A Technology Infrastructure for Our Education System

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White Paper
October 1994

Abstract

This is a position paper prepared as basis and inspiration for organizing the *First Workshop on Digital Libraries for K-12 Education*. It is hoped that eventually this vision, founded on existing technology solutions, will be useful in the development of a demonstration project.

Introduction

The United States spends between 400 and 600 billion dollars a year on public K-12 education and training. This is an industry still largely unaffected by technology. Education is not only an area of social and economic concern, but to scientists, as citizens engaged in the advancement of science and technology, it is an area of responsibility. The scientific challenge is to put in place an infrastructure that facilitates teaching, learning, and the sharing of educational resources via the effective application of technology. In education the concept of a complex, open, and recipient-targeted technology infrastructure does not yet exist; and, until such a foundation is put in place, technology will not be meaningfully and massively applied to education. Automation has enhanced productivity and has moved other industries toward gradual but formal and massive use of technology. The education infrastructure suggested would target the automation of a multi-billion dollar education industry that is labor intensive, and would help control the growth of the 93% of total expenditures that goes toward labor costs, rather than simply focusing on the upgrading of materials that only account for 7% of total spending.

The advent of digital libraries will precipitate the need for an education infrastructure and the services it will provide. Should the country not include K-12 educational services in the digital library strategies, the impact will be felt for many years with devastating and perhaps irreversible outcomes. As the collective legacy of human knowledge and information begins to find its place in the digital libraries of the future, we must think of how it is to reach all 100,000 schools and 47 million children. This ubiquitous reach is critical, because we must avoid the creation of populations of information-haves and populations of information-have-nots. The ability to harness the power of information technology in the education of the work force of the future will have a tremendous impact on the competitiveness of the United States.

Motivation

The basic knowledge and competence of graduates of the education system of the United States continues to decline. Ironically, breakthroughs in computer and communications technology continue, particularly in the U.S., but are not being used to help reverse this decline.
Current and unprecedented turmoil in the area of education reform has not been accompanied by the emergence of any system, facility or infrastructure to support the new demands being directed at teachers, administrators, and students. The demands are evident in discussions of topics such

as accountability, performance assessment, and the formulation of new and national standards. Education is being revised broadly in terms of standards for all Americans; and the lack of technology use in the classrooms is being seriously examined. But, while many interesting and potentially useful initiatives are being proposed, none of them will lead to systemic change unless they are explicitly formulated with regard to a common, pervasive mechanism for deployment. An approach to systemic change is absolutely needed and it will not emerge spontaneously from collections of disparate educational reform activities.

Historically, educational innovations and reforms have had limited effect. In spite of intrinsic merit, the benefits have not been sustained over time, and often the programs are not deployed beyond their initial project sites. This position paper proposes a technology infrastructure to provide the systemic support and coordination needed to uplift the national drives towards education reform. An effort must be led in the design, specification and prototyping of the first National Education Infrastructure.

Nature of the Problem

The problem of creating a technology-based education infrastructure is not in engineering or computer science, it is in management and organization. To illustrate the problem, imagine an information base of thousands of multimedia documents describing various aspects of the physical sciences.

- ✓ How can this knowledge be disseminated to all the school systems in the United States?
- ✓ How can this be done so that multiple schools can work with the same information concurrently, and at the precise times when it is needed?
- ✓ How can disparate pieces of related information from multiple sources be brought together in such a way that they can all be accessed, interpreted, and presented coherently to educational audiences?
- ✓ How can a teacher find the appropriate six-minute video segment that is needed to reinforce a particular point in a science lesson?
- ✓ How does the teacher know that it is there, how can it be found, how can it be accessed, and how can it be presented to the students at the point in time when it would have the most impact?

A systems design for an education infrastructure that can provide a basis for addressing such questions will require the application of powerful advanced tools and techniques. Furthermore, it must be designed with education closely in mind. Experience in this area as it relates to other domains has shown that the management of complex systems requires application dependent approaches.

To formulate a systems approach to education, both the activities necessary to sustain educational processes and the collections of information needed to carry on those activities must be considered. These are functions of enabling technologies and comprehensive content. Models of control and information flows can then be developed.

In the domain of education the three broad classes of activities generally recognized as fundamental should be used to guide the design of these models. The activities can be designated as: organization, coordination and execution.

These levels of activities can be clearly aligned with different systems requirements (data storage characteristics, access control, time sensitivity, etc.) and can be used to capture interrelated but separate collections of management tasks in terms of one common system.

Curriculum development, for instance, spans the organization and coordination levels. New curriculum frameworks need to be formulated, specifically based on digital repositories of information in order to provide the means for organizing that information based on sets of educational goals. The design of new curriculum models, and in general lesson plans that exploit these new open sources of information will then follow coherently. Student performance issues, scheduling, and monitoring of specific activities are functions of the execution of the educational processes that derive from the organization and coordination activities.

Education experiences can be enhanced with new opportunities for access to information and these opportunities can be supported in a comprehensive and structured manner. However, this cannot happen without a sound pedagogical approach that specifically addresses the incorporation of critical technologies. The current intensity of activities in the area of educational reform provides a singular opportunity to formulate systems that reap the benefits of current technology. At the same time, and for the first time in U.S. history, there is consensus about the need for national goals and standards. Specific legislation for the achievement of educational goals has been introduced in the U.S. Senate through the "Technology for Education Act of 1993" (S.1040), that fundamentally proposes the creation of a National Education Infrastructure. Assurance that such an infrastructure will be used widely and used equitably can be provided by means of technology. The coming together of new technical developments and reform movements signal the promise of technology for education is about to become reality.

Parts of the solution

Founded on a supportive technology-based infrastructure, a new education system can be formulated. Basic requirements are:

- ✓ Accepted educational content
- ✓ Enabling technologies
- ✓ Methodology for integration

Educational Content

In order to design a successful education system it is necessary to have in-depth knowledge of educational content and its uses. Involvement with organizations that are active in the area of educational content will help us to understand the basic systems requirements. A broad collaborative effort must be formed for understanding the needs of the education industry.
The National Council of Teachers of Mathematics (NCTM) has completed work on Math standards while the National Research Council (NRC) has started a Science standards effort. Even with extensive participation in these efforts, without a systematic approach for integration into actual teaching practices, the work of these organizations will be ineffective.

The intellectual and pedagogical basis for scientific literacy has been defined by Project 2061 of the American Association for the Advancement of Science (AAAS). In a two-year collaboration with Project 2061, the author has developed a technical approach and proposed a technology-based systems infrastructure for the implementation phase of Project 2061 in the schools.

Currently the work of Project 2061 includes the development of six curriculum models that focus on inter-disciplinary and trans-disciplinary curricula that by their very nature span more than science education. These new curriculum models are already receiving national acceptance, with the 2061 Benchmarks for Scientific Literacy being used to guide the National Science Standards work of the NRC. Involving at least six pilot sites, with plans for national deployment, and positively regarded by 13 foreign countries, Project 2061 is one of the best-established activities in educational reform.

The North Central Regional Educational Laboratory (NCREL), one of eleven (regional) national laboratories for education research funded by the Department of Education, has guided the design of a wealth of content for teacher enrichment, much of it in video form. NCREL is hoping to bring these videos to teachers' homes in Chicago and other parts of the Midwest, a region where 60% of the nation's teachers are trained. In addition, NCREL is engaged in the formation of partnerships with organizations that possess large inventories of successful educational content, such as: PBS, BBN (Bolt, Beranek, and Newman), Encyclopedia Britannica, Public Media Inc., Simon and Schuster, as are the other national education labs.

NSF, ARPA and NASA have been given the lead role in the establishment of national digital libraries in response to HPCC S.4 "Authorization Bill for the National Competitive Act". The research anticipated will target the core technologies and applications needed for the formulation and exploitation of digital libraries. As part of this activity a workshop on the "Role of Digital Libraries in K-12 Education" has been organized by NASA, NCREL, the University of Maryland, and IBM Research, for the purpose of raising awareness among educators possibly leading to proposals that will bring funding to K-12 digital library efforts. This position paper has been prepared to motivate thinking for that workshop.

Universities are themselves undertaking the deployment of local education infrastructures for the delivery of multimedia courseware to supplement the dominant old-style lecture approach used in most university courses. Campus-wide deployment efforts coupled with ties to local schools have the potential of creating powerful delivery systems that could be included in a more comprehensive infrastructure. It is important that universities participate both in order to guide the acquisition of content and maintain its long-term validity, and to prevent the infrastructure from becoming overly commercialized.

By working with these groups and others, it should be possible to develop a coherent plan for organizing and disseminating a comprehensive digital library of educational value within the context of an effective strategy.

Enabling Technologies

The critical enabling technologies are those needed for:

- ✓ **Data storage** of large repositories of content
- ✓ Efficient **content compression**
- ✓ **Large scale servers** with I/O capabilities that can support high volume, on-demand delivery of information
- ✓ **High speed** digital local and wide area networks

These "digital library" requirements can be met by exploiting existing technologies.

Consider that:

✓ Existing **data storage** technologies, such as multi-Gigabyte magnetic disks and multi-Terabyte optical tape, can support large repositories of content.
✓ New **compression** technologies allow up to 100:1 compression with minimal visual loss, thus requiring significantly less storage.
✓ Current **database** technologies allow for efficient storage and search of vast amounts of information, centralized or distributed.
✓ **Superservers** today can deliver hundreds to several thousands of simultaneous streams of digital video.

Coupled with wide-area cable or phone company networks, these servers can support content delivery on-demand for applications with large volumes of data and large numbers of users. These technologies are insufficient by themselves. They must be effectively integrated into a single solution. Even if all knowledge and information was captured in multimedia form and deposited in vast digital libraries, the problems would still remain of how to access the information as needed and how to structure, organize, find, and manage it so that it could be understood and applied. The processing power required to achieve these goals is considerable, with the added burden of supporting the extensive use of interactive multimedia and full-motion video that will be part of the digital library environments. A testbed platform is needed to allow the implementation of large, complex applications and to permit the study of the many technical aspects that must be considered.

Additional systems issues will need to be addressed in order to accommodate mass delivery and distributed usage. Because the education system in this country is largely local in nature but with state and national influences, a hierarchical distributed delivery solution would seem to be most appropriate. The existence of well-established organizations that operate on a regional basis, such as boards of education, educational laboratories, schools of education, and communication carriers, suggests that regional servers and local delivery mechanisms would work best for our schools. This approach would also lend itself well to massive simultaneous deployment in many geographical areas.

Methodology for Integration

Coherent acquisition of educational content for the infrastructure has to be coordinated with a comprehensive plan for capturing and disseminating the information. Multimedia technologies have the needed qualities for meaningful and compelling representations of a vast variety of educational materials. Existing sources of information will be converted to multimedia and many new sources of information will be tapped. Real-life activities will be captured for widespread sharing and repeated analysis. Potential sources of multimedia content such as museums and centers of learning will begin to motivate new applications. Research will be stimulated with new and interesting projects for examining, re-grouping and integrating all kinds of information, and these efforts will create a wealth of material for our teaching and learning environment.

However, it will not be sufficient to simply exploit these technologies and provide access to the classroom. The multimedia content must be employed in ways that integrate with learning experiences and with the practices of teachers and administrators. If technology is to be meaningfully and massively applied to education it will be necessary to do more than just bring technology into the classrooms. As more emphasis is placed on the use of these new technologies, we must be concerned with more than just the penetration of technology in the schools, but with how to integrate technology in such a way that the current crisis in education is alleviated.

In order to do this the technical infrastructure must be designed in such way that it can be used to exploit both existing and emerging computer technology, and can therefore serve as a stable, long term platform for the application of computers to education. While education may employ drastically new approaches, the mechanisms that deliver them need not be as volatile. The overall goal should be to bridge the gap that exists between technology and education by providing technically aggressive solutions in a flexible, yet reliable manner.

The author has begun to specify an architecture and systems approach for integrating the various aspects of the solution. In collaboration with national education reform programs, national education laboratories, school districts and teachers, we have explored systems strategies for teacher training (with NCREL), curriculum development (with Project 2061), informal science education (with the Discovery Museum), and advanced education delivery systems (Exploratory Educational Environment, EEE, with CUNY).

How the Education Infrastructure Might Evolve

In order to illustrate a possible implementation strategy, the following scenarios describe the progress that can be made along a time dimension as technology evolves and as a systems design is put in place that focuses on the various classes of users. This evolution reflects the need for targeting the teachers first. The deployment of a new education system founded on a technology-based infrastructure will require staff development in the areas of collaboration, facilitation skills, communications and technology literacy in addition to pedagogy. Curriculum reform must follow. Since curriculum reform activities abound (currently more than 160 in science alone) it will not be necessary to defend the use of new curriculum strategies. Finally, affecting the "classrooms" will follow logically.

Teacher Support Via Interactive TV and Video On-demand

The time is the present. Ms. Davis is a veteran teacher in the Chicago area. She subscribes to education journals and has been privileged enough to attend many teacher workshops over the years. This evening she will not read a journal, instead she plans to tune in to the local educational access channel and view a staff development video of her choice. The event is one that she welcomes. Until the service was announced less than a few weeks ago no-one would have imagined that this could be made possible so soon, it was indeed a surprise.

The North Central Region Educational Laboratory had for years sought for a way to give their greatly acclaimed staff development videos wider circulation. The instant this organization discovered that interactive television was about to become a technical reality they planned for its role in teacher training. This coming together of needs and opportunity is about to make it possible for teachers to have access to the best sources of information, on-demand, when they need the knowledge and at their convenience.

Ms. Davis will be among the first in experiencing this new resource. She turns on her TV and then dials the educational access channel. She finds a number of areas of interest to choose from.

Among those is assessment. She chooses that area by dialing a digit on her telephone. Within assessment there are many subcategories to choose from, the one entitled "Multidimensional Assessment" immediately catches her eye because she has heard about the work of Dr. Howard Gardner and others at Harvard University. Indeed one of the invited speakers during an NCREL panel session was Dr. Gardner. Without wasting any time she selects the Gardner clip. She remembers some of his work from a news article, but listening to Dr. Gardner himself explain the rationale for his theories is much more rewarding. The other clip options from the video are not of particular interest to her at this time. Besides she knows that she can come back to this information at any time, so she decides to explore and find out what else is available. Before long she has covered the exact materials that she wanted to cover and discovers many others that she would like to examine in time. Before turning off the TV she takes note of the phone-mail number associated with "Multidimensional Assessment". Later on she plans to leave some questions on phone-mail that she has formulated regarding Dr. Gardner's work hoping to get more specific answers from NCREL.

The following morning during lunch break the conversations gravitate to the various topics that some of the teachers explored the previous evening. Few teachers viewed the same clips, but they all realize how this new resource will impact teaching. Staff development is only one of many things that can be supported via a technology-based infrastructure for education, and these educators agree that it is the right thing to address first, but they are already aware of the possibilities. Clearly curriculum support will be next and maybe someday educational programs for each student.

Curriculum Coordination Via Interactive Multimedia On-demand

Five years have passed and teachers all over the country know the advantages of on-demand sources of information. Some have accessed digital libraries and visited digital museums. Teacher's colleges have used the Project 2061 Frameworks for some time. But by now as part of the National Education Infrastructure the 2061 Curriculum Framework has been made available to every school district in the country via direct or cached access to regional education servers. Coordination systems are being put in place to make comprehensive use of this new resource for curriculum design and it now seems inconceivable that educators could once have functioned without it. Organized curriculum programs are administered locally to create local frameworks and to balance them against National Standards for Education.

Mrs. Smith runs a curriculum coverage program that checks which topics the members of her Earth Science class have and have not covered. The program detects that one group of students has missed covering the topic of severe weather patterns. Mrs. Smith uses the curriculum technology infrastructure to select a suitable curriculum block. She finds a block that deals with hurricanes in Charleston, SC that (a) covers the missing topic, (b) has no prerequisites that the students have not covered, (c) uses resources that are, with but one exception, available in Mrs. Smith's district, (d) fits reasonably well into one of the themes the class has been pursuing, and (e) coordinates with a history subject that the relevant students are also studying in Mr. Jones' history class. She believes that this topic will interest several students who seem to be reluctant to participate fully in class discussions.

Mrs. Smith notes that the selected curriculum block suggests a library reference, a class activity, an outline for discussion, five links to related topics the students have recently studied, a 15 minute audio recording of an expert discussing this topic, and five minutes of related video. Mr.

Brown's physics class has used this video recently, so it is in the school's cache. Mrs. Smith uses these resources to prepare for the class, including devising a way to work around one unavailable resource. She assigns the library reference and also uses the audio and video during the class. During the class, Mrs. Smith videotapes the suggested activity, as modified to not make use the unavailable resource. After the class she accesses the school level data base to record that this group of students has successfully covered the required topics, so that the next run of the curriculum check program will note that the students have satisfied a requirement. She may also record a more detailed student assessment. She also makes the videotaped materials available in the district level database for use by other teachers who lack the same resource. Eventually few teachers will have to prepare lesson plans without these facilities, but even now it seems to Mrs. Smith that students, parents and mentors should share the responsibilities of making decisions and the privileges of making educational choices.

Cooperative Responsibility and Two Way Interactive Multimedia

The time is 10 years from now. With the encouragement of her parents and high school academic advisory committee, Mary Ann Lee has decided to spend next semester in Sitka, Alaska. She plans to work as a tour guide on a Glacier Bay cruise ship and also as a nanny. Mary Ann will need to keep up with her studies. She has decided to apply to a college that requires two years of calculus, which is not her best subject, and also requires a foreign language, which she has not yet begun to satisfy. Alaska's new fiber optics link will allow her to meet both requirements using interactive multimedia correspondence, including two way video, along with rapid worldwide data base access.

Her head mentor and coach, Dr. Ng, felt that Alaska's newly developed apprenticeship program had much to offer her in these two subjects and also in building teamwork and independence. Dr. Ng, Mary Ann, and her parents have worked together to customize an academic program in which she can excel. They have had two-way contact with the school that offered these two courses as distance- learning modules and with people in Alaska, at least once a week. Dr. Ng plans to monitor and revise her interactive lessons from his home in Florida, carefully adding Russian language modules that are keyed to Sitka's history.

Mary Ann is looking forward to being away from home for the first time, yet being able to see and talk to her family every day. She is accustomed to studying where she can look up and see what her parents are doing. The video network will let her open a window into her home, while she works on her courses. She is confident that her stay in Alaska will help her make the transition to college, both academically and emotionally.

Conclusion and Recommendations

The paradigm shift in education will take place. This must happen because education systems are profoundly affected by social and economic changes. The radical changes that affected our education system during the Agriculture Age and the Industrial Age have not yet happened during the Information Age. The one room schoolhouse of the agrarian society gave way to the factory-like schools of an industrial society. Driven by an information rich society the role of education is to teach students to organize, interpret and understand information. For that to happen there must exist an infrastructure inside and outside the school that makes information available in a consistent, manageable form. Education is now awaiting the fundamental change without which it cannot move forward. With broad diluted participation the changes would be evolutionary. With strong leadership the change will be revolutionary.

In this paper it is argued that:

1. Systemic change is absolutely needed and it will not occur without a supportive technology infrastructure.
2. The use of technology will dramatically increase the efficiency and effectiveness of the education industry.
3. A strategy for implementation should be developed.

Elements of that strategy include:

1. Work that focuses on the partnerships that will provide the educational content and deep understanding of the technical requirements.
2. Work on the enabling technologies that support the requirements.
3. Research to develop a comprehensive systems design for a National Education Infrastructure.

These can be realized by taking action in terms of engaging in trials and pilot projects expeditiously.

Acknowledgements

The vision presented in this paper was compiled and articulated by the author, but constitutes a coming together of ideas and knowledge provided by many colleagues. Among then are: Palmer Agnew, Rose Mary Bell, Dr. Seraphin Calo, Dr. Beau-Fly Jones, David Keefe, Anne Kellerman, Linn Marks, Jeanine Meyer, Dr. Linda Tsantis, Ray Ramirez, Dr. James Wynne, and others. These people made specific and direct contributions to this vision through conversations, references, debates, and heated arguments. Many others read it, made comments, and gave encouragement and support.