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KNOWLEDGE-BASED LEARNING ENVIRONMENTS

A Vision for the Twenty-First Century

PATRICK J. FITZGERALD *and* JAMES C. LESTER

Upon entering a school of the late twenty-first century, an American teacher, having been transported one hundred years into the future, is shocked at what she *doesn't* see. She searches for signs of blackboards, books, maps, and libraries but finds none. Aside from the cafeteria and gymnasium, our teacher recognizes the function of none of the rooms. Meandering down a colorfully decorated and brightly lit corridor, she peers into a room where the chatter of excited middle school children competes with the percussive sounds of African music. The children sitting on the floor surround a three-dimensional projection of tribal dancers in full regalia. The teacher converses with the children about the role of dance in the history of African culture.

In the next room our visitor observes a quieter setting in which children are seated in comfortable partitioned carrels. Every child is absorbed in thought as he or she manipulates small luminous devices floating freely before them. Flanking each student are two-dimensional display panels filled with ever-changing text and graphics. Periodically the students pose questions and point at the floating object and panels. It seems they are engaged in very different activities from one another. Surprisingly, no teacher is to be found.

The visitor ambles down the hall and enters a larger room, where groups of students congregate around strange-looking consoles. The students speak to each other and to teachers and other students who appear on the consoles. It is evident from their negotiations that they are holding some sort of diplomatic talks. As the teacher moves from station to station giving advice, she is surprised to see the students receiving suggestions from a spectacled, wizened, 3-D animated character with whom they are engaged in conversation. He is lifelike except for his diminutive size, which belies his electronic origins. Enthralled, the children laugh and ask questions of their charismatic companion.

This remarkable vision of the twenty-first century could easily become a reality. Given the current rate at which technology is improving, the next one hundred years will most certainly witness the disappearance of the vast majority of technological limitations that currently prevent us from realizing this vision. What now seems technologically impossible will be ubiquitous by the year 2100, and all innovations of this twenty-first century school will have one common feature: the computer. The powerful computational technologies that have begun to appear at the end of the twentieth century, combined with exponential improvements in telecommunications, will come to fruition in a new breed of educational technology known as *immersive knowledge-based learning environments.* Below, we articulate a technology-rich vision for the twenty-first century in which immersive knowledge-based learning environments integrate advances in artificial intelligence, massive digital libraries, and riveting three-dimensional simulations.

UNITED NATIONS DIPLOMACY: A CASE STUDY

To understand the power of immersive knowledge-based learning environments, let us rejoin our visiting twentieth-century teacher. Intent on taking a closer look at the unfolding activities, she wanders into a seventh-grade classroom in the twenty-first century school. Upon entering the classroom, the visiting teacher beholds a a panoramic view of the stately U.N. conference center. Installed in every wall of the classroom is an expansive rear-screen projection panel. Together, the panels supply a 360-degree view of the interior of the United Nations conference center. Colorful flags representing nations from around the world surround the students. Rising prominently in front of the class is an enormous data display panel depicting a detailed record of all votes cast on various resolutions. Periodically, the display panel presents elaborate maps and other graphical information, video, and electronic news flashes. A flurry of quiet activity pervades the room.

Suddenly, a news bulletin flashing across the central display panel catches the attention of everyone in room:

> (A.P. New York) General Electric's CEO announced this morning that the corporation's recent invention of a nearly perfect photoelectric panel has successfully passed the scrutiny of the independent scientific community. These highly efficient panels convert light to electrical current with a newly discovered crystalline form of a chromium-based compound. Although officials will not reveal details of the manufacturing process, they explained that the ultra-thin panels can be produced for pennies. This finding confirms recent rumors that the holy grail of abundant, cheap, and clean energy has been found.
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> Although mass production of the panels cannot begin for six months, the stock market has reacted violently, dropping 400 points before automatic trade

mechanisms closed down trading. In a catastrophic chain reaction, both the Tokyo and London exchanges dropped a record number of points before they too were shut down. Analysts attribute these reactions to a fundamental economic realignment resulting in the toppling of oil-dominated multinationals. This points to an end to the petroleum-based economic infrastructure that has evolved over the course of the past century.

These developments have been greeted with signs of increasing political unrest throughout the world. In reaction to what is perceived as more imperialistic behavior on the part of America, riots are spreading rapidly throughout the Middle East as leaders of the oil-producing countries express grave concerns about world stability. As developments continue, political leaders and investors wait and watch.

On the platform at the front of the room, a distinguished-looking Secretary General dressed in his native garb instantly materializes before the students. A product of 3-D technology, this virtual artifact has an almost lifelike appearance. The Secretary General explains to the students that they are U.N. diplomats representing countries around the globe. A major event has occurred that will have significant ramifications for the political and economic stability of their simulated world.

Each student's desk is equipped with an embedded screen and a small 3-D projection system. Some students are already interacting with diminutive 3-D characters projected from their desks. These impish characters are their mentors, who have already begun to offer advice about what course of action should be taken, as well as rationales justifying these recommendations. In addition to 3-D projection capabilities, the desks also provide sophisticated tools for retrieving historical, geographical and economic data from digital libraries around the world.

Turning their attention from the screen, to the teacher, to the Secretary General, and back again to their screen, students glean information from all these sources as they begin to address the situation unfolding before them. The Secretary General explains that each student, as a representative of a particular country, must take actions that will not only be in the best interests of his or her country but will also preserve world peace. To do so requires that the students become experts in their country's geography, history, economy, and political systems. In addition, they must form strategic alliances that can enhance their political influence as well as remain cognizant of alliances that may form between other countries. The Secretary General explains that students will be presented with U.N. resolutions. They will then consult a variety of information sources: their teacher, digital libraries, dynamic economic models, other students, as well as their mentors.

Following standard U.N. protocol, the Secretary General announces that a resolution to address the violence in the Middle East has been submitted for

discussion. The Secretary General describes the first resolution, which concerns the trouble in the Middle East reported in the A.P. news flash. Proponents of the resolution believe that U.N. troops should be committed to the region. This peace-keeping mission would prevent further violence and pave the way toward a peaceful settlement. Opponents dispute this claim and argue that the problem is in fact much more global in nature; they argue that committing troops would produce devastating results and divert the world's attention from the central issue. They argue instead that the U.N. should address the situation by incrementally reallocating resources on a global scale.

The Secretary General then announces that after an hour for research and discussion, each student must determine the stance that will be taken for his or her country and then cast the vote accordingly. Votes will be tallied by an accounting system, and a simulation engine (a powerful software tool that models the interactions between complex scientific, political, and socioeconomic systems) will compute the votes' effects on the global economy and political environment. The Secretary General explains that the A.P. feed on the central panel will communicate the resulting state of world affairs by continuously updating the latest edition of the interactive multimedia news channel. As the Secretary General slowly disappears, the teacher informs the students that their success will be gauged by observing the effects of their actions on reports of international political stability and economic growth.

As negotiations commence, the Secretary General reminds students of the actions they may take as representatives of their countries. In addition to voting on specific U.N. resolutions—including voting to commit U.N. troops to troubled regions and expelling countries from the U.N.—students may independently:

- modify economic policies of their own countries, e.g., by altering exchange rates;
- form alliances, either informally or by signing treaties;
- impose trade sanctions against specific countries or blocs of countries; and
- infuse foreign aid into allied countries.

With amazement, our twentieth-century teacher wanders through the room to observe all of the activities. After a few moments, it becomes apparent that students have been preparing for their mission for some time. It is evident from the conversations between students and their mentors that the students have become intimately acquainted with their countries' histories, economies, national resources, political structures, and religious traditions. Even now, students are

pressing their mentors for specific information pertinent to the new resolution under consideration.

The visiting teacher meanders among the students as they embark on their fact-finding missions. She approaches an energetic young man who represents the United States in this exercise. To determine the effects of the newly created photoelectric panels on the U.S. economy, the student calls up his mentor. Instantly, a disheveled, professorial 3-D character with striking white hair appears on the desktop. Because the student immediately begins asking the mentor very detailed questions that require knowledge about the invention and its possible effects, it is clear that the mentor is already knowledgeable about the situation at hand.

Concerned about maintaining a technological advantage over other countries, the student argues that the government should support this new technology because it is controlled by a U.S.-based corporation and the revenue earned will exceed the income lost from lost oil production. To bolster his argument, the student asks the mentor to display graphically the revenues generated by the oil industry over the past five years. Immediately, the mentor presents the requested information in a concise graph depicting the requested economic data. He then explains to the student that he might also consider examining data available on the percentage of the petroleum industry's revenue that was not generated by transportation use. The student agrees this would be helpful, so the mentor presents this information as well.

After analyzing the data, the student and mentor discuss the possible implications of the new photoelectric cell on the U.S. petroleum industry and, consequently, the U.S. economy as a whole. The student is convinced that the invention will benefit the economy considerably and that the United States should not regulate it, but the mentor suggests that the student should continue to consider alternative interpretations.

For example, the mentor points out that the United States is a dominant figure in the world political scene. He explains that careful regulation and control of the technology are of paramount importance for avoiding a massive trade imbalance and the ensuing worldwide instability. He then goes on to discuss the importance of corporate alliances for the design and production of petroleum-powered machinery. To provide evidence for a particular line of reasoning, the mentor invokes a dynamic economic model to simulate the effects of various assumptions on the U.S. GNP. A 3-D visualization tool displays graphically the results of these simulations, which the mentor presents to the student. The student and the mentor continue to investigate different scenarios as the visiting teacher ambles over to another desk.

At this desk, an intense student representing Norway is considering the debilitating effects of projected revenue losses when North Sea oil production declines. Her mentor is a Ghandi-esque figure with flowing robes and intriguing smile. The student is engaged in a heated discussion with her mentor about the

role of natural resources in Norway's future. The mentor suggests that the student will be in a better position to make predictions if she first explores the country's economic history.

She requests her mentor to invoke an interactive multimedia document that presents general trends and specific details pertaining to Norway's dependence on North Sea oil income. The information is presented as an interactive time line that has been highly customized to the student's current needs: information about the distant Nordic past is abbreviated; information about Norway's eighteenth-century economy is more verbose; and information beginning with the discovery of North Sea oil is rich with detail. The interactive time line permits students to view textual, graphic and animated presentations about particular periods and even about particular events of interest. For example, the student quickly develops an appreciation for the economic differences incurred as Norway transitioned from a seafaring nation with income drawn primarily from shipping and fishing to an energy-based economy with significant oil production. Images of Viking ships, colossal industrial freighters and the country's first offshore oil rig flicker across the screen.

It is clear that the mentor has produced an exceptionally well-crafted presentation of information for the student. Of the literally millions of facts available in digital libraries throughout the world, the mentor has assembled a document that includes precisely those facts that are germane to the situation at hand. Moreover, of the selected facts, the mentor has emphasized those items that are of the greatest relevance to the student. Nevertheless, the student is free to pursue additional sources of information and browse at will (within the given time constraints). As the our visiting teacher leaves this student, the student begins to chat with the mentor about developing a strategy for predicting the consequences of the sudden appearance of the photoelectric chip for Norway's petroleum industry.

The visiting teacher's attention is then caught by a neighboring student representing Kuwait. This student, a serious young man, is equally troubled by the prospects offered by the new photoelectric technology. His mentor, a stately woman in an elegant burgundy dress, advises him to consider soliciting support from other oil-producing nations. The mentor explains that Kuwait is facing a strange sort of double jeopardy: not only will it be crippled by the appearance of the alternative energy source, but it has recently depleted all but a small amount of its oil reserves. Barring the discovery of any new oil fields, the country is in dire straits.

Given these factors, the mentor recognizes an opportunity for the student to exercise his algebraic skills. She poses this highly-contextualized math problem to the student in a way that the student can understand without difficulty. To estimate the total volume of remaining oil, the student realizes that he must determine the amount of oil in well-charted fields and extrapolate from this data. The mentor suggests that he request a detailed cartographic representation of

oil holdings in fields for which data is available. For each of these fields, the color-coded 3-D map depicts not only the topographical surface but also the volume of remaining oil. It also indicates the rate of change over the previous six months. The student then sets up a system of equations and, with the mentor's assistance, solves for the variables of interest.

Next, the mentor suggests that the student might wish to investigate other resources in Kuwait. During the course of this investigation, the student discovers that the Kuwaiti Treasury holdings are significant. He factors this information into a second system of equations to determine if Kuwait has the financial wherewithal to purchase the new photoelectric technology outright, thereby eliminating the political unrest that is certain to follow otherwise.

Finally, the visiting teacher spots an energetic young woman who is discussing the effects of the invention for her country, China, with her mentor, a miniature Asian sage with a flowing white beard. The mentor recommends that the student consult interactive multimedia documents illustrating the defining moments in Chinese history. Specifically, he directs the student's attention to presentations that discuss China's historical tendencies to adopt policies rejecting Western technology. The student eagerly agrees and instantaneously finds his screen filled with an intricately detailed animation: In Hong Kong, Chinese royalty hold court with Portuguese missionaries, who present the Emperor with automata and mechanical clocks as gifts.

The student realizes she can take advantage of her mentor's ability to present the same situation from multiple perspectives. She first chooses the perspective of the Chinese royalty. The mentor constructs a multimedia presentation with text, graphics, and animation depicting the Portuguese missionaries as barbarians. These uncultured foreigners offer nothing more than mechanical trinkets to the Emperor of the Celestial Kingdom. The Chinese are distrustful of the foreigners and insulted by the visitors presumption in presenting such worthless gifts. In the second perspective the student chooses, that of the Portuguese missionaries, these historical events take on a much different interpretation. In the missionaries' eyes, the Chinese heads of state are ignorant and pompous. These heathens have no right to bar the missionaries from spreading the true religion, and they have no appreciation for the modern industrial world that the Portuguese represent. The student discusses both of the perspectives with her mentor and concludes that it might be wise to act quickly with regard to the new photoelectric technology.

To verify this conclusion, the mentor offers the student the opportunity to view an "alternate history": What would have happened if the Chinese had recognized the significance of the trinkets' underlying mechanisms for their future? What if the Chinese in their organized and efficient manner had duplicated this technology and incorporated it into their society? How would this have resulted in a different culture for the Chinese? Would the dream of the Celestial Kingdom have been realized? With the assistance of her mentor, the

student manipulates numerous variables in a complex social simulation and explores the consequences of the Emperor's decisions. Eventually, the mentor suggests that the student may wish to pursue a comprehensive trade agreement in which China would serve as the world manufacturing center for photoelectric chips.

The learning session culminates when a news bulletin interrupts all activities across the network. The virtual Secretary General requests that all votes be cast. All students register their votes which the system tallies on the central display. The results on the classroom's wall indicate that the Assembly has opted for a plan that incrementally reallocates resources in hopes of achieving global political and economic stability. The vote is fed immediately to the simulation engine. As the visiting teacher makes her way to the door a barrage of news bulletins fly across the central display. . . .

ELECTRONIC MENTORS

Mentors will provide highly individualized advice and instruction to students. Built on the most advanced artificial intelligence technologies, these intelligent animated personae will play a central pedagogical role in the twenty-first-century classroom. Mentors will pose problems, understand speech, answer questions, produce multimedia explanations and even offer advice. Most importantly, mentors will track students from the time they enter school in order to tailor all responses and presentations to the student's learning style and experiences. Since the Greeks, the privileged have educated their children by hiring learned scholars who provide individualized instruction. Twenty-first-century society will provide the most advanced form of one-to-one tutoring in a nurturing, long-term relationship between student and teacher that would otherwise be unavailable except for the most affluent members of society.

Mentors will continually assist students as they access information from digital libraries around the globe. These libraries will be linked by massive networks that provide rapid access to every conceivable type of information, all of which will be deliverable in any medium. The ability to filter and assimilate an ever-increasing barrage of bits will be of paramount importance in the *hyper-information age.* Without the assistance of mentors, everyone (particularly students) would be so inundated with the incalculably large volume of information that they could not cope. Consider a mentor assisting a student as she analyzes eighteenth-century economic upheaval. The mentor will provide an information filter that selects pertinent economic data. It will also dynamically assemble a historical narrative about the role played by the industrial revolution in this period. The mentor will produce a narrative that is highly customized to the student's knowledge of economics. With this type of personalized information, students will be well positioned to evaluate a broad range of complex economic hypotheses.

Building on research in computational simulations of emotion, each mentor will have its own unique appearance and personality. Combining such traits as seriousness, humor, curiosity, gender and eccentricity, each mentor will simulate human-like qualities that become apparent to the student through ongoing interaction. Students will choose mentors from immense electronic catalogues. Each student will be able to modify the appearance and personality of his or her mentor by selecting different character "shells." An elementary school student might be enamored with a variety of superhero mentors while a high school student might prefer mentors with an attitude. Despite its changing outward appearance, a particular mentor's knowledge of its student's abilities will persist throughout the lifelong relationship. Importantly, mentors exemplify the coalescence of the software, hardware, education, and entertainment industries that is only now beginning.

DIGITAL LIBRARIES

Every student will have immediate access to the best libraries in the world. Fiber optic cables, one of the few inventions of the twentieth century to survive unchanged into the twenty-first century, will connect every information source on every continent. Optical cables will boast virtually unlimited bandwidth, i.e., the volume of information transmitted within a given period of time will be enormous. As a result, every publicly and commercially available information archive will be instantaneously accessible to students in every classroom. In addition to cable connections, the virtual, distributed library will be available to those not on the physical network through omni-directional, satellite-based, wireless transmission. The combined cable-wireless network will constitute a shared, international resource that will be essential to students in their formative years and, equally important, as they pursue both professional and recreational activities throughout their lives.

Continuously updated and expanded, the library will serve as the international repository of human knowledge. To access information from the library, students will not be required to browse endlessly, conducting futile searches in the enormous information space. Rather, students will delegate this task to the mentor by asking questions. Students will pose questions to their mentors by pointing and speaking. Because mentors will be sensitive to body movements and subtle gestures, students will interact with them naturally. Mentors will use their knowledge of students' information needs to retrieve the appropriate information from a collection of library sources, integrate it into a well-organized hyper-media structure, and, finally, present it to the student.

Mentors will create expansive hyper-media documents that facilitate rapid investigation of tangents as the situation demands. This technology will stand in stark contrast to the twentieth-century paper-based mode of knowledge communication that was primarily linear; in the twenty-first century, students

will be at home with non-linear knowledge presentation. The long-touted "paperless society" will finally become a reality because of universal access and mentors' ability to tailor information to any given user and problem-solving context.

Suppose that a student asks a mentor how the industrial revolution began. The mentor will scour the network searching for relevant material, thereby saving the student hours upon hours of search time. From one repository, the mentor may unearth an intricate map of London in 1750. In another digital warehouse, the mentor may discover a beautiful piece of prose chronicling the birth of the factory system. In a third library, the mentor may encounter a collection of animations of inventions, including an intricate animation of Darby's coke smelting process. Taking into account the student's interest in economics, the mentor will integrate the selected information packets into a compelling hyper-media document unified by the theme of economic impact.

As the student poses questions and solves problems, the mentor will anticipate the student's needs and continuously work behind the scenes to gather additional knowledge for future presentations. At opportune moments, the mentor will proactively offer the student the opportunity to view these customized documents. For example, by the time the student expresses her interest in the textile industry, the mentor will have already retrieved, customized, and prepared for presentation a rich hyper-media document describing the invention of Hargreaves' spinning jenny.

To enable mentors to rapidly retrieve information about a given topic, massive index structures will define the organization of information packets in the library. The index structure will enable mentors to score exceptionally highly on standard measures of information retrieval quality: mentors will exhibit high *recall* (percent of appropriate available objects that are retrieved) and high *precision* (percent of retrieved objects that are appropriate).

The indices will also permit mentors to access information along multiple dimensions. For example, mentors will be able to retrieve information about the development of the steam engine along several dimensions: temporally (the steam engine's development reached its apex in the mid-1770s), geographically (the steam engine was developed in England), economically (the steam engine had an enormous impact on employment), politically (the steam engine resulted in the formation of unions) and scientifically (the steam engine constituted a radically new approach to energy transformation).

Perspective-based indexing will play a central role in the library's overall functionality. For example, depending on the perspective that is being emphasized, the mentor will extract a vastly different body of information about the steam engine. If the mentor is emphasizing the labor perspective, it will extract information about factory working conditions: if the mentor is emphasizing the industrialist perspective, it will extract information about production efficiency.

In short, indices (particularly perspective-based indices) will enable the mentors to extract precisely the information packets that bear on a particular problem-solving session.

IMMERSIVE ENVIRONMENTS

All student-mentor interactions will take place in an immersive 3-D projection. In these synthetic worlds, students will visualize information through numerous channels, including 3-D space, color, and time. (See chapter 3 for a discussion of the critical role of visual technologies in social studies education.) Students studying the Industrial Revolution will navigate through a three-dimensional facsimile of London in the mid-eighteenth century. In addition to viewing scenes of factory workers' squalid living conditions in vivid "fly-throughs," students will experience a bird's eye view of the city with a color-coded schematic representing concentrations of pestilence and death. These lucid displays of information will demonstrate the devastating effects of unsanitary sewage systems on urban dwellers.

Powerful *simulation engines* will lend a verisimilitude to educational experiences that is unavailable in twentieth-century computing environments. In contrast to first-generation simulation packages that offer simple, abstracted, and pre-defined models of the world, twenty-first-century simulation engines will enable students to model the interactions between complex scientific, political, and socioeconomic systems. Both the number of available parameters and the amount of world knowledge encoded in mathematical and symbolic models will exceed the complexity of first-generation simulations by several orders of magnitude. This will enable students to test significantly more sophisticated hypotheses—and do so very quickly because of the computational power available on their machines—and give them near-instantaneous feedback for a variety of initial conditions and assumptions.

For example, students will be able to model England's national textile productivity as a function of the size of the workforce from 1700 to 1850. They will be able to observe the effects of the introduction of the flying shuttle in 1733, the spinning jenny in 1764, and the power loom in 1785. Students will be able to "zoom in" spatially to see the structural details of a simulation. They can zoom from a factory-level view of a production simulation to a machine-level view of the same simulation, to an intra-machine view of the mechanisms of a particular machine in the factory. Students will also be able to zoom in temporally to see the time-based details of a given simulation. They can view a textile production simulation over a span of two centuries, or they can view the same simulation over one-week period to observe more fleeting "temporally local" effects such as variances in cotton supplied to the factory.

SOCIAL, ECONOMIC, AND ETHICAL CHALLENGES

Like all revolutionary technologies throughout history, immersive knowledge-based learning environments will offer great promise but will be accompanied by serious social economic and ethical dilemmas. Students, parents, school systems, communities and all levels of government will experience the repercussions, both positive and negative. To a great extent, the political structures and economic conditions that hold when a technology is integrated into the education system largely determine its overall contribution to society. If information is power, then the political nature of the entities that control technology will have a profound effect on its uses and, more importantly, on its misuses. Consequently, it is crucial that educators and technologists come to grips with the social, economic, and ethical implications of these technologies. Growing pains will be inevitable.

Given the irrevocable march of technology, the emergence of mentors and immersive knowledge-based learning environment technologies seems certain. The time frame in which they appear and the degree to which they are integrated into the classroom are matters for conjecture, but their technical feasibility in the coming century is almost certain. Nevertheless, whether the appearance of any given technology constitutes "progress" depends entirely on the social milieu in which it emerges.

With the bi-directional causality inherent in human affairs, educational technology will control the social and economic forces shaping society; these same social and economic forces will dominate decisions about how the technologies are applied. It is difficult to predict the path that a society will follow, but it is clear that educational technology, often deemed the great equalizer, can just as easily become the great separator. Two radically different futures warrant exploration: a utopia in which communities use the technologies to empower students of all socioeconomic backgrounds in their quest for education and economic security, and a dystopia in which these potent technologies are used to preserve and even increase inequalities.

A Utopian Vision

Immersive knowledge-based learning environments may well be the holy grail that educators have long sought. The technology has the potential to offer a broad range of benefits including the cost-effective delivery of universal education, twenty-four-hour accessibility that is independent of location, and efficient, individualized educational experiences that are highly interactive.

Immersive knowledge-based learning environments can educate every child in the country in a cost-effective manner. Although the initial cost of constructing the digital libraries will be immense, and developing mentor and immersive simulation technologies will be costly, this capital will be invested for two rea-

sons. First, it will be amortized over a multitude of students and a broad range of subjects over a period of decades. The technological infrastructure required for fully functioning mentors and simulation engines need only be developed once. This technology can then be reused for mentors and simulations for different disciplines, grade levels, and learning styles. For example, the technology underlying a comical mentor for a third grader is identical to the technology responsible for a sagacious mentor belonging to a sophomore college student. Second, the investment will be shared across the education, entertainment, and communication sectors, thereby reducing the fiscal load incurred by any individual industry or agency. In short, the rapid emergence of these technologies will be such a market-driven phenomenon that investing in their development will be inevitable.

As a result of the massive infusion of capital, students around the country will have access to the most advanced technology available for the proverbial "pennies a day." Just as Alexander the Great was tutored by Plato, every child, regardless of parental income, will consult a mentor who will provide him or her with personalized instruction and access to the massive body of information available in the digital libraries.

The high cost of creating the content in the digital libraries will be offset by the fact that an information packet can be recycled for a multiple number of contexts without reduction in value: it is the ultimate non-depletable resource. Not only will the production and dissemination of information in the digital libraries be major—possibly the primary—sources of industry activity, the public digital libraries will constitute a national treasure. Unlike the Library of Congress, whose information use is limited at best, the digital libraries of the future will be the single most active entity in the country.

Immersive knowledge-based learning environments will produce life-changing improvements in the quality of education. They have the remarkable potential to remake the education system from the ground up. Mentors will create a warm, inviting atmosphere that will draw students to education as video games of the 1990s have drawn adolescents to arcades. Mentors will communicate subject matter in a clear, exciting, and compelling manner. By combining text, graphics, animation, audio, and video, mentors and 3-D simulation engines will create a sense of immediacy that is unobtainable—and almost unimaginable—in today's classroom. A student in the twentieth century *reads* about U.N. diplomacy; a student in the twenty-first century *lives* diplomacy by visiting an immersive simulation of the Chinese embassy and conversing with a synthetic Emperor about the potential benefits of a trade agreement. In combination with tradition methods, these sophisticated visualization techniques will enable children to assimilate information much more quickly than by the traditional methods alone. Moreover, the ability to communicate readily with other students online will facilitate group dynamics never before possible (see chapter 5).

An education should give students a solid grounding in the fundamental principles and problem-solving skills they will draw on throughout their lives. To a great extent, educational experiences should mirror those that students will encounter later in life. Just as everyday life has few disciplinary boundaries, a great education should interleave the myriad problems, information, perspectives, and interrelationships of the world around us. Immersive knowledge-based learning environments will provide exactly this capability.

The 3-D simulations immerse students in situations demanding cross-disciplinary problem solving. For example, when a student estimates the oil reserves in Kuwait, he or she must be able to combine mathematical skills with geographical, economic, and political knowledge to solve the problem. Mentors will encourage multidisciplinary thinking by providing advice that involves a broad range of disciplines and perspectives.

Because society in the twenty-first century will be even more mobile than today's, mentors will be completely portable. Students will be able to interact with their mentors in virtually any location. Given the ubiquity of fiber optic cable and advances in the telecommunications industry, students will be able to "plug in" to their mentors at school, home, museums—literally anywhere. Students will have twenty-four-hour access to the entire network and their mentors will always be at the ready.

At the end of the twentieth century, information is available in ever-increasing volume. However, the ability to evaluate automatically the relevance of a particular document for a given problem is severely limited. Clearly, accessing information efficiently and effectively will be *the* critical skill required in the "hyper-information" age. Students will acquire this skill in their everyday interactions with their mentors. Mentors will assist students in posing the most important questions helping them pursue the most promising lines of inquiry, and providing feedback at every step of the way. Because students will learn how to extract particular bits of information from digital libraries with great facility, they will be well prepared to enter the job market, which will require an intimate knowledge of the global information space. And of course, their mentors will make the transition with them from the academic world to the job.

Perhaps the most significant difference between this utopian world and the one we inhabit today lies in the teacher's quality of life. Today many teachers spend excessive time on mind-numbing administrative tasks and unfulfilling duties that are better left to machines. In the twenty-first century, teachers will be able to focus on the rewarding aspects of their profession. They will lead the way by harnessing the power of these new technologies to engage students in active dialogue and creative problem solving. If they are properly trained with these technologies (see chapter 3 for a discussion of the importance of pre-service training), unfettered by administrivia, they will once again play the pivotal role in the overall learning experience.

A Dystopian Vision

These promising new technologies are unfortunately not without their dangers (see chapter 4). Along the way to a fully realized system it is possible that temporary technological inadequacies will result in a series of less-than-perfect learning environments. Although these intermediate versions lack qualities that will make the ultimate system so attractive, they are nevertheless inevitable. Mentors' performance may suffer from poor recall, resulting in students' inability to locate critical information. Mentors' performance may also suffer from poor precision, forcing students to sift through mountains of unfiltered information. While the digital libraries are initially under construction, large packets of critical information will be poorly developed or completely absent. Although students may have a tendency to assume that the libraries are comprehensive, this will not be the case. In short, a fully fleshed out library will not appear for a number of decades.

At the other extreme, when digital libraries and mentors mature, students could well become "over-mentored." If mentors provide exactly the information and analysis required in a situation, students' reasoning abilities will go unexercised. Students will not be forced to consider alternate hypotheses and solutions. Consider a student learning about Pacific Rim economic diplomacy through a simulation. If a mentor served as a surrogate for the student during the entire negotiation, benefits to the student would be minimal. In short, students would fail to develop critical problem-solving skills, and their inherent creativity would go untapped.

A significant danger in the desperate search for digital library content lies in the marriage of the entertainment, communication, and education industries. The powerful influence of the entertainment industry, coupled with the public's insatiable desire for instant gratification, may well result in entertainment-oriented technologies thinly disguised as educational software. Missing from the sugar-coated experiences provided by these technologies is a solid grounding in rich problem-solving experiences and stimulating tutorial dialogue. In the worst case, such software might engender a form of cognitive passivity with no educational value whatsoever.

Despite these pitfalls, by far the most disturbing vision is an Orwellian nightmare in which a small number of corporations create a highly centralized information culture. Corruption and disinformation run rampant in this world with a radically skewed distribution of wealth and power. The education system is in shambles. Drugs and violence reign. Teachers are underpaid. In many cases, schools from socially disadvantaged areas offer vastly inferior educations to private wealthy, suburban ones. It is easy to envision a divided country where the haves and have-nots are clearly separated socially, economically, and even geographically. Society itself is in jeopardy.

The impact on education—and on society as a whole—cannot be underestimated. As we have seen, immersive knowledge-based learning environments have the potential of narrowing the gap between the affluent and the disadvantaged; however, this technology also has the potential of expanding the gap significantly. It is not difficult to imagine a twenty-first century in which the schism between the technology-rich and the technology-poor continues to broaden. Unfortunately, it is also easy to imagine a gap that is increased *by design.* Disregarding moral imperatives, the technology-rich are fully aware that knowledge is power and could be used as a weapon to preserve their status in society.

The technocrats are well positioned to use technology—particularly educational technology—to steer society in the directions that benefit themselves. Those in the inner circle can buy, sell, trade, and withhold information at will. Without a government that values open access and a strong national press, the technological cognoscenti will manipulate public perception on every issue that they believe affects their standing. By controlling access to information, they have the power to reinterpret (or rewrite) history, influence (or determine) the outcome of future elections, and misinform (or misdirect) the general public.

Concentrating information access in the hands of the few almost always has the same effect: as demonstrated time and time again in Communist China, Stalinist Russia, and Nazi Germany, the repercussions of centralized information control can be devastating. The potential for catastrophe will be even greater in the twenty-first century because information control can be much more insidious. Mentors could easily be programmed to misdirect or mislead students as they search for information. A mentor created by a dictatorial government could direct a student away from politically sensitive information. In the worst case, mentors could be subtle purveyors of propaganda by slanting *all* the information they present.

Even if mentors were innocuous, the content in the digital libraries they access could be invalidated. Select partitions of digital libraries could be made inaccessible to "blacklisted" students from specific socioeconomic or political groups. Most disturbing of all is the prospect of digital libraries serving up untruths or, worse yet, partial truths. Students and their parents—literally all of society—must trust the veracity of information disseminated in the schools. In the hyper-information age, if this trust is breached, the integrity of society as a whole will be compromised.

CONCLUSIONS

Much as children of today find it difficult to understand how their grandparents could have been entertained by radio dramatizations, students of the twenty-first century will find it exceptionally awkward to read books in a linear (and comparatively limited) fashion. Watching two-dimensional non-interactive videos will seem as quaint to them as watching Technicolor drive-in movies.

The twenty-first century, however, will witness the convergence and integration of artificial intelligence, digital libraries, and immersive environments to form the most extraordinarily sophisticated educational technologies. They will give rise to a new generation of interactive learning systems that will fundamentally alter the education process.

Mentors, synthetic 3-D environments, and powerful simulation engines will create highly individualized learning experiences that are almost unimaginable today. By utilizing compelling educational tools such as auto-adaptive mentors, massive, multi-perspective digital libraries, and customized, interactive simulations, students will be well prepared for full participation in the coming global society. These technologies offer the promise of an educational system in which all students develop an indefatigable passion for learning that continues throughout their lives.

Because of the unparalleled potential offered by immersive knowledge-based learning environments, they call for a substantial funding commitment at the national level. Each of the enabling technologies (artificial intelligence, virtual environments, and high bandwidth telecommunications) must be nurtured and allowed to mature. Because the challenges of integrating these technologies cannot be overestimated, national policy makers should begin this effort sooner rather than later.

Educational technology by itself cannot solve society's fundamental problems. It can address neither the drugs nor the violence. It can replace neither the love nor the security that the family offers. There is no panacea. Nevertheless, educational technology can significantly increase motivation, adapt to individual learning styles of students, and instill curiosity. It can offer instantaneous delivery of vast stores of information, increase comprehension and retention, provide multiple perspectives on social, economic and political issues, and facilitate cross-cultural communication. Clearly, in its fullest manifestation, educational technology can be a powerful force for radically improving not only the educational experience per se, but the way that students consider society and their role within it.