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ABSTRACT

It is important to achieve effective innovation in computer-assisted instruction (CAI). Meaningful innovation can be achieved only by changing the system--that is, by changing not only the technology, but also the institutions and persons involved. Two institutions are proposed: a National Institute of Education which would support creation of a research and development base for educational innovation and a system of institutions and technology designed to make instructional use of the computer in higher education truly effective. To achieve innovation, one must plan institutions to encourage and facilitate it, paying careful attention to financial incentives. Instructional use of computers today has a cottage-industry character. Two trends may change this situation: commercial time-shared computer service and cheap, standardized mini-computers programed through an exchangeable medium such as a cassette. Change would require the concerted efforts of higher educational institutions, time-sharing industries, publishers, and the government. (SM/JK)

INSTITUTIONS, INNOVATION, AND INCENTIVES

Roger E. Levien

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Three things have brought us together for this conference. First, we are *engineers*, inclined by nature and by profession to want to build useful things. We are--or should be--leaders in innovation. Second, we are *computer specialists*, fascinated with the yet unfulfilled potential of information machines to serve us in our intellectual labors. We see the computer as a vehicle for innovation. And third, we are *educators*, engaged in the transfer of knowledge, skills, and values to the coming generation. Most of us see that education is itself in need of considerable innovation.

Indeed, each of the speakers during this conference will be reporting on the ways in which he has engineered educational innovation via the computer. The conference program is an exciting one, displaying, as it does, activity from the University of Florida in the south to the University of Toronto in the north, from Johns Hopkins in the east to the University of Santa Clara in the west. And demonstrating, as it does, uses from freshman through graduate level in the problem-solving, simulation, laboratory, graphical display, and tutorial modes. The impression of widespread, diverse, and imaginative activity is compelling. The computer seems to be engineering a revolution in engineering education. But is it?

After all is said and demonstrated, after the speakers have quietly packed their terminals and stolen away, how much of what is talked about and seen here during the next few days will affect the practices on your campuses? How many of these lovingly engineered innovations will flourish

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beyond the initial enthusiasm of their creators? How many will germinate and take root on other campuses away from the fertile energies of their developers and the hospitable ecology of their home grounds? If we look to experience for the answer, we must conclude--*very few*.

The record of innovation in education is a poor one, and the record of those innovations based on technology is even poorer than the norm. Were it not that you are engineers, hospitable to innovation, and computer enthusiasts, friendly to technology, the chances of anything lasting coming from these efforts would be nil. As it is, even with the best will, each of you who is anxious to foster significant innovation must overcome tremendous inertial forces. Many of you will find the effort necessary beyond your capacity as individuals and will be forced to retire from the field. Others of you, especially favored by chance, skill, or circumstance, will succeed in moving the vast educational mass a tiny millimeter forward.

Is this a counsel of despair? Not at all. It is a plea for understanding. A plea that we, as engineers, see the problem of achieving effective innovation in education for what it is--a design problem, and seek solutions in the large, instead of accepting the consequences of inaction in the small. The fault, you see, lies not with our technologies, but with our systems. In this case, the system is the one which should bring about innovation in education. I say "should" because, like most of our systems intended to serve societal ends, it is more a random collection of elements than a system, and better characterized by what it does not do, than by what it does. If the individual efforts that will be described at this conference in the next few days are to have the consequences that they should, the system for mobilizing, evaluating, distributing, and marketing them must be improved. The system must be changed--by design.

There is a problem with my admonition, however. When I say "system" in this context, I mean the combination of technology, institutions, and persons intended to serve some purpose. Our criminal justice system, for example, comprises technology--in the form of weapons, means of transportation and communication, buildings and the like; institutions--in the form of police departments, courts, and corrections activities; and persons--policemen, judges, corrections officers, and so on. Our health care, communications, transportation, welfare and similar systems also comprise such combinations of technology, institutions, and persons. The problem is that as engineers we have specialized in only one aspect of these system designs--the technology. Yet it is now evident that the proper functioning of our public systems is not principally a question of competent technological design--classical engineering. Better weapons, patrol cars, and computer systems will not, by themselves, significantly improve public safety and the quality of justice. To achieve such improvement will require changes in institutions as well. The same is true of the system for educational innovation; to improve it is a matter of institutional, far more than technological, design. And that is the problem: we as engineers have little experience with and little inclination toward such activities. For many of us, institutions are for the social scientists and professors of business administration. However, for those of us who were drawn to engineering neither by a love of resistors and condensers nor by an infatuation with Laplace transforms, but by the desire to create things that serve a useful purpose, there is no escaping the need to expand our concerns and analyses to include institutions. And there is no reason the engineer cannot be trained to bring to the design process a comprehension of social and institutional phenomena as well as a command of physical ones. It is in that spirit that I am now going to direct your attention, as engineers, to the question and importance of designing institutions for educational innovation.

I am going to discuss two case histories, both of which I have participated in during the past year. Through them I hope to convince you of the importance institutional design has for the process of educational innovation. And I hope also to demonstrate what considerations institutional design includes. The first design is for the proposed National Institute of Education, which would support creation of the R&D base for educational innovation, much as the National Institutes of Health do for health. The second design is for the system of institutions (and technology) needed to make instructional use of the computer truly effective.

As will become clear when I discuss these examples, the state of the art of institutional design is not all that it might be. While institutional inertia is a daily acquaintance of us all, the laws of institutional dynamics still await their Newton--and even their Kepler. But just as the ancient engineers built aqueducts, cathedrals, and pyramids before the physicists told them what they were doing, so too we must build institutions by relying on experience, intuition, and experiment, rather than analysis and science.

When a science of institutional phenomena does mature, I expect that one of its critical notions--playing a role similar to the notion of force in physical phenomena--will be that of incentive. Incentives are what make people move. They may be positive--money, status, authority, prestige, honor, security; or they may be negative--fines, dishonor, subjugation, insecurity. Individuals may exhibit different masses to different types of incentive; some people are easily moved by money, others find authority, power, and prestige more compelling. In any event, a major function of institutions is to provide a framework of incentives that will cause individuals to move together to achieve some social purpose. The design of institutions, then, must be concerned with the proper structuring and orchestration of incentives. The task is not easy, especially since many of an individual's incentives are outside of the institution's control. But then that is not so different from the usual engineering problem of designing objects that are subject to external forces. Institutional designers, thus, must attempt to analyze, balance, and direct individual incentives so as to motivate individuals to serve the institution's objectives.

So I have revealed now the reason for my title: institutions, innovation, and incentives. My theme is that if we are to achieve *innovation* in education, we shall have to consciously design our *institutions* to encourage and facilitate it, and in designing those institutions we must pay careful attention to the *incentives* faced by each of the principal participants. Now to the cases.

The achievement of educational innovation has two phases. The first is the development of the innovation. The second is its introduction into practice. The proposal to create an NIE derives from the recognition of severe deficiencies in the first phase. Our ability to improve and reform education is knowledge-limited. Thus, the NIE was proposed by the President in March 1970 to serve as a focus for educational research and experimentation in the United States; to support creation of the knowledge and technique needed for innovation in education.

The need is great. 'merican education is facing severe problems, despite its achievements in broadening access to the classroom. You are doubtless familiar with the symptoms:

Educational disadvantage adds onto and sustains social and economic disadvantage, while even the more privileged find much education joyless and inadequate.

Many schools and colleges face severe financial crises, while continuing to use their existing resources ineffectively.

Learning is disrupted through acts of violence, while the several factions make irreconcilable demands for changes in governance.

New clientele demand access and service from existing institutions, while powerful non-school sources of education (such as television) dissipate their power in drivel and disservice.

But we do not know enough to solve or alleviate these problems. We need:

- o better knowledge about learning
- o improved curricula at all levels
- o revised forms of schooling
- o improved management tachniques
- o better evaluation of educational policy alternatives
- o new means of selecting and preparing teachers--at all levels.

Yet the existing educational R&D system is not meeting these needs; it is widely held to be deficient. Let's examine the system to seek the cause of that deficiency.

Although research on education began in the 1890's, it was not until the mid-1950's that significant national investment became available, and only after 1963 that the Office of Education-provided funds passed the $10 million mark. Even now educational R&D receives only slightly over $200 million each year, which is tiny compared to the size of the educational enterprise: $70 billion yearly expenditures, 3 million personnel, 60 million students. R&D investment is only 0.3 percent of total educational expenditures. This is a trivial investment in developing the knowledge for innovation, especially when compared to the R&D investments of other national enterprises.

Health, for example, invests about $2.5 billion in R&D each year. That is 4.6 percent of total health care expenditures and 12 times as much as education expends.

Even agriculture invests about 1 percent of total expenditures in R&D; that is, almost $1 billion for innovation in farming--5 times as much as education.

Perhaps the most striking comparison is with industry. If education were ranked among the major industries according to R&D expenditures, it would stand in 13th place--just below the stone, clay, and glass products industry, and far below the $5.6 billion aircraft R&D program or the $4.2 billion R&D program of the electrical equipment industry.

Of course, the comparison with health, agriculture, and industry is not sufficient to demonstrate the need for more funds for educational R&D. Educational R&D is not as fortunate as those areas in the solidity of its scientific base; the demand for and acceptance of innovation by its clientele; or the ability to measure and display improvement. Nevertheless, these comparisons are useful because they show the cost and scale of reasonably successful R&D systems in other major enterprises of no greater complexity or challenge than education.

Thus, the inability of the present educational R&D system to satisfy the needs of education for innovation becomes understandable: it is very likely too small.

But smallness has been exacerbated by other difficulties:

- The reputation of educational R&D has been relatively low. It has not occupied the rank in the hierarchy of scientific activities that its importance and challenge warrant. As a consequence, it has not attracted as many people of high competence as it needs. And as a consequence of that, its reputation has remained low.

- Its scientific base has been narrow. Research in education has been the almost exclusive province of psychology. Yet, education is a many-faceted subject. It impinges on every aspect of our lives--cultural, social, political, and economic; it draws upon most of our resources--human, technological, institutional,* psychological, biological. Education should, therefore, be a subject of concern to an exceptionally wide range of specialists, from scientists to artists to engineers. With few exceptions, it has not been.

*p. 6, line 33--the comma after "institutional" should be changed to a semicolon and the following words added: and it concerns all aspects of humanness--philosophical,

- o Its focus has been diffuse. Most of its efforts have been dissipated in small projects asking small questions with small effect. This has been partly the result of skimpy funding and partly the consequence of educational R&D's exceptionally high reliance on college and university-based researchers whose incentive and reward systems drive them toward individual, disconnected efforts.

- o The linkage between educational R&D and the classroom has been weak. Little output has found its way into practice; nor have many classroom problems been solved through R&D. Here again the academic bias of much educational R&D has taken its toll.

- o Finally, the support for educational R&D has been unstable. Rapid changes in staff and priorities in Federal agencies have caused frequent shifts in emphasis.

Thus, the causes of educational R&D's deficiency are manifold. A new system, if it is to be effective, must seek to overcome each of them. The goal, then, must be to create an educational R&D system that:

- o can mobilize significantly greater support,
- o has higher stature in the scientific and educational communities and with the public,
- o engages the efforts of higher quality personnel from a far wider range of disciplines,
- o channels effort into critically-sized activities addressing issues of high scientific or practical consequence,
- o is closely linked to the educational system, and
- o has stable support and leadership for multi-year programs addressing major educational problems.

The key to creation of such a system is to focus on the central force shaping it, the source of its major financial incentives. Almost 90% of educational R&D funds are provided by the Federal government. How much Federal money is spent, how well, where, and for what, strongly affects the direction and quality of educational R&D. Thus, redesign of the educational R&D system must begin with the Federal part of it. The characteristics of the principal Federal agency supporting educational R&D are of central importance.

Intuition and experience suggest that if the system is to be changed as desired the Federal support agency should satisfy at least the following conditions:

(1) *It should have a stature within the government at least comparable to that of the National Institutes of Health, National Science Foundation, and National Bureau of Standards.*

Such a position is essential if it is to fight for and achieve the necessary financial support from the executive and legislative branches. It will also contribute to an enhancement of educational R&D's stature among the public, educators, and the R&D community. And that enhanced stature will strengthen the incentives it can offer to first-class prospective personnel.

(2) *It should have active advisory councils, broadly representative of the public, and the education and R&D communities, to help it develop policies and programs.*

Such councils help to strengthen the linkages between R&D and practice as well as to build the external support essential for large fund increases. They can also, if strong, serve as a stabilizing force to counteract the influence of fluctuations in Federal educational policies.

(3) *It should have a strong intramural R&D activity concerned with illuminating the major issues facing education and identifying promising directions for R&D.*

The intramural research program would provide guidance to the Institute's extramural program and help to create the climate of excitement that would help to draw first-class staff to the agency.

(4) *It should have a flexible, non-civil service personnel system, modeled on those in other Federal R&D agencies, such as the NSF and NIH.*

The salary and other employment provisions possible through such a system have been shown by experience to be more effective in drawing high-quality scientific and professional staff members than the conventional civil service.

(5) *It should have the authority to carry unexpended funds over from one year to the next.*

This would remove one strong disincentive to wise program management, the need to commit all appropriated funds before the end of the fiscal year or return them to the Treasury.

Thus our basic design for a Federal funding agency for educational R&D has five major features: Stature comparable to other Federal R&D agencies, effective advisory councils, in-house research activity, flexible personnel system, and flexible funding authority. The next step in the design is to to compare these desired features with those possessed by the existing Federal agency, which is the Office of Education's National Center for Educational R&D. One can quickly determine that it has none of them. It is buried so deeply within the Federal hierarchy that its director attains only GS-17 rank (when the comparable R&D activities of OEO, NSF, and NIH are led by Executive Level appointments, several steps higher). Its advisory council is moribund. It has no authority to conduct in-house research, must hire according to civil service regulations, and cannot carry over funds. The conclusion is that the first step in redesigning the national system for educational innovation is to supplant the existing agency by a new one--the National Institute of Education, which would be separate from and parallel to the Office of Education within HEW and be led by an Executive Level appointment. Legislation to create the NIE is now before the Congress and hearings are underway. Authorization may occur this fall.

This is as far as I can carry this case of institutional design today. I should note, however, that my engagement in its design was not primarily concerned with these general features, but with the next level of detail: what should be the NIE's objectives, program, organization, relation to the educational system, and initial activities? A report(1) containing those details is now available.

Now for a quick rundown of the second case--instructional use of the computer in higher education.

As all of you are aware, individuals and projects have been exploring the technology of this use for almost a dozen years now. There are really two kinds of instructional use: instruction *about* and instruction *with* computers. Instruction about the computer occurs in fields such as engineering, business, mathematics, and computer science, in which the computer itself is the subject of study. Instruction with the computer occurs when the computer is being employed as a tool to assist the teacher or the learner during the instructional process.

The Carnegie Commission on Higher Education asked us to characterize the state of the art of such use and to explore the prospects for its development during the next decade or two. How widely would it be used? in what subjects? in what kinds of schools? with what effects on the educational process?

Our examination of the state of the art[2,3,4] convinced us of several things.

First, that the technology of computer use is already sufficient to support a wide range of instruction *with* the computer. As this conference demonstrates, at a variety of schools across the country the computer *is* being used to simulate phenomena, to provide access to realistic data bases, to provide responsive drill and practice, and to demonstrate complex concepts in subjects as diverse as economics and music, engineering and psychology, physics and medicine. And, when used as a supplement to conventional courses, it does this at a not-unreasonable cost.

Second, the technology of computer use is advancing rapidly enough, both with regard to hardware and software and as measured by cost and performance, that even more widespread use is going to become economically and educationally attractive. Neither processor, storage, terminal, nor communications technology is a bind; perfectly adequate devices are now or will be available in the near future. Similar statements may be made about software; operating systems and languages will be perfectly satisfactory for instructional use.

In sum: technology is not a problem.

The problem resides elsewhere. The central issue in achieving effective instructional use of the computer is the design of the institutions to encourage the production and distribution of instructional materials--that is, instructional software--to be used via computer. The computer is the medium, materials provide the message.

At present, the production of instructional materials is a *cottage industry*. The usual case is that some local enthusiast becomes excited about the possibility of using the computer in teaching a course. One way or another he obtains some machine time and many hours away from his work and produces a simulation, or a problem set, or perhaps some drill materials. He gets them up and running and uses them for a semester or two. Then he starts meeting difficulties. Perhaps the machine changes, outdating his program; he does not have the enthusiasm to redo them. Colleagues from other campuses may express interest in using the materials, but after trying to help several adopt them to their local facilities, he stops answering the mail. His department chairman may hint broadly that if he wants to be valued he might devote more of his time to good research or to his teaching load. He may decide to put his time into things that are more professionally or financially rewarding. In the end he, like scores of his colleagues, will have conducted a single interesting experiment, whose net effect on computer use in instruction will probably be nil. There is likely to be no continuity of effort; no distribution beyond the local campus; no cumulation of the experiments of many into knowledge and products available to all.

Just as once we had monks laboriously illuminating manuscripts one at a time for use by the few who could read, now we have programmers laboriously illuminating cathode-ray tubes for use by the few who can gain access. And just as the movable-type printing press and the publishing industry made available to the massess all that the monks had and far, far more, so can judicious design of institutions to capitalize on the technology becoming available to us make computer-based instructional materials widely available and encourage the production of far, far more.

If computer use in instruction is to become widespread and effective, we have to deploy our technology and design our institutions so as to develop a *market for instructional materials*. And, as I shall say in a moment, the important thing about current technology is that it now can support that possibility, if the proper institutional choices are made.

By a market for instructional materials I have in mind an arrangement that satisfies the following conditions:

(1) It must provide incentives to authors to produce instructional materials.

(2) It must provide means of distributing materials to many different sites of instruction.

(3) It must arrange for payment of use.

(4) It must provide incentives for distributers to get materials into use.

(5) It must provide means of convincing instructors to use the materials.

Almost none of these conditions is satisfied today. Hence the local, cottage industry character of instructional use of computers.

But, two trends in computer technology offer the chance of establishing a market. The first is the commercial, time-shared computing service. The second is the cheap, standardized mini-computer programmed via some exchangeable medium, such as a cassette.

Let us consider the time-shared services first.

They solve the problem of distribution and standardization very simply. A computer whose store contains a wide variety of materials for use with introductory engineering courses, for example, can be accessed from many different campuses within its service area. The larger services, which maintain nationwide networks, can be accessed from many sites across the country. Conversely, each campus terminal can be used to connect into Service A at one time and into Service B or C at another time. That terminal cares not at all whether it is communicating with an IBM 370 or a CDC 7600, as long as the programmer has organized the right terminal interfaces.

Time-sharing services can also solve the problem of arranging for payment for use. Of course, you pay for the computer time you use, but some time-sharing services also now have arrangements whereby they collect a royalty fee for the use of prestored application software. Thus, the faculty member has a convenient means of collecting a royalty for each use of his simulation program, anywhere around the country, by a student or fellow professor; just as he does now when he writes a textbook.

The royalty should go a long way toward encouraging authors to develop and improve materials, especially as the market becomes large and some lucky author hits the jackpot. Further incentives can be provided by seeing that each instructional package is signed and authorship indicated to each user. The point here is simply that the fame (or notoriety) coming from a widely used instructional package could add to the professional stature of its author and help in gaining him promotion or academic mobility.

This is beginning to sound like the textbook business, isn't it? Well, I mean it to. The book and printing press have been an exceptionally successful instructional technology. Our aim should be to put the program and the computer into the same flexible, self-renewing usage.

The remaining problems concern distribution. And since the textbook analogy has occurred, let's follow it out.

The refinement, editing, polishing and storage of the author's instructional materials should be handled by a publisher. This would probably be one of the existing ones, but it is possible that new computer material specialists will develop. The publisher will employ a prestigious professional editorial board to select the materials to be polished and distributed. Such a board would help attract good authors and help convince reluctant users. The publisher will also employ a corps of salesmen who will travel from campus to campus, portable terminal in hand, demonstrating their wares to doubting faculty members. Quite likely initial uses will be tied directly to textbooks already sold by that publisher; problem sets associated with Samuelson's *Economics*, for example.

We turn, finally, to the faculty member. What is going to convince him to use these materials? It seems to me that there is one principal way--through his discipline. That is, if it becomes clear that electrical engineering cannot be taught well without extensive use of computer-based materials; if prominent colleagues in the discipline are engaged in the production of materials for the computer; and if faculty members have the freedom to select from a wide range of segments and add some materials of their own, then I think many of them will be convincible. Of course, it will still take the salesman and his offer of free trial computer time and other encouragements to do the convincing. But, the point, it seems to me, is that this kind of innovation in teaching must occur *via the discipline*, and not, for instance, *via the campus*.

The final advantage of the commercial time-shared service is its incremental nature. A little use can be tried and then more and more use can be added. There is no need for one large assault on the budget; use can grow bit-by-bit as enthusiasm grows and funds can be made available.

There remains one problem: who pays? I fear that if money for computing must come from departmental budgets, then it will be very hard to get. If given the choice, I expect, most department chairmen would opt for paying the salary of a flesh-and-blood colleague, who writes papers, sees students, and sits on committees, rather than pay for instructional uses of a computer. It may be that, as with the textbook, the only one willing to be forced to pay for the message in this medium is the student. At current costs that is a problem; it might remain so even for a while as costs are reduced. In this respect, the second technological possibility that I mentioned looks especially interesting.

Mini-computers are becoming quite inexpensive. Several thousand dollars now purchases a very competent machine. The cheaper they get, the greater is the desirability for standardization in their characteristics. It is now also possible to hook a cassette-tape deck to such a machine to serve as a program entry device. It should not be long before an inexpensive CRT terminal is available. Now, if you wish, the computer can become an *intelligent tape player,* carrying out the instructions contained on the cassette tape. The conventional audio cassette, thus, can become the medium for distribution of computer-based instructional materials.

The system of production and distribution would work very much as before, except that now the product would be a cassette sold in the college bookstore like books and records. The college might be expected to make the capital investment in computers and the student to buy or rent the cassettes he needs for his courses of study.

The problem with this institutional design is that it cannot be brought about so directly as a National Institute of Education. It cannot be created by act of Congress. Instead it must develop through the concerted efforts of *higher educational institutions* (who must overcome tremendous internal inertia to seek computing service off-campus), of the *time-sharing industry* (which must make special arrangements to meet the needs of higher education), of the *publishers* (who must see and seize the opportunity), and of the *government* (which may have to subsidize the development of a critical mass of materials). The best that a designer can do is to sketch a picture of what the system should be and describe it often and thoroughly enough so that the individual implementers will each agree to and work toward that common goal.

I have tried through these two examples to convince you, as engineers, of the need for a creative concern with the rest of the system-- the institutions that employ our technology. And I have attempted to demonstrate to you, as educational innovators, the importance of achieving change in the system for educational innovation. I hope that I have left you with strong incentives to apply your creative talents to the design of institutions for educational innovation.

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