COGNITIVE SCIENCE, INFORMATION TECHNOLOGIES, AND THE REFORM OF LEARNING ENVIRONMENTS: HIGH LEVERAGE OPPORTUNITIES FOR THE MACARTHUR FOUNDATION

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The purpose of this concept paper is to explore some of the high leverage opportunities for the MacArthur Foundation to help the nation utilize advances in the fields of cognitive science and information technologies to dramatically improve pre-college education. We briefly outline the assumptions that guide our analysis and proceed to discuss a set of options in the context of other initiatives in this area. (It is not our purpose in this document to review the progress of cognitive science in education, so we must presuppose basic familiarity of these developments by the reader.)

1.0 Key Assumptions

The Importance of High Leverage. We recognize that it is crucial for foundation funds to be used strategically to maximize their impact. Properties of "high leverage," from our perspective, are those in which initiatives could serve to have impacts on the field which catalyze major qualitative changes in education, attract significant additional levels of affiliated support and activities, and have effects disproportionately large relative to their costs. This is particularly essential with the decentralized K-12 education system of the United States, costing over $250 billion per year to serve over 45 million students, with 2.5 million teachers working in about 115,000 total elementary and secondary public and private schools.

An Appreciation of Both the Power and Limitations of Technology. We emphasize our awareness that information technologies can only serve a supporting role for the plethora of problems facing American pre-college education. Issues of latchkey children; high dropout and violence rates in inner city schools; large numbers of teen parents; depleted community and social service support structures; outmoded curriculum, assessment, and teacher education systems; poorly-managed and inertia-bound school administrative systems, as well as many other considerations render obvious that information technologies are no panacea for the improvement of educational practices or outcomes.

By the same token, technology-based tools can broadly serve as vehicles of positive change in many educational systems, and as symbols of progress and hope for solving some of the major problems of education. And it is primarily in

the context of the use of such technologies that cognitive scientific studies of learning and thinking have been attracted to the study of real problems of educational practice rather than primarily, as in decades past, laboratory studies of memory and cognitive processes.

The Need for Systems-Level Thinking. It seems clear to us that any serious attempt to improve education must focus on it from a systemic perspective. Too many previous efforts to improve education through cognitive research and technology have foundered, in part, due to insufficient attention to institutional, policy, economic and other considerations. If reforms of designs for learning do not operate at the level of holistic systems, they rarely last.

The Presence of Opportunity. This is an unusually opportune time for considering new initiatives in education that involve cognitive science and educational technologies. The most important feature of this context for our purposes is that information technologies now allow for extensive decentralization of learning across time and space. Such decentralizations are akin in their potential impact to that of ATMs in banking, which is no longer primarily the "place-centered" activity that it was. While radio is also decentralized in this sense, the media made possible by interactive computing technologies today are far richer, and they allow for the substantial interactivity important to human learning. We can see new opportunities at the intersection of technical developments in the field and markets of computer, telecommunications, information and related industries; research knowledge and experience with effective designs for learning environments in the cognitive science community; and policy readiness among the school systems of the states and teacher organizations for increasing strategic uses of information technologies in educational practices. Each of these contexts is briefly reviewed below.

2.0 Important Areas of Opportunity

Technology. We view new advances in technology as a means to an end rather than an end in itself. The end we envision is one of using technology to break the traditional isolation of classrooms and teachers by creating dynamic learning communities that foster collaborative, lifelong learning. The following advances in technology make the development of learning communities much more feasible than was true even a few years ago.

The advent of desktop publishing incorporating drawn or scanned graphics into documents is less than a decade old. Even newer is the increasingly common use of real-time data types such as sound, animations, and video, in applications such as computer voice mail, desktop video production, and multimedia document preparation. Dynamic documents incorporating live animations, video clips, and sound "annotations" to cells in a spreadsheet or paragraphs in a word-processed document are no longer laboratory demonstrations, but can now be produced with commercial programs. Desktop computers today are increasingly connected to peripherals such as videodisc or videocassette players, still image digital cameras, and CD-ROM or CD-Audio decks. Computer video and audio boards enable the capture and use in multimedia software applications of these traditionally analog data types. Network data communication of computer-created documents has moved beyond "ascii" text characters and numbers to include formatted documents with graphics and text, and innovative technical solutions are being sought to allow for the interactive exchange of communications over broadband private and public networks and the standard telephone public-switched network.

These changes in the communication and production environments of documents are evidence of the arrival at the desktop of the coalescing of the industries of computing, telecommunications, information publishing and related industries such as video and entertainment. A major indicator of this coordination was the March 23, 1993 joint public policy statement supporting the Clinton-Gore technology initiative to establish a *National Information Infrastructure* (formerly called the NREN, or National Research and Education Network), by all the Chief Executive Officers of the nation's leading local and long-distance telecommunications companies (Ameritech, AT&T, Bell Atlantic, Bellcore, BellSouth, Cincinnati Bell, Inc., GTE, MCI, NYNEX, Pacific Telesis, Southern New England Telephone Company, Southwestern Bell Corporation, Sprint, US WEST). Joint initiatives by major entertainment, publishing, and computing companies have been a constant news features in 1992-1993, unlike ever before.

Policy. The Chief State School Officers (1992) have produced a document on "Improving student performance through learning technologies." Since the

Council represents each state's chief education administrator, it provides leadership in major policy concerns through its access to the state's educational and governmental establishment. In this statement, recommendations for state action are made to provide guidance for "a comprehensive approach to incorporating technologies into the center of teaching and learning," in order to advance educational practice using information technologies. They highlight statewide strategic planning, bold plans for funding (including expenditures for technology as part of capital outlay), importance of equitable access, staff development, the development and expansion of telecommunications networks, use of technology-based assessments of student learning, and the need for national leadership.

The Federal Government is also in the midst of crucial deliberations concerning the appropriate roles of the government and industry in creating national telecommunications networks. First, there was the important Congressional legislation, S. 272, sponsored by (now Vice-President) Albert Gore, that authorized in the High Performance Computing Bill of 1991 about $3 billion to facilitate the development of a National Research and Education Network (NREN) using high performance computing and communications to create the national data-highway for digital communications across universities, and, as a result of substantial educator and researcher enthusiasm and lobbying, K through 12 schools. Now S.4 (in development on the Hill) incorporates what is known as "Gore Bill II," and seeks major funding of education-related initiatives (among other areas, such as health) to effectively use the national information infrastructure initiated under the High Performance Computing Bill.

Both the AFT and NEA have been active participants at the National Educational Computing Conference (NECC), and in calling for more strategic efforts to identify teacher development needs for learning to effectively integrate technology into their curriculum and pedagogical practices.

School-Based Research Initiatives. A number of researchers in the area of cognition and instruction have moved from the limited "ivory-tower" approach to research that has been so characteristic of the academic community to full-scale implementation projects that have brought them face to face with the challenges of broad-scale change. The insights derived from confronting these challenges

have important implications for educational reform. Several forthcoming books on this topic highlight these insights---including findings about the key role of ongoing professional development and ways that technology can be used to help solve this problem. One of the forthcoming books, edited by Jan Hawkins and Allan Collins, focuses on a variety of cognitively based "Design Experiments" with educational technologies in schools carried out by researchers from Bank Street College, Bolt Beranek and Newman, Northwestern University, University of California-Berkeley, University of Rochester, Vanderbilt and other institutions. Another forthcoming book, edited by Kate McGilley and John Breuer, explores the experiences of the McDonnell Foundation's CSEP Program (Cognitive Studies of Educational Practice).

We cannot over-emphasize the importance of the availability of individuals who are actively involved in cognitive science research and also have extensive experiences working with school systems plus a commitment to continue working in these contexts. A critical mass of such individuals did not exist even as recently as three years ago.

New Options in the Publishing and Communications Industries. Changes in technology have major implications for the future of companies involved in the publication of textbooks, videotapes, films, and other forms of communication. They realize that multimedia products are gradually replacing traditional textbooks, but many with whom we have talked (e.g., Paramount, which owns Prentice Hall, Jostens, Computer Curriculum Corporation, and a number of other publishing companies) are unsure of exactly where to go and what to do. The increasing feasibility of "distributed multimedia" (e.g., shipping text, video and sound across switched broadband networks such as the telecommunications ISDN, or forthcoming cable company services) is lending additional uncertainty to these industries.

We find that representatives of companies such as Paramount, Sony and others are extremely interested in opportunities to link with researchers and other educators to explore new possibilities. Included is the possibility of linking the entertainment industry with home and school products. For example, family-oriented feature films can introduce characters and ideas that are carried over into interactive educational products for the home and schools--products that can

accelerate the development of literacy in areas such as reading, social studies, science and mathematics. When parents and other community members share common contexts with what children are doing in school (e.g., these common contexts can be communicated through the use of feature films), opportunities for enhanced learning increase considerably.

3.0 Two General Strategies for the MacArthur Foundation

We distinguish two overall strategies for a Foundation program in the area of cognition, technology, and education: As a primary source or as a major integrator.

As a primary source, MacArthur would target specific high-leverage program topics in which its initiative could make a major difference. In the integrative role, encouraging seminal collaborations and partnerships, MacArthur can bring diverse actors together to help establish common grounds and coordinatively plan programs to ameliorate the problems of education which technology may creatively contribute to solving.

Before we describe specific options under these two strategies, we will first describe several directions -- software development, basic research, and teacher development -- that we do not believe would be productive as targets for high-leverage foundation support, with the exceptions for relatively neglected age ranges and curricular areas we describe below.

Software development, while a need in the field, is both very costly and for at least science and mathematics, already supported at a respectable level by the NSF, and to a lesser extent, by the McDonnell Foundation. Joint initiatives between researchers and various industries may also be a productive direction, although venues for seeding such collaborations are ill-developed at present.

Basic research on learning with educational technologies is not evidently a high-leverage strategy either, supported primary by the NSF (although again with the subject area restrictions noted).

Teacher development in this area is a major need as well, since many projects with information technologies have indicated that traditional teachers' roles undergo considerable stress and change when integrating technologies into curriculum and pedagogy. But given over 2.5 million teachers, the costs of designing, implementing, and refining programs supporting the development of teacher uses of educational technologies guided by new research on learning and teaching, in our view, would be prohibitive at the level required for substantial impact. A recent Annenberg grants program targets this issue for mathematics and science education with approximately $10 million in resources.

3.1 "Primary source" opportunities

One class of opportunities involves targeting programs of research and development for student ages who have been relatively neglected. The two most evident periods are the preschool to early school years and the youth development years. The later elementary school years and the high school years have benefited most from information technologies.

Targeting preschool to grade three. This is an important period when literacy, and now-neglected mathematics and science could be well-integrated with supportive multimedia learning environments, especially in relation to Head Start programs which are likely to see increased funding support during President Clinton's administration. For example, research indicates that science is virtually ignored in learning settings during these years, and that very few early primary teachers have the background to teach it. Microprocessors and displays have been sufficiently miniaturized and rendered powerful and portable enough to be integrated in toy-like objects, rather than "desktop computer" in size and profile. Yet these toy-like "learning appliances" could serve higher-level cognitive objectives. Furthermore, experience with easy-to-use input devices for this age range by Nintendo and other manufacturers has made feasible the creation of interactive learning environments for these early ages. Recognizing the importance of hands-on development and physical play for child development in these early years, research and development with prototype systems could nonetheless lay crucial early foundations for children's motivation to learn diverse and integrated subject domains.

Targeting youth development years. This period, as the 1992 Carnegie Corporation report "A Matter of Time: Risk and Opportunity in the Nonschool Hours" has highlighted, is troubled with fragmented support for learning outside the school day. Innovative uses of information technologies in appropriate organizational structures may provide opportunities to reduce drop out rates, increase motivation for school learning, and provide safe havens from crime, violence, and other unsavory options. The 1000 hours a year a student spends in school could be supplemented by activities during several after-school hours and by three hours or more of evening time spent doing something besides watching broadcast television. An initiative could establish collaboratives among researchers and developers with community organizations (e.g., youth associations, parks), universities, schools, and computing, communications, publishing, and entertainment industries.

A related class of opportunities involves *targeting neglected times for learning outside school.* Quite a few exchanges in a recent electronic educational policy forum funded by NSF called "DeweyNet" emphasized the missed opportunities in "down-times" for people to be incidentally learning (not only children but adults). These down-times range from time spent waiting in lines, in waiting rooms, and while commuting (in cars, trains, school buses). Many of these down-times are in communal contexts where "learning moments" are available and high motivation to learn may be present (doctor's offices, unemployment lines).

Another class of opportunities involves *targeting neglected topics.* Beyond the science and mathematics emphasis of NSF, and some technology emphasis at the upper secondary level in these areas and engineering by a program at the Sloan Foundation, there is rather broad neglect of information technologies to support education in the arts and humanities, and in the social sciences. There are special opportunities for dramatic improvements in teaching fields which multimedia systems make potentially much more interesting to students, such as history, music, art, geography, literature, and social and cultural studies. While there is some momentum in this direction, the problem here is that industry

developments of what are described as "integrated learning systems"[1] to date are largely off track of recommendations from cognitive research , because they emphasize learning surface skills found on tests now commonly viewed as counter-productive to teaching for understanding. New emphases on important extensions to traditional text literacy, such as fluency in understanding and producing diagrams, graphs, and other explanatory graphics are also possible in interactive learning environments emphasizing these neglected topics.

A final and important option involves addressing *equity of quality access* to information technologies in educational settings, especially given budgetary plights of inner city schools. There is a distinctive need for guiding public policy on these questions, especially in light of the present debates in Washington considering the federal role in establishing telecommunications connectivity to schools and homes as part of the National Information Infrastructure. This approach could have several components, one focusing on schools, one focusing on families, one focusing on communities. The latter two emphases could target creation of programs to establish more involvement of parents and community organizations in supporting children's learning through new technologies, especially given increasing availability of low-cost network information services (e.g., America On-Line, Compuserve, Prodigy), forthcoming interactive television services, and next-generation consumer video games with educational foci. With respect to schools, some pilot experiments in K-12 and small colleges, funded by NSF, the Department of Energy, and other agencies, provide for less affluent schools to connect to higher performance computers through telecommunications connections.

3.2 "Major integrator" opportunities

A second set of options would involve the Foundation as change agent for bringing together diverse groups to help establish common grounds and plan programs that, in their systemic orientation, may creatively contribute to solving some of the problems of education with technology. For the most part, such coalition-building is not a spontaneous tendency among the constituent groups

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[1] For example, Jostens and CCC (owned by Paramount) sell "solutions" of network-based curriculum, testing, and instructional management software for teachers whose components are "integrated." These are typically closed systems.

described below. But with appropriate attention to the incentives for such collaboration, specific programs with an integration emphasis could be high-leverage in their outcomes for educational improvement. The support of the MacArthur Foundation could make a major difference by catalyzing the leadership in these constituent groups to work together in systemic level initiatives. We view this approach with enthusiasm, while recognizing the organizational challenges intrinsic to pursuing many of the options described.

Integrating diverse cognitive research-informed educational technology projects in the schools. For the most part, the leading studies in this field, inspiring as they may be, have been conducted as piecemeal efforts limited in curricular scope, involving few classrooms, teachers, and schools. Perhaps more fundamentally, what is learned in these diverse efforts, even though school-based, in not evident in its implications for school curriculum design, all topics considered. So the opportunity exists to establish a coalition of these initiatives and foster one or more well-planned and coordinated coalition efforts that may yield replicable improvements of learning environments on a far broader scale than what the spontaneous activity of the field would produce.

"Seeding" the various organizations wishing to find the best designs for networking support for learning in American schools. While there has been considerable enthusiasm among educators and network organizations for establishing network connectivity to schools, it is often noted that connections alone do not offer intrinsic instructional capability. But instructional uses of simulations/microworlds, intelligent tutoring systems, games, and other paradigms for computer use in education favored by the cognition, technology, and education community have been little studied for networked learning environments. NSF is supporting a few network studies on these questions, but only in science and mathematics curriculum areas. This integration option would specifically highlight networking, which given the Federal initiatives in establishing the National Information Infrastructure, will have large but somewhat unguided momentum with respect to the cognition, technology, and education community. The synergy sought in this case is between energies of the school-based networking initiatives, and cognitive-research informed technology applications that could serve learning effectively over such networks.

Targeting designs for learning environments which integrate non-school and school public institutions. This emphasis recognizes the crucial need to better integrate with schools the non-school public institutions that organize resources for learning, such as art, history, and science museums, libraries, and zoos. No one is currently taking a leadership role on this topic. It is widely acknowledged that with computer networks and other telecommunications options (e.g., satellite), the possibility of connecting up disparate settings for learning is possible, not only desirable. While the Sloan Foundation has developed a program on informal learning with technologies outside schools, it is narrowly targeted on late secondary and two-year college level students, and on science-oriented topics.

Acting as matchmaker for two "movements": restructuring schools ,and cognition-educational technology. The primary movements for school reform (e.g., James Comer, Hank Levin, Ted Sizer) have had only marginal relations to planful uses of information technologies based on new understanding of learning and teaching. And the primary work in cognition and instruction involving educational technologies has tended to work at the classroom level until recently, in ways which will not be likely to spread in impact without more fundamental consideration of the institutional, leadership, and teacher development issues that have been integral in the school reform movements. While we believe work to integrate these two bodies of work for improving education would be important, it may be too specific and top-down in its orientation.

Creating a new coalition incorporating stakeholders in systemic change in education, as supported by research-informed uses of information technologies. The concept here is to create a new coalition, which recognizes the systemic nature of learning environment reforms, and which build on cognitive-science-influenced and best-practice applications of educational technologies. This coalition would include researchers, states, industry, teaching organizations, and teacher education institutions. More specifically: (1) the cognition and instruction/ educational technologies community; (2) the States, through the Council of Chief State School Officers (whose CEO is Dr. Gordon Ambach); (3) the computing, communications, entertainment, publishing industries; (4) teaching organizations (AFT, NEA); and (5) schools of teacher education. This coalition would move from the best substantive ideas for reform of learning environments

with technologies to programs for professional development for teachers and state-level systemic reform. Foundation support would target the planning efforts, and actual support for programs of work would come from states, industry, and government research agencies. The closest example from past experience was the Center for the Study of Reading (University of Illinois, Urbana-Champaign), whose influential cognitive studies for improving reading instruction met with publisher acceptance but were largely lost at the level of the persuading states to adapt their curriculum requirements. In our view, this option holds considerable promise in its broad, systemic basis, and could yield major and sustained improvement in educational practices, supported by educational technologies, and informed by cognitive research.

4.0 Summary

These are propitious times for establishing one or more high-leverage programs which advance the reform of learning environments at the crossroads of cognitive science, technology, and education. We have outlined key dimensions of what we view as high-leverage opportunities in this area, briefly sketched two different strategies for Foundation support of the area, and exemplified these strategies with a small set of specific suggestions. Since our primary goal was to provide a global view of the topic by delineating a set of promising directions, we have not addressed specific issues of program size and duration. Determining the size and duration of programs which would be required for substantial impact in education if the Foundation pursued any of these suggestions is a task requiring further analysis and more involved consultation with leading figures in the field.

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