of participation by providing students with access to instruments at remote locations, the nanoHUB Web site (and the sophisticated cyberinfrastructure that supports it) makes it possible for learners to use software tools and services that would otherwise be reserved exclusively for well-funded specialists in the field. Again, as with the MIT iLabs Project, the nanoHUB has been designed to deliver resources transparently, without the need for users to worry about downloading, installing, and supporting special software or accessing specific machines.

With the help of the nanoHUB Web portal, undergraduates can become active participants in a new virtual research organization, one that may well revolutionize entire industries, from computers and medical diagnostic devices to sensors for homeland security and environmental monitoring.

What problem does it solve?

Fundamental research in nanoscale science and engineering has the potential to revolutionize most industries, from manufacturing to health care. It promises to facilitate the development of more powerful computing devices, more efficient lighting and energy-storage devices, more effective catalysis processes, and new composite materials with greater strength and durability. Drawing on concepts essential to many different engineering disciplines (quantum mechanics, thermodynamics/statistical mechanics, physics, chemistry, biology, and materials science), the field of nanotechnology could be used to excite and motivate future scientists and engineers. It makes a student's core science and engineering education come alive in unique and engaging ways. On the other hand, nanoscience poses significant educational challenges. Straddling departments and crossing conventional disciplinary lines, nanoscience education requires a reconsideration of inherited pedagogies and curricula, perhaps even an evolutionary change of course content across disciplines.

An undergraduate education in nanotechnology must bridge theory and practice from the very start. Students need to have a broad and rigorous introduction to core science, technology, engineering, and mathematics (STEM) concepts combined with regular hands-on learning activities that help them make active technical contributions in design and manufacturing based on that core knowledge. Individual faculty may not have the interdisciplinary breadth required to handle introductory courses, which instead demand a team-teaching approach. Lab components are absolutely critical because novice nanotechnologists learn to form infinitesimally small structures and connect them with the macroscopic world. Team-based instruction, lab components, exposure to specialized instruments, and active participation all require facilities and resources that will stretch most academic institutions—this at a time when global competition in this field is growing exponentially.

The nanoHUB Web site represents a new paradigm in science education: using grid computing resources and easy-to-use Web interfaces to catalyze the development of a global, virtual community of practice, one in which students are invited to work side-by-side with potential mentors and employers. Offering free access to professional simulation software, the nanoHUB makes it economically feasible for institutions to offer large numbers of undergraduates an active lab component that can supplement classroom lectures. As the community grows and the site's communication and collaboration services expand to emphasize the needs of students and educators, the true potential of online community-building may be realized: the ad hoc formation of genuine research teams made up of experts and student apprentices from multiple institutions and disciplines.

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How did they do it?

The nanoHUB Web portal is the outreach initiative of the Network for Computational Nanotechnology (NCN), a multiuniversity initiative supported by NSF. The NCN was established to create a cyberinfrastructure for what some have called “service-oriented science.”⁶ Through this partnership with NSF’s middleware initiative, the hub makes it simple for users, wherever they are in the world, to log on, access tools formerly accessible only to the specialist, run simulations from their desktops, and view the results online. In essence, users are plugging into a vast virtual network of machines already configured to their needs—and they never have to worry about how it all works. By harnessing the massive computing power of the NSF-sponsored TeraGrid, the nanoHUB project is able to meet the multisensory needs of students facing the challenges of a data-intensive future.

Today, the portal features more than 50 high-performance tools that allow users to observe and interact with simulated nanoscale structures. Students can change the placement of atoms in a carbon nanotube, for example, simply by inputting their own data and parameters. They even have access to state-of-the-art simulation software once reserved for NASA scientists. The NEMO 3-D Nanoelectronic Modeling Tool, first developed at NASA’s Jet Propulsion Lab, has been optimized by Purdue University to meet the needs of students and veteran investigators alike. While theoretical scientists use NEMO 3-D to conduct large-scale experiments that test the limits of the available compute power and take 12 hours to run, students can use the same resource to perform their own scaled-down experiments—computing and visualizing a simple pyramid or cylinder model in a matter of seconds. Along with its simulation tools, the nanoHUB site provides online seminars, tutorials, college-level courses, self-paced Web-based instructional modules, and collaboration services.⁷

While students often enter the nanoHUB at the direction of their instructors to access course assignments, site traffic data shows that they linger to search for supplemental lectures, animations, and simulations that help them visualize difficult concepts. In 2006 alone, a total of 4,285 users executed more than 142,000 simulation jobs. Since its launch in 2001, the site has registered more than 44,000 visitors, 90 percent of them faculty, students, or academic staff. Increasing emphasis is being placed on the educational components of the site and on the design of learning modules, guided exercises, podcasts, and lecture series that are geared to student learning preferences while integrating well with classroom activities. With the NSF-supported cyberinfrastructure in place, the nanoHUB project leaders are reaching out to experts in the cognitive and learning sciences while seeking new avenues of funding for the development of innovative educational strategies.

Investigative Case-Based Learning

Case Study: Beloit College

BioQUEST: Undergraduate biology students have access to investigative case-based learning modules.

Biology education is being transformed by two powerful movements: the *investigative case-based learning* (ICBL) approach, first used in the 1970s to revolutionize medical school training, then adapted to undergraduate needs; and *bioinformatics*, which offers educators a relatively straightforward way to engage students in active investigations, using real-world data and analytic tools available in the public domain. Tellingly, the “quest” in BioQUEST is an acronym for “quality undergraduate education simulations and tools” in biology, which the organization has been dedicated to developing and sharing since 1986 when founder and

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Beloit College biology professor John R. Jungck first recognized the role that computers could play in fostering educational reform.

What problem does it solve?

The underlying philosophy of ICBL recognizes a growing problem in education: no curriculum can adequately encompass an entire discipline, given the rapid rate at which the knowledge base of most professions is growing. Introductory biology instructors, in particular, decry the “packed curriculum,” with so much to cover in a single semester that little time is left for students to develop a feel for the deeply collaborative and investigative nature of real-world scientific practice. In typical cell-biology courses, for example, lab components make up only 3.6 percent of the total hours in a student’s week.⁸ Rather than taking on the impossible task of covering all the content and conveying the mistaken impression that science is a litany of correct answers, educators can turn to active learning. Students need to know not just what the Krebs cycle is but how to use that information when it really counts and they are facing authentic problems. Students need to know what questions to ask and how to find the information they need when they need it.⁹

Frequently confused with the mere introduction of problem-solving activities into traditional lecture-based curricula, problem-based learning (PBL) only rises to the level of authentic engagement when it changes the entire way in which a course is conceived so that instruction revolves around complicated, true-to-life dilemmas. Since the 1970s, transformative uses of PBL have found their place in medical school curricula across the country. Now they are being adapted for use in both secondary and undergraduate science education, such as at the University of Delaware, where a Web site is devoted to PBL. The ICBL approach is a variant on the PBL theme, engaging students through realistic stories—or “cases”—that serve as “memorable anchoring experiences” in the course.¹⁰ Teaching strategies encourage students to work in teams, identify what they already know about the case, become aware of their idiosyncratic misconceptions through dialogue with their peers, and use their self-reflective skills to assess their own understanding.

How did they do it?

Among BioQUEST’s featured projects are LifeLines Online (a program in support of investigative biology instruction) and BEDROCK (or Bioinformatics Education Dissemination: Reaching Out, Connecting, and Knitting-together, a program for disseminating bioinformatics teaching materials and tools), both of which developed their core collection of resources with the support of grants from NSF and now offer Web-based educational materials through the BioQUEST Web portal (<http://www.bioquest.org/>). The LifeLines Online and BEDROCK projects leverage the resources of the BioQUEST Curriculum Consortium, which originated in 1986 in order to demonstrate the role that software could play in reforming the biology curriculum by introducing active learning—problem posing, problem solving, and persuasion—into the undergraduate educational experience.

The BioQUEST curriculum development has focused on bioinformatics, entry-level geoscience, and exploratory, experiential mathematics, encouraging educators to construct authentic learning environments using online simulations, databases, and software tools. LifeLines Online (<http://www.bioquest.org/lifelines/>) is the brainchild of principal investigators Margaret Waterman of Southeast Missouri State University and Ethel Stanley of BioQUEST, who began developing their active learning modules to help community college biology teachers reach and engage adult learners by leveraging their past experiences and their interpersonal skills. The investigative case studies in the LifeLines Online library draw on students’ prior knowledge and current interests in real-world dilemmas. Intriguing problems,

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questions, and case studies are used as “hooks” to engage 21st-century learners’ need to appreciate why something is worth knowing before they plow into it.¹¹

Waterman and Stanley held their first workshop for community college faculty in 2000. Since then, they have introduced ICBL to faculty at four-year liberal arts colleges and larger research institutions, gathering evidence that ICBL activities work well for learners in a variety of disciplines and institutional settings. As a result of their efforts, 135 faculty members from over 40 colleges and universities, to date, have produced 65 curriculum modules, all freely available through the LifeLines Online library. Each module consists of one “case” (essentially, a story scenario), along with related investigative activities, resources, assessments, and implementation plans.

A typical LifeLines Online authentic learning experience might begin when an instructor asks students to access a case study in the Web site’s online library, which will launch an extended authentic learning experience designed around ICBL strategies. Take, for example, *The Donor’s Dilemma*, one of hundreds of case-study learning modules contributed by faculty members and vetted by the project’s principal investigators. This case concerns an employee who finally decides to donate to one of his company’s frequent blood drives. Having heard that cases of West Nile virus (WNV) are popping up in Boulder, Colorado, where he had recently returned from a hiking expedition, the employee begins a long conversation with an interviewer about how his donated blood will be tested for the virus. The conversation is designed to generate student questions about the way epidemiologists track WNV as it moves from location to location. After reading the story, what do they know and what needs to be known? Working in groups, students identify major themes and specific paths of inquiry. They define appropriate and productive problems for scientific investigation (one of the greatest challenges in biology) before designing and conducting their own experiments. Students use a variety of resources, including traditional laboratory and field techniques, software simulations and models, datasets, Internet-based tools, and information-retrieval methods. Students might decide to use modeling software to investigate how variations in host and vector populations might effect the transmission of WNV, for instance. Finally, each group is expected to produce materials in support of their conclusions so that they can experience a key aspect of scientific discourse: peer persuasion.

In 2002, just two years after Waterman and Stanley held their first LifeLines workshop for community college faculty, BioQUEST launched a new program that adapted ICBL instructional approaches to bioinformatics education at four-year colleges and universities as well as community colleges. BEDROCK (<http://bioquest.org/bedrock/>) organizes its curricular materials around “problem spaces,” Web-based modules that provide instructors with everything they need to stage an authentic, active learning experience for their biology students. The introductory materials, background, sequence data, curricular resources, links to analytic tools such links to the Biology Workbench and NCBI, the National Center for Biotechnology Information, along with handouts, assignments, research resources, and examples of student work, are available. Six problem spaces are currently on the site (http://bioquest.org/bedrock/problem_spaces/): Chimpanzee Conservation, HIV, Prion (proteins known to cause certain neurological diseases), TRP Cage (one of the smallest model proteins synthesized to date), West Nile virus, and Whippo (devoted to whale evolution).

The BEDROCK developers embrace an open educational model, encouraging instructors to use and modify the resources to suit their needs. The characterization of the problem spaces is meant to evolve over time and in response to the needs of users. However, more immediate modification of the core collection by members of the broader educational

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community (of the kind associated with Wikipedia, for example) is not yet permitted. Taking an alternative approach to populating its online curriculum repositories with quality educational materials, the BioQUEST strategy is to stage frequent face-to-face workshops at host institutions around the country. Often held at Beloit College in Wisconsin, these 10-day summer workshops invite faculty from around the country to construct new curricular materials that are data-rich, problem-based, collaborative, and mathematically and computationally intensive, focusing each year on a different aspect of the biology curriculum. In 2006, for example, the workshop was built around exploring complex data sets, while the focus of 2007 is on exploring evolution education. The objective is to foster a community of experienced educators interested in contributing to and using learning modules that incorporate inquiry-based approaches. As with any number of open educational resource initiatives, the question remains whether projects fuelled initially by grant dollars can sustain themselves through the voluntary contributions of faculty content experts and learning researchers.

Conclusion

For every example of authentic learning showcased in this discussion, hundreds more exist.¹² Technologies of the future promise to expand the range of authentic learning experiences exponentially. Participatory and active-learning exercises will always incorporate an important element of projection as students emulate professional models and consider what it means to *be* an engineer, biologist, or historian. Role-playing simulations that situate learning inside a complex and highly social real-world context have long been a part of courses in the social and political sciences. But only in the past few years have educational researchers begun to propose project after project aimed at moving these class-bound exercises into the immersive, online realm, where students can try on varying perspectives and work in tandem with peers, mentors, and potential employers who may live continents away.

As the undergraduate educational experience grows ever more participatory, matching more closely the nature of our technology-mediated lives, we will need inventive new ways of recognizing individual student achievement and assessing its quality. The next and final paper in this three-part series on authentic learning will look at the brave new world of authentic assessment and what it might mean for the future of higher education.

Endnotes

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