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A Proposal for the Reengineering of the Educational System

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We propose a reengineering of the educational system that focuses on mastery and on more substantial learning activities and eliminates the constraints on learning that arise from the current insistence on grouping children by age. Our basic argument is that eliminating the age-based approach to education has striking advantages that outweigh any social disadvantage. Age-based grouping is, in historical terms, a recent reaction, driven initially by social trends that grew partly out of the realization that children pass through developmental stages and even more out of a wave of superficial approaches to efficiency that attended the beginning of mass production in industry. Through most of history, age grouping has been minimal. We think there are good reasons for this, which we discuss below. The most powerful reason is the extremely large variance found in any index of learning achievement, even in relatively homogeneous populations. We further argue that modern information systems allow richer educational activities, research-based methods, and multiage schooling to proceed efficiently and effectively. This creates a moral imperative to provide real learning opportunities to the whole of the student population.

We see numerous indications of the failures in our educational system. It is commonplace to blame these failures on lack of student motivation to learn, on lack of motivation or competence of teachers to teach, on taxpayer stinginess, and on interference from television. However, as we show below, virtually every available source of data shows that students differ substantially in the rate at which they can learn various bodies of knowledge, and the variance of learning achievement is generally of the same order of magnitude as the mean.

The Failure to Educate

A different interpretation of current educational system failures is that age-grouped education is inherently unstable and inefficient. If it is enforced completely, numerous children will necessarily be waiting bored while others struggle to keep up. When teacher subject-matter weaknesses, lack of funds, rapid curricular demand changes, or other difficulties arise, the system collapses. We seem to be in the midst of such a collapse. Our children need to know much more than before in order to remain useful in an age when the predictable and the pedestrian are done by machines. Some people may hope that we will see the end of work and a new social order for sharing resources, but it is more likely that the economic system will continue to reward those who can engage in economically productive enterprises. If so, then students will need to learn more and become more facile in quickly marshaling their accumulated knowledge to engage in new, complex, and probably collaborative work. The core of work itself will be learning how to produce new goods and services and then producing them.

There are many jobs that can be instantly moved anywhere in the world because they consist entirely of information handling. Such jobs include slow-turnaround data entry, fast-turnaround imaging and claim processing, computer-assisted design and geographical information systems, electronic publishing, voice center operations, remote secretarial services, customer support, and indexing and abstracting. Since the cost of information transmission is rapidly becoming independent of distance, these jobs can be moved anywhere that one can find people with adequate competence to perform them. As a result, all low-level jobs will shift to the places with the lowest wages. For example, based upon recent World Bank data, we compute that data entry jobs will tend to shift away from developing countries very quickly, because such jobs do not require much education and because wage differentials are high. Even with communications costs still three to four times as high in Jamaica as in the United States, it is worth shifting data entry operations to Jamaica whenever the number of jobs involved exceeds 10. When communications costs become more equal, the smallest businesses will find it profitable to send elsewhere the work that can be done by the incompletely educated. As computer software improves, human workers with inadequate education will be competing with machines, and artificial constraints like minimum wage laws will simply accelerate the shift of jobs away from the less educated members of the costlier societies.

In the face of this new need for increased educational outcomes, we see minimal improvement in education. There is debate over whether college entrance tests show continuing decline in student achievement or merely no improvement. Almost every university in the country needs to remediate the mathematical and communications skills of substantial numbers of its students. Similarly, apprenticeship programs in technical trades need to spend time reteaching basic algebra, geometric constructions, and the use of measuring scales. With such a wide range of achievement and basic learning skills in any age-grouped classroom, much material is covered, moderate amounts are regurgitated on memory-based exams, and little is retained by many of the students. Comparisons of the achievement of U.S. students with those in other countries have not been favorable (Stevenson, Lee, & Stigler, 1986; Stevenson, Lummis, Lee, & Stigler, 1990). This is critical in view of the worldwide trend toward a small group of better educated workers who accumulate inordinate shares of both the burdens of work and its rewards.

There are a variety of indications that while the socially and economically disadvantaged are the main victims of educational inadequacy, the problem is more universal. Many of the middle class of the 1950s were middle managers who earned a good livelihood by distributing information from above and condensing information from below. Generally, these middle managers did not have very specific skills or knowledge, but they had learned to follow and give directions in a modestly verbal world, and their role was essential so long as communication among workers was as limited as it was. Today, with computer tools available that distribute and cumulate information more efficiently than humans, and with the discovery that organization at higher levels cannot replace line-level knowledge and problem-solving skill, these middle management jobs are gone. Many other jobs have disappeared for similar reasons. For example, in previous generations, it was not possible to arrange health or life insurance for a worker without the intervention of a human agent. The agent translated the worker's needs into standard company jargon. Sometimes, he even dropped by weekly to collect the insurance premium, since use of checks and electronic drafting was not an option for most workers. Today, the cost of such service is so high as to be feasible only for the largest insurance policies. Most worker insurance is commoditized and handled by the record-keeping facilities of the employer rather than individually. Indeed, even bank tellers are being replaced by machines.

Our point is that until recently society had a wide range, perhaps even a majority, of jobs available for the people who did not really learn everything that was "covered" in school. Today, those jobs are gone. We need to make schooling much more effective, and cost problems will force us to become more efficient, too. We do not believe this is possible without arranging the learning process so that time spent in learning is optimal in its yield. We subscribe to the calls for new and higher standards of schooling. These are necessary because only high levels of competence are economically rewarded these days, but we do not believe that exhortations to harder work are sufficient to make these standards productive. Rather, we believe that part of the needed change is to arrange student's learning work to be optimally productive. This will require grouping students for learning tasks on the basis of what they know and can do, not merely age. If we do not do this, then school will be like today's workplace, with those students who do not give up struggling ever harder to achieve ever more precarious opportunities for a productive later life.

The Educational Research Findings

The scholarly tradition has left the world of education with a maladaptive view of learning. For too long, we have seen learning as the storage of verbal material in the mind. This leads to some severe problems, especially the disjunction between school learning and competence in the world. As Whitehead observed, we often fail to realize that we have learned something that is relevant to a situation we encounter; from this viewpoint, our knowledge seems "inert."[1] The cause can be discerned readily. Verbal knowledge is, by definition, encoded in words, and those words gain meaning from experiences. However, the words of principles and definitions learned in school do not necessarily point to the life situations to which that knowledge could be applied. And, the problem is really even worse: Verbal statements abstract over the additional knowledge needed to relate a general principle to a specific case. In situations where students and teachers come from a common experiential background, this problem is less severe, since the teacher is in a position to point out the situations to which a given piece of knowledge might be relevant, making reference to experiences and situations both teacher and student have shared. However, our fast-changing, multicultural society is exactly the opposite, with substantial gaps among students and between students and teachers in prior experience or likely future experience. Hence, verbal enhancements of verbal instruction will be insufficient to solve the knowledge inertness problem.

The Learning of Useful Knowledge

Three basic principles for solving the inertness problem have been put forth in recent years: knowledge negotiation, knowledge construction, and knowledge situation. We believe that any effort to restructure schooling must be driven by these three principles. The principles grow out of several different learning theories (see, for example, Slavin, 1990). However, variations of these principles seem to find their way into many different current approaches.

Situated learning. The principle of situated learning is quite old in some respects; it is a successor to Thorndike's identical-elements theory of transfer. On the other hand, it often derives from a strikingly different view of knowledge than Thorndike held. Basically, the principle asserts that knowledge is built from experience in interacting with the environment and hence that all knowledge is tied to the situations in which it is acquired or to categories of situations that may have been learned. Any generalization to categories requires sufficient experience with real situations to drive the mapping of knowledge onto abstractions of those situations.

This principle is a bit different from Thorndike's even though it derives from a similar view of the difficulty of transfer. In Thorndike's view, one acquired certain elements of knowledge in a particular situation. If later situations required those elements of knowledge, then learning to perform in those situations was a bit easier, solely because some of the needed knowledge elements had already been acquired. The situationist perspective is even more pessimistic about transfer. It says that all knowledge elements include, as part of their core, the situations to which they are bound. There being no such thing as a generic element of knowledge, there is no transfer at all, unless work has been done to build abstractions from extant knowledge. Of course, sometimes a new situation is so close to the old that this abstraction can take place on the spot when the new situation is encountered. However, when that is not the case, old knowledge will be completely useless unless work has been done to abstract it sufficiently to apply to the new case.

Constructivism. This extra work is the focus of the second principle of cognitive learning, namely, the principle of construction. Because knowledge cannot be conveyed independently of the situation one is in, or a situation class that has been aroused in the student, learning must be seen mostly as the building of knowledge abstractions by individual students. Within a constructivist view of learning, the process of learning is an active one in which the learner observes a situation from multiple viewpoints, forms abstractions of what has been learned from that situation, and tests those abstractions in new situations. Good learners, in this view, are aware of the need to notice enough to be able to generate a plan for finding and experimenting in relevant new situations.

Knowledge negotiation: The social structure of learning. The principle of knowledge negotiation provides a specific mechanism for knowledge construction that is motivating and, to a considerable extent, self-correcting. The basic idea is simple. When two people need to discuss a situation with one another, they need to come to an agreement about the meanings of the terms that they use, and that agreement is tested by their ability to use these terms in talking to each other. In the ordinary flow of life, we use terms whose meanings are largely stored in our culture,[2] and the need for precision in shared reference for terms is quite limited. When one confronts novel situations, for which new learning is required, effective interaction requires more careful attention to the referents of terms and to the meaning of predicates. This greater attention is at once motivated by the need to succeed in an interpersonal interaction and focused by the automatic feedback that results when terms are used in ways that confuse the partner.

A primary means of learning is to work with a partner in trying to figure out a difficult situation or trying to solve a difficult problem. Collaborators can check their understanding automatically as they interact, and each represents to the other an additional resource, a source of broader and different viewpoints. Of course, this advantage of collaboration can be lost if the interaction degenerates. It is no more helpful for a learner to hear groundless confirmations from a partner than for him to deceive himself that agreeing to the correctness of statements in a text is equivalent to understanding and assimilating them. Like all other forms of learning, collaboration benefits from periodic checking of the consistency, coherence, and completeness of one's understanding. A conversation with a collaborator can be a stimulus to such checking.

Cognitive Apprenticeship

One special form of collaborative learning has been called "cognitive apprenticeship" by Collins (1991). This approach is a special structuring of collaborative learning in which the collaborators are successful practitioners of some expertise and the student is a "legitimate peripheral participant" (in the sense of Lave & Wenger, 1991). As in straight collaboration, learning is partly through the negotiation of meaning, but the negotiation is appropriately one-sided, since the terms being discussed are shared by a community of practice. The learner is, therefore, cast in the role of a novice or postulant who is entering the community of practice.

Cognitive apprenticeship has three basic features. First, the tasks students complete are realistic, complex, and examples of valued performance in a domain. Second, domain simulations make the tasks more realistic and less anchored in words that may not yet have full meaning for the student. Third, a coach and various aspects of the performance environment provide a "scaffolding" to support the student, which enables him to complete valued and difficult tasks even before he is fully competent to act on his own. An important addition to these basic components (see Gott, Lesgold, & Kane, in press) is that opportunities are provided for reflection on tasks after they are completed, with various devices being used to reify the components of cognitive processing.

Cognitive apprenticeship is extremely costly in terms of the amount of human expert time that each student demands. On the other hand, it has become possible to offload many aspects of coaching and scaffolding to intelligent computer systems, along with the domain simulations (see Lesgold, Katz, Greenberg, Hughes, & Eggan, 1992; Gott, Lesgold, & Kane, in press). In effect, some of the conversations occur between student and computer instead of between students. This is practical because the computer system can remain faithful to a model of the task environment and a model of expertise independently of whether it fully understands what the student does and does not know. Of course, if it keeps talking the truth and the student keeps failing to understand, an impasse might be reached. However, recent computational linguistic work has shown that intelligent systems can work with confused students to solve many of those impasses, if the systems are properly designed (cf. Moore, 1994).

A different kind of problem for cognitive apprenticeship is the choice of tasks and levels of scaffolding for different students. Here, a computer system is useful only if it can come to understand approximately what the student does and does not know. We must distinguish here between two modes of student diagnosis. The early period of intelligent computer-assisted instruction (cf. Carbonell, 1970) saw the computer's role as diagnosing exactly what knowledge was missing from the student's head and then acting as a sort of knowledge spigot that would pour forth the needed new content. This approach did not fare too well, perhaps because it failed to afford opportunities for knowledge construction and certainly because it is extremely difficult to make real-time, microdetailed estimates of what a person knows.[3]

In contrast, the goal of proposing a range of tasks that are approximately at the right level to support learning does not require such detailed diagnosis and can be based upon longer progressions of performance. This kind of individualization, perhaps with the computer role limited to offering the student choices of tasks and commenting on areas where the student is doing less well than other performances would predict, can be and is provided by some current systems. We envision, therefore, a macrolevel of computer-supported apprenticeships (and other learning opportunities) that is individualized, approximately, with a microlevel of learning tasks that are computer supported, coached, and scaffolded with accurate reflection of the task domain but perhaps imprecise machine knowledge of what exactly the student does and does not know. In such environments, it remains the student's responsibility to question his own actions, to ask for explanations, and to keep working diligently. Machines can, of course, provide some normative guidance about the adequacy of such student efforts.

The Shape of the Learning and Forgetting Curves

We turn now to a traditional concern of the instructional world, namely, the course of learning and forgetting. Views of learning and forgetting are very much a function of the research community of the viewer. People in the cognitive apprenticeship world tend to see learning as permanent if done right and forgetting as an indication that mere verbalisms and not true competence were acquired. Similarly, in everyday life we see great differences between our retention of factual knowledge, which fades quickly after examinations, and lifelong skills like riding a bicycle, which seem to endure without support. It would be easy to treat forgetting as a problem only for the traditional view of learning as knowledge storage, but this would likely be overly optimistic.

In a variety of high-demand cognitive tasks—such as catastrophe management, airplane piloting, medical procedures, and power plant control—experience has taught that periodic refresher practice is very important. Similarly, the failings of schooling suggest that learning will not endure unless it has been supported by multiple opportunities to exercise that learning in different settings. So, life experience tells us that we do not really lose knowledge that is well established, but school experience tells us that much is gone by the day after the exam. There are data that can help us understand this.

Several different kinds of data suggest that it is useful to think of at least two stages of learning. For example, Judd and Glaser (1969) found a first level of learning in traditional verbal learning tasks in which accuracy of performance slowly improved, reaching asymptotic levels after multiple practice opportunities, while speed of memory retrievals kept improving long after performance was perfectly accurate. Further, forgetting decreased as a function of extra practice. This suggests that perhaps schooling is so readily forgotten because none of what is taught is used or practiced for very long. We believe that this is partly because time spent in practice in a group setting is time that could otherwise be used to cover more material for the faster learners. Nonindividualized education cannot efficiently provide for universal learning and has even more difficulty assuring universal retention.

Coming at the problem from a very different point of view, Fleishman and Quaintance (1984) found that verbal aptitude was the best predictor of the early stages of learning, while cognitive and motor performance measures better predicted later stages. In the world of learning, even with cognitive apprenticeships and other improvements, there remains a trend toward first having to engage in the conversations of learning, with oneself, another person, or a machine, and then having to tune one's knowledge by confronting tasks in which diverse situational aspects are altered. Our views of individualized learning must attend to these very different kinds of evidence about the stages of learning.

A critical problem for the slower student, given this multistage view of learning, is that all of his learning time is focused on the earlier stages. These are more easily tested and are all that the slower student will have time for, even if things go well. The result is that through most of schooling, the slower student enters each course with a deficit, in terms of facility with which he can exercise what he learned before. By the end of the year, he is further behind classmates, having had each year a progressively harder time keeping up. Our proposal would permit students to master each body of content before going on to the next, that is, not only to be able to regurgitate some verbalisms but also to use the knowledge.

The Distribution of Individual Learning Rates

The age-grouped classroom is quite new to education and is largely a product of the industrial revolution and especially of the scientific management movement (cf. Taylor, 1967), though there were somewhat earlier threads of similar character. Three main forces have driven the age grouping practice. First, the realization that children's cognitive capabilities differ from those of adults, stimulated by Freud and Piaget, led to the belief that children of different ages need different cognitive resources, need different learning methods, and have different cognitive dispositions for acquiring various forms of knowledge. The extreme form of this view is that children need age mates to support the particular kinds of thinking and emotion that their level of maturation involves. So, for example, the very idealistic kibbutz movement in Israel arranged living facilities so that children lived with age mates rather than with their families (of course, community was valued over family in this culture, but still a major investment in social change was driven by beliefs in the importance of age-peer interaction).

The second major force toward age grouping was the drive for universal education. This, and the third force, efficiency demands, forced a move from a tutorial approach to a didactic approach in age-grouped classes. When a wealthy person had three or four children to educate and no communal resources to provide that education, hiring a single tutor to teach all the children made great sense. However, when a community had all of its children to educate, specialization of labor became appropriate, and the most obvious and socially compatible specialization seemed to be by age. Had society set its sights higher at this time, the specialization could just as well have been first by subject matter, but the initial goals of universal literacy were low enough that it was assumed that any teacher had already mastered the content. Rather, teacher preparation focused on teaching methods, especially adaptation to children of different ages.

Through all of this time, minimal attention was paid to the variability of learning rates among children. We do not have complete data on how disparate educational achievement would be if we did not limit the speed at which children could progress, but there is every reason to believe that it would be dramatic (cf. Gettinger, 1984a, 1984b, who cites other findings of a 5:1 ratio among students in time to learn). Even within a highly constrained system, in which faster learners are not afforded sufficient learning opportunities, there is ample evidence of major variability. We present here a few modest examples of the evidence that supports this view.

Consider the standardized educational achievement tests we give to college bound students. In the case of the College Board's Scholastic Achievement Test (SAT), for example, scores of college bound seniors have a standard deviation of about 100, by design. What is less often discussed is the average rate of growth in SAT scores over the course of schooling. Now that we have a substantial number of children taking the SAT as early as 11 or 12 years of age, there is plenty of evidence to support the view that SAT scores grow an average of about 35 points per year (L. Bond, personal communication, ca. 1985).[4] This means that the standard deviation of the test scores at the end of secondary education is about 3 years' worth of normative learning. While the construction of the test limits the absolute precision of the following claim, it still seems worthwhile to infer that only about two thirds of high school seniors have attained a level of intellectual capability within 3 years of the average. To include all but perhaps 5% of students, we would need to have a range of perhaps 12 years of normative education, that is, the mean plus or minus 2 standard deviations. In general, this reasoning, as well as an examination of a variety of data sources, suggests that in age-grouped education the range of achievement is roughly equal to the average; if we look at students after n years of schooling, they will range over 0 to $2n$ years of normative achievement.

A very different view is available from the entry end of the public schooling world, though the conclusion is roughly the same. Lesgold, Resnick, and Hammond (1985) conducted a longitudinal study of learning to read. Over the first 3 years of schooling, children were tested up to eight times in an effort to understand the differential effects of two different approaches to reading instruction. For our purposes, though, what is important is the variability in outcomes of learning over the three grades. At the end of the third grade, when students are assumed to have learned the basics of reading, oral reading speeds in the top 20–25% of the students averaged about 100 words per minute on passages similar in difficulty to those in their readers but not prepracticed, roughly the speed of conversation and clearly fast enough to support higher-level thinking processes. The bottom 20–25% of students, though, averaged only 50 words per minute for one curriculum and 80 words per minute for the other, slow enough to be a substantial barrier to understanding. Even with multiple reading groups, major differences in achievement remain; many students read so slowly after 3 years that they will have trouble doing much meaning processing of what they read, and others are clearly done with the basics of learning to read after a year or so.

While primary reading instruction is partly individualized, with each classroom usually having several different reading groups, this individualization tends to end after the third grade. It is interesting to note that Lesgold, Resnick, and Hammond (1985) observed substantial differences in achievement that did not decrease with years of schooling over the primary grades, yet the capability of the instructional system to support continued individualization past Grade 3 is generally quite limited. While dispersion of achievement did not narrow over grades, Lesgold, Resnick, and Hammond found that dispersion of "reading level" was maximal at second grade. That is, students begin primary education in a system that allows reading to be acquired at differential rates, but between the second and third grades, even though achievement continues to vary widely over students, classification variance decreases; our society expects almost all children to reach the top reading level by the end of third grade, so they do (on paper), independently of their real competence, as measured by the reading of passages not previously drilled in class.

We see reading instruction as it begins in first grade as a model for individually paced learning. Much of the learning activity takes place in groupings that reflect achievement, and there is room for considerable variability in rate of learning. However, this flexibility is provided only for reading and only for a couple of years. By Grade 3, efforts are under way to find ways of "passing" all the students out of basic reading, usually by subtle movement from capability to engage new texts as a measure of progress to capability to read a fixed text given sufficient drill. What happens is not "cheating" by teachers but rather an evolution of the third grade curriculum to focus more on rote, rehearsable performances and less on broadly useful skill. In this way, most students can make it through all the "covered" content of the first three grades independently of whether they really learn to read in any meaningful sense outside of school. A truly individualized system would preserve the standard of competence in engaging new tasks as the measure of achievement and would provide appropriate resources for students who need longer to achieve that real goal, rather than substituting schoolish goals or unabashed social promotion for measured success in adaptive competences.

The Attempts

Historical Background

> Let him that is skilled in teaching ascertain first of all, when a boy is entrusted to him, his ability and disposition.... Let him next consider how the mind of this pupil has to be managed. (Quintilian, 1st century A.D., in *Institutiones Oratoriae*)

We open this section with an epigraph by Quintilian, who lived in the first century A.D., not only because it shows how long ago the need to adapt education to the capabilities of each learner was already clear, but also because Quintilian was precisely a teacher, a Roman teacher, as opposed to a Greek tutor. He taught classes, and he confronted the same problems of student diversity that a teacher confronts today. It is important to make this point, because the classical ideal of Western education is given by the Socratic dialog, but this dialog, as the word implies, refers to a one-to-one situation. The Socratic dialog characterized an aristocratic society, and we find throughout educational history the tension between ideal education and mass education. We think that society has reached a point, both in educational knowledge and in technological power, where it can offer excellent education for all.

Schools are known to have existed in the Western world since approximately 2500 B.C., when Sumerian schools specialized in the teaching of writing. Schools, in their diverse manifestations, consist of places where students gather to learn, under the guidance of one or more teachers. Quintilian's quotation allows us to emphasize another point, very frequently forgotten in present days: Except for the last two centuries (a relatively short period in historical terms), schools provided students with individualized instruction. The fact that students were together, even in the same room, did not mean that they studied the same materials.

We are used to examples from the Greek Golden Age, but even if we take the risk of plunging into the Dark Ages, we find that

> a medieval school was primarily an educational relationship entered into by a private teacher and a group of individual scholars. Like guild masters and their apprentices, teachers took students at all levels of competence and, accordingly, organized their teaching largely on an individual basis. Such individualization fed back, in turn, upon the general organization of schooling. First, there was no presumption that every student was "learning" the same passage. Secondly, there was no pedagogical necessity that all students should remain in the teacher's presence throughout the hours of teaching—they could just as easily study (cf. memorize) their lessons elsewhere. And thirdly, there was no expectation that students would stay at school after their specific educational goals had been reached. (Hamilton, 1989)

It was after the industrial revolution that methods of mass production were copied by educational systems (England, France, and Germany were the most conspicuous exponents), with the clear objective of augmenting the efficiency of instruction and reducing its cost. It is easy, from our vantage point, to detect the effort made by society to obtain the manpower required by industry, paying the lowest possible price for the process.

One of the first successful exponents of this line of thought, the Scottish-born Andrew Bell, wrote in 1815 about the need to "diminish the labour, multiply the work, and perfect the manufacture ... of our schools" (as cited in Hamilton, 1989). A major contribution was to divide the students into classes of presumed "equal proficiency."

The person most influential in introducing these ideas (from their Prussian implementation) into the American school system was Horace Mann,who, in his seventh annual report to the Massachusetts Board of Education in 1843, wrote, "Among the nations in Europe, Prussia has long enjoyed the most distinguished reputation for the excellence of its schools" (as cited in Binder, 1970).[5]

What these efficiency experts did not consider when transferring industrial methods to the educational environment is that industry selects the raw materials used in its processes in order to guarantee the level of homogeneity necessary for the processes to be successful. Education cannot and should not try to proceed in the same fashion, because the educational system has a social obligation to provide education to everybody, without preconditions, without filters, and without rejections.

It did not take long for the first voices to be heard strongly opposing the mass production approach to education:

> In 1890 ... C. W. Eliot [president of Harvard] claimed that the "grouping together of children whose capacities are widely different" was not only "flying in the face of nature" but also the "worst feature of the American school." Returning to the same theme two years later, Eliot proposed a solution. To fulfill their democratic mission, schools should take the "utmost possible account of individual instruction"; should grade "according to capacity"; and should promote pupils not "by battalions," but by the most "irregular and individual way possible." (Hamilton, 1989, p. 132)

Nevertheless, the mass production system did not disappear. As Goodlad and Anderson (1987) wrote,

> many things not making much sense persist because they serve too many people too well. The graded system serves well recordkeepers, textbook publishers, administrators oriented to management, many parents and teachers, and others. The fact that it does not serve children and youth well is too often a secondary consideration.

In 1925 the National Society for the Study of Education had already devoted its 24th yearbook to the topic of "Adapting the Schools to Individual Differences." In that volume, William H. Kilpatrick, of Teachers College at Columbia University, analyzed the problems of "class teaching." He wrote,

> No one procedure would fit equally well all the children put into any one class. It was the old problem of institution and individual all over again. And, as always, the easiest solution was to hold to the institution and let the individual suffer. So we did.

A remarkably honest recognition!

Let us finish this section by noting an interesting (and painful) paradox. Although the change in education from individualization to mass production was the result of copying the methods that industry was applying so successfully, education has been unable to individualize "production" the way modern industry does. In today's automobile production line, a car or truck may be different from its predecessor and its successor, each one produced according to individual specifications. The same computerized technology that allowed for the reengineering of industry could and should be used to reengineer education.

Major 20th-Century Efforts in the United States

In the preceding section, we noted Eliot's criticisms of the educational system as early as 1890. By the turn of the century, the progressive movement in the United States, fighting for a truer democracy in America, was instrumental in supporting progressive education, with John Dewey as its most influential figure. As Cuban (1993) wrote, "a defensible tradition of student-centered instruction existed and was practiced in schools operated by Sheldon, Parker and Dewey and their followers throughout the late 19th and the early 20th centuries." Progressive education never achieved vast dissemination because, as Cuban comments, this "version of student-centered instruction was embodied in innovations tried in small, mostly private schools." The disappearance of the progressive movement can be seen as sealing the fate of progressive education, although many of its principles are still valid and permeate the educational style of the best examples of good education found today.

We have to move to the 1960s to find major reform movements, this time grounded not in political ideals but rather in educational research. We will distinguish three reform denominations, using the labels selected by their practitioners (*nongraded, adaptive,* and *multiage*), but we must say from the outset that there are many common elements in their educational conception. It is enough to quote Goodlad and Anderson (1987) on this point: "In fact, it is probable that the most valid examples of nongradedness in practice are to be found within multiaged (or multigraded), team-taught situations."

Nongraded Schools

The nongraded school was proposed by Goodlad and Anderson in their 1959 book called *The Nongraded Elementary School* as a reaction against the graded school, which they compared with a Procrustean bed. In their own words, "certain time-honored practices of pupil classification, while perhaps not lethal, trap school-age travelers in much the same way as Procrustes' bed trapped the unwary. These practices are concomitants of our graded system of school organization." A "brief operational definition" is presented by Anderson and Pavan (1993):

> In an authentically nongraded school program:
>
> 1. Individual differences in the pupil population are accepted and respected, and there is ample variability in instructional approaches to respond to varying needs.
>
> 2. Learning, which is the "work" of the child, is intended to be not only challenging but also pleasurable and rewarding.
>
> 3. Students are viewed as a whole; development in cognitive, physical, aesthetic, social, and emotional spheres is nurtured.
>
> 4. The administrative and organizational framework, for example with respect to pupil grouping practices, is flexible and provides opportunities for each child to interact with children, and adults, of varying personalities, backgrounds, abilities, interests and ages.
>
> 5. Students are enabled through flexible arrangements to progress at their own best pace and in appropriately varied ways. Instruction, learning opportunities, and movement within the curriculum are individualized to correspond with individual needs, interests and abilities.
>
> 6. Curricular areas are both integrated and separate. Instruction, programmatic, and organizational patterns are flexible, with outcomes rather than mere coverage of content as the primary focus.
>
> 7. The expected standards of performance (in terms of outcomes) in the core areas of the curriculum are clearly defined, so that the points to be reached by the end of the designated (e.g., a three- or four-year) period are

well known. However, the time taken to reach that end, and the path followed to that end, is allowed to vary for students with different histories and potentialities.

8. Within the curriculum and related assessment practices, specific content learning is generally subordinate to the understanding of major concepts and methods of inquiry, and the development of the skills of learning: inquiry, evaluation, interpretation, and application.

9. Student assessment is holistic, to correspond with the holistic view of learning.

10. Evaluation of the learner is continuous, comprehensive, and diagnostic. Except for reference purposes as necessary to parental and staff understanding, chronological age and grade norms play a much smaller role in evaluation and reporting activities than does the child's own growth history and potential.

11. While there are some core components of the curriculum that are especially valued (as reflected in performance standards in the major content areas) the system is largely teacher-managed and controlled. Thus, it empowers teachers to create learning opportunities and to use instructional strategies at their own discretion, based on the perceived needs of the students they are serving. Assessment procedures are similarly flexible, individualized, and teacher-managed.

As a declaration of principles, this list would receive almost unanimous approval, and we may gladly incorporate it into our proposal, except for one article, Number 7, which may have been influenced by a prior declaration: all men are created equal. There is an inherent contradiction in Article 7. In order to reach "expected standards of performance," "the time taken to reach that end ... is allowed to vary for [different] students," but the "designated (e.g.., three- or four-year) period" is the same for everybody. An unconscious or implicit or hoped for assumption of (near) equality of learning rates is behind this article, and, as discussed above, this assumption is false (cf. Gettinger, 1984a, 1984b).

The clear advantages of the nongraded school over the graded one, very well presented by Goodlad and Anderson (1987), gained adherents for the movement, and a nontrivial number of schools adopted these principles. The University of Pittsburgh's laboratory school was one such place, relying on an individualized curriculum developed at the Learning Research and Development Center as well as a computer-based management information system to track student needs. Another major implementation, known as IGE (Individually Guided Education), was developed at the University of Wisconsin and at the Institute for Development of Educational Activities (IDEA). But principles and implementation are two different fields of human endeavor: "Among the findings of one study ... was that, although about 60 percent of the schools in a sample of 900 could be called at best 'nominal adopters' of IGE, only about 20 percent could be called true implementers" (Goodlad & Anderson, 1987). Comparative research studies, and particularly those surveyed by Barbara Pavan, clearly favor nongradedness in the areas of academic achievement, mental health, and positive attitudes toward school. Furthermore, "longitudinal studies indicate that the longer students are in a nongraded program, the more likely is that they will have positive school attitudes and better academic achievement" (Goodlad & Anderson, 1987).

With such results, we would expect the movement to expand. However,

> current literature searches, such as one we conducted in 1985–1986, show a preponderance of studies in the late 1960s up to 1971, after which the term "nongraded" appears infrequently. The 1970s witnessed the beginning of a return to the traditional ways of thinking about schooling from which we had sought to depart. (Goodlad & Anderson, 1987)

To end up in a more optimistic vein, Willis (1991) described a renewed interest in nongraded programs in several states, particularly Kentucky and Oregon.

Adaptive Education

This is another case where we can identify the theory of a movement with the contents of a book, namely, *Adaptive Education: Individual Diversity and Learning,* by Robert Glaser (1977). The most important name related to implementation is that of Margaret C. Wang, who initiated her activities in this area with Glaser in the Learning Research and Development Center at the University of Pittsburgh and has continued at the Temple University Center for Research in Human Development and Education.

Glaser (1977) defines his objectives in the preface of his book:

> I have been particularly sensitive to extremes in recent writings on educational reform. At one extreme is vacuous generalization that precludes even the beginning of operational definition. The other extreme is an overly dogmatic, extremely literal presentation of rules and procedures for teachers. I have tried to strike a stance between these two—a combination between an understanding of general principles and specific practices.

As would be expected from a book written by "a psychologist concerned for many years with the relationships between psychological knowledge and educational practice," the book on one hand "discusses the psychological concepts underlying present-day school practices and contrasts these with newer trends in psychological knowledge and theory" and on the other hand "begins to operationalize the concepts of adaptive school environments and presents general principles for the design of flexible, learner-centered school programs," particularly "focusing on the elementary school." On a very concrete level, "a classroom organization and management system, a preschool program, and an elementary school reading and science program are discussed—all of which were developed for an adaptive environment."

For Glaser (1977), the goals of schooling are

> A. Self-centered
>
> 1. Attaining the cognitive and noncognitive skills necessary for occupational opportunities and economic independence.
>
> 2. Developing the capability to effectively manage one's own affairs.
>
> 3. The development of capabilities as a consumer of the cultural riches of civilization.
>
> 4. Development of capabilities for engaging in intense, concentrated involvement in an activity.
>
> B. Other-centered
>
> 1. To provide experience with persons differing in social class, culture, and age.
>
> 2. To develop the experience of having others dependent upon one's actions.

3. Involvement in interdependent activities directed toward collective goals for which the outcome depends upon coordinated efforts of everyone involved.

Our only comment is that we wholeheartedly agree with these goals, and our proposal will try to create an educational environment appropriate for their fulfillment.

Next, Glaser (1977) presents concrete stages through which education is adapted to each learner's needs. The first stage is the development of initial competence, in which (a) it is determined whether a learner possesses the abilities required to learn a task and (b) a remedial process is designed to develop those abilities that may be lacking. The second stage is the accommodation to different styles of learning; in this stage, alternate instructional paths are provided, and an adaptive interaction occurs when there is a match between an individual's abilities and the activities in which he or she engages.

In another dimension, there is the dichotomy between simple and complex attainment systems:

> In simple attainment systems, the educational goal is to teach the basic literacies to all students, as is the emphasis of elementary school. Complex attainment systems would be more predominant in higher education. In general, throughout the educational span, complex attainment systems encourage the development of different constellations of human abilities, and award equally recognized credentials for many different ways of succeeding and attaining different outcomes in the educational system. (Glaser, 1977)

To parallel the "brief operational definition" of the previous section, we present a list of Resnick's (1972) principles, as summarized by Glaser:

> 1. The human and material resources of the school are flexibly employed to assist in the adaptive process.
> 2. Curricula are designed to provide realistic sequencing and multiple options for learning.
> 3. Open display and access to information and instructional materials are provided.
> 4. Testing and monitoring procedures are designed to provide information for decision making to teachers and students.
> 5. Emphasis is placed upon developing abilities in children that assist them in guiding their own learning.
> 6. The role of teachers and other school personnel emphasizes the guidance of individual students. (Glaser, 1977)

The goals, adaptive methods, and operational principles are all excellent. Nevertheless, an even smaller minority of schools than label themselves *nongraded* will label themselves *adaptive.*

The Multiage Classroom

The multiage classroom has been with us for all of the history of the United States in that wonderful institution called the one-room schoolhouse, popularized by the television series *Little House on the Prairie.* We start with this example to emphasize that it was perfectly natural to have a mix of students of all possible ages, each one studying according to his or her needs and capabilities. When the factory model of school was introduced for economic reasons (and a short term vision of economics), the small rural school survived the onslaught, not because of its virtues, but precisely again for economic reasons: It was not practical to form grades with such a small number of students in each.

Today, when we speak about multiage education we are talking about the introduction in conventional schools of classes with an age span of about 3 years, usually in elementary schools and particularly in the lower grades.

> The multiage concept is undergoing a resurgence in popularity in the 1990s. All over the United States schools are restructuring to multiage programs. Some states, like Kentucky and Oregon, have mandated multiage programs for their primary classrooms. Others, like Maine, have strongly supported movement toward multiage education through innovative grants and state workshops. (Chase & Doan, 1994)

But, as we mentioned in the section about nongraded schools, it is very hard to isolate the multiage concept from the global change a school experiences. Chase and Doan (1994) made the following observations.

> The developmental philosophy encourages educators to address individual differences in children. As teachers recognize individual differences, they realize that there is no graded curriculum appropriate for all students of a particular age. In a multiage classroom children of differing ages work together, with each child participating to the best of his or her abilities. Since children remain in multiage classes for more than one year, their growth and learning is individually paced.
>
> Multiage classrooms also provide a natural extension to the whole language approach to literacy and the problem solving approach to math. These movements encourage student use of literacy and math for real purposes.
>
> In a multiage classroom each child works at his or her own pace without the fear of competition or retention.
>
> Co-teaching offers us the opportunity the share the workload, building on each other's strengths.

For these practitioners, multiage education includes nongrading, adaptive education, cooperative learning, real-life projects, and team teaching. It is not surprising, then, that the research results, very well compiled by Diane E. McClellan in chapter 12 of Chase and Doan (1994), match essentially those found by Pavan and quoted in the section on nongrading. McClellan provides additional insight, from several sources, related specifically to the multiage aspect:

> (1) Children in their natural activities (outside school) can be found usually in multiage groups, and much less frequently in same-age groups.
> (2) What is learned socially in multiage groups differs from that learned in same-age groups.... Each may meet a variety of different needs and contribute to the development of different social capacities.
> (3) Children's exposure to others younger than themselves ... elicits greater rates of prosocial behaviors.... Prosocial behaviors include helping, sharing, cooperating, and caring for or taking responsibility for another.
> (4) Knight and Kagan ... found that children's behaviors (in conventional schools) increased in rivalry and decreased in altruism and cooperation as

they progressed through elementary school.

(5) Mixed-age groups may provide the child with a rich and complex social environment that contributes to greater social facility, as well as to greater cognitive facility.

(6) Empirical findings support the supposition that children's opportunities to interact with more advanced and less advanced peers strengthens their cognitive skills.

As with the two reform movements previously analyzed, we subscribe to the principles of multiage grouping without reservations.

Statewide Reforms

Important steps towards a wider implementation of the reform principles were the statewide decisions adopted in Kentucky (Kentucky Educational Reform Act) and Oregon (Oregon Educational Act for the 21st Century).

Success of this implementations requires an important investment in planning, teacher training, curriculum change, development of authentic assessment procedures, and fostering an attitude change in students, teachers, educational administrators, and parents. It is too early to have statistical data proving significant achievement improvements brought about by these reforms.

The Low Rate of Success in Adapting to Student Differences

The educational system can move from such an unnatural and inhuman structure as the graded system to one the may benefit from all the insights of nongrading, adaptiveness, and multiage grouping, but we find that (a) only a very low percentage of schools adopt the change and (b) the results in those that actually take the reform path are not dramatically better than those found in conventional schools. This is why, in spite of the positive results the reformers present (with a justified sense of accomplishment), we consider that from a systemic point the experience was not successful. The results were not convincing enough to be applied nationwide, and this in a situation where everybody is looking for solutions to the pressing problems of the educational system.

As Pressey (1959) wisely said,

> It is not enough that in the experimental situation the proposed new methods work well. They must do so in the average situation where they are to be used and with average people there; and they must there be sufficiently better than the methods and materials these same people have been using, that a changeover is both warranted and feasible.

Were the results "sufficiently better"?

A major effort to integrate the results of the many individual evaluations about the reform methods we have described (reasonably gathered under the unique label of *nongradedness*) was published by Gutierrez and Slavin (1992). The central finding of that article, to quote from its abstract, was:

> Results indicated consistent positive achievement effects of simple forms of nongrading generally developed early: cross-grade grouping for one subject (median *ES* = +.46) and cross-grade grouping for many subjects (median *ES* = +.34). Forms of nongrading making extensive use of individualization were less consistently successful (median *ES* = +.02).

The effect size, or *ES,* is obtained by comparing the results of an experimental group (applying the new methods) with those of a control group (applying the conventional methods). The comparison is done over the same subject (reading, arithmetic, or language arts), usually at fixed points in time (after 1, 2, or 3 years of instruction). In this case, the effect size for a given subject is defined as the difference between the mean achievement levels of the students in the nongraded and graded programs, divided by the achievement level standard deviation of the students in the graded program.

For this comparison to be meaningful, either both student populations are similar, or a pretest has to be conducted before the beginning of the programs, and the achievement values adjusted according to the pretest values.

Gutierrez and Slavin (1992) wrote,

> This review synthesizes the findings of research comparing the achievement effects of nongraded and traditional organizations in the elementary grades (K–6). The review method used is best-evidence synthesis, ... which combines elements of meta-analysis ... with those of narrative reviews.... Every effort was made to obtain every study ever reported that met the broad substantive inclusion described below.

It worries us that "most of the studies located were doctoral dissertations." We would have preferred larger-scale studies conducted by established researchers. Nevertheless, this best-evidence synthesis is the most reliable source we can use for our analysis.

What do we learn from this review?

(1) The results favor the nongraded programs, but not dramatically. In another dimension of measurement, in 20 cases the nongraded programs performed better, but in 3 cases the graded programs performed better.

(2) When the complexity of the nongraded program increased, the results decreased. When multiple subjects were studied, or when individualized instruction methods were used, the results obtained with the nongraded programs were essentially equivalent to those obtained in the conventional school.

(3) Although the raison d'etre of nongraded programs is to free students from the Procrustean standards imposed by the grades, in reality this aspect did not change. Gutierrez and Slavin (1992) wrote,

> Surprisingly, only one study actually assessed the degree to which nongraded students took nonnormative amounts of time to complete the primary or elementary grades. This was a study ... which compared students in graded and nongraded primary programs in eight New York State school districts.... In 1964–1965, an average of 4.4% of students took an extra year to complete the primary grades in the nongraded schools; 4.6% took an extra year in the graded ones. In 1965–1966, 2.9% of nongraded students took an extra year, while 7.3% of graded students were retained. No students were accelerated in either type of program in 1964–1965, and 1/10 of one percent were accelerated in the nongraded schools in 1965–1966.

Very clearly, the promise did not materialize.

The Reasons for the Low Rate of Success

We claim that the main reason for the low rate of success is that the teachers, on whose shoulders (and heads) success is based, were assigned a mission impossible. The complexity of the task they had to confront in order to fully implement nongraded programs or individualized instruction was above their real possibilities. With the technology of the 1960s and 1970s it was impossible for a teacher to follow up on students each of whom had a different curriculum and a different trajectory in the universe of knowledge, to assign to each one a learning task compatible with his or her previous trajectory, to help in the knowledge development process, and to individually assess each student for diagnostic and adaptation purposes. The reform movements, which (justly) criticized graded schools for assigning impossible tasks to students (particularly the low achievers), tried to solve this problem by assigning impossible tasks to teachers.

We will corroborate this assertion by referring to three of the sources already quoted, Gutierrez and Slavin (1992), Goodlad and Anderson (1987), and Anderson and Pavan (1993).

Gutierrez and Slavin (1992) showed that if the complexity of the change is small (like introducing the new methods in one subject only), then the teachers succeed, and the results are better in a statistically significant form. If the complexity increases, although the methodological changes are conceptually the same, teachers cannot cope with it, and there is no progress.

Goodlad and Anderson (1987) wrote,

> The general absence of precise operational definitions of nongradedness, and especially the failure of both practitioners and researchers to employ them, prompted Barbara Nelson Pavan to develop a comprehensive ideal model in terms of assumptions and behavioral implications.... She derived 36 statements of principles divided into six categories.... This list of statements was then distributed.... The statements represented an excellent and authentic overview.

These principles are reproduced in their book, as well as in Anderson and Pavan (1993). In the latter, we find a report on the answers of teachers in nongraded schools to questionnaires asking for their agreement or disagreement with this set of principles of nongradedness. To quote again,

> Hoffman ... reported that her respondents were in greatest agreement with the following assumptions:
> GOALS OF SCHOOLING
> 2. To maximize individual potential
> 3. Individuals' uniqueness
> 6. Positive learning environments
> INSTRUCTION
> 20. Teacher as a facilitator of learning
> MATERIALS
> 25. Variety of learning materials
> 26. Range of reading levels
> 30. Students working at an appropriate level
> On the other hand, there was the least agreement with these items:
> ORGANIZATION
> 8. Change of child's placement at any time

CURRICULUM
13. Goals set by student with teacher
14. Individual curriculum
16. No predetermined sequence
18. Based on individual interest
INSTRUCTION
24. Improve, not compete
ASSESSMENT
33. Student involvement
36. Portfolio, not grades

It is immediately clear that teachers agree with the high level principles, but strongly disagree with all their practical (and natural) implications which are expressed as an increase in their workload.

We are not attacking the designers; their ideas were excellent, and we think that the educational systems should adopt most of them. What we claim is that their practical implementation was not possible in Pressey's (1959) terms, that is, "in the average situation where they are to be used and with average people there."

We are not attacking the teachers either. As we said, they were assigned an impossible task, in the situation and with the materials at their disposal.

What we do claim is that now the technology is ready to build an infrastructure that will make the teacher's task feasible, and that the progress in educational research has provided us with additional insights required to design environments in which the reform movement's ideals can be realized.

A last point. It is possible to explain the lack of extended popularity of these reforms at the two other levels that count. The educational authorities never saw really convincing results that would justify the budget increases that are always asked in order to implement a reform, and the parents never saw great benefits, because the nongradedness never took their children out of the Procrustean bed.

The Proposal

Mapping the Traditional Linear Curriculum Onto a Project Space

Consistent with current thinking in the educational community, we propose that more of students' learning time be spent in work on substantial learning projects. At least three of the viewpoints on learning we mentioned—constructivism, situated learning, and cognitive apprenticeship—agree on the importance of learning through substantial student projects, as opposed to classical teacher presentation. While these three positions differ in their explanations of how learning happens, they concur in the need for project-based learning. Still, there is no complete definition of what a project is, so we need to consider carefully what we mean by project-based education. In general, some or all of the following characteristics appear in the specifications of learning projects:

- A relatively complex task is posed for the student(s).
- Accomplishing the task requires, and hence fosters the development of, proficiency in different knowledge areas from several disciplines.
- Students often work on projects in teams of two or more.
- A (relatively) long time is allotted for completion; the time varies, according to task difficulty and student maturity, from several days in the lower grades to several weeks or even months in the upper grades.

- Each student is responsible for clearly defined parts of the task, but all the students discuss the work and progress of each task component.
- Project execution may require interaction with external resources or individuals, outside the class (or even school) environment.
- The project is evaluated in terms of its results (reports, laboratory notebooks, artwork, instruments, exhibits, services).[6]
- The evaluation of each student's activity within the project is incorporated into his or her personal record.[7]

Projects provide natural challenges to students and a feeling of real accomplishment when the tasks are performed. They constitute a reasonable model of the type of activities students encounter outside school, as opposed to the scenario we find in the expository model of a conventional classroom. Projects permit the replacement of *talking* about thinking with opportunities for *doing* hard thinking. In addition, they permit a more direct assessment of a student's readiness to perform real cognitive work, as opposed to schoolwork, thus overcoming the old problem of "inert knowledge."

Although project-based education is gaining support (see Bolt, Beranek and Newman, Inc., 1994), the majority of teachers are not practicing this method in their classes, at least not regularly. Routinely, high school students get perhaps one major project assignment each semester in each class, but the day-to-day work is traditional. This is not because teachers reject the basic idea but rather because there is minimal supporting infrastructure in schools for project work. The day, as well as the curriculum, is excessively fragmented for each student and teacher, which makes it difficult for a team project to be supported. In contrast, in conventional education, the coverage of material in classroom presentations is supported by a rich infrastructure of textbooks, complementary materials, and conventions about responsibilities and schedules, and teachers are judged in terms of their presentation of a curriculum defined in terms of scopes and sequences, and not in terms of projects. Furthermore, teachers were trained for and by means of conventional teaching.[8]

Developing an infrastructure for projects that may compete with conventional textbooks is not a task that can be assigned to individual teachers. What is required is the initial development of a large collection of projects that can be mapped, in terms of cognitive achievement, over the existing curricular strands (see Lesgold, 1988). In this way, the performance of a project can be recognized as the satisfaction of the requirements for certain segments in an overall set of schooling standards, whether the conventional scope-and-sequence structure of one or more subjects or a new set of outcome standards. With the mapping of student achievement as well as project learning goals onto a common space, a teacher gains the ability to select which parts of the curriculum to teach using a project-based approach, and which parts using other methods of instruction.

Project development, as we see it, will require

- the definition of the task to be accomplished.
- the characterization of the prerequisites required from the participating students—probably in a two-tier structure: (a) cognitive or skill demands all of the participants must satisfy and (b) cognitive or skill demands at least one member of the group must satisfy.[9]
- the development, production, and distribution of any resources required for

the project which are not readily available to individual schools.

- a list of the resources that the project requires and that may be obtained at or by the school.
- an estimate of the time required for project completion (in student-hours).

Teachers and their students may define their own projects to be included in the school library of projects; however, for a curriculum to have an important project-based component, the development of the infrastructure we propose is critical.This point is essential to our proposal and is presented first, because the possibilities for individual student progress, which is one of our main concerns, are very limited within the framework of conventional education. We will show the importance of projects in freeing students' progress. Of course, project-based education will require teacher training and follow-up support.

Defining a Required Common Curriculum and Supporting Additional Student Choices

We do not undertake to specify what students should learn. That is a major task for educational researchers, the public, and the political process. For example, the largest of the current standards-setting efforts, the New Standards Project, is a consortium of two major research centers (the Learning Research and Development Center and the National Center on Education and the Economy),17 states, and six urban school districts. Funding comes from the states, the school districts, the federal government, and a number of foundations. Such a broad approach, with differences in standards for different communities, is a political necessity and perhaps also adaptive to local needs.

However, regardless of where the standards, and hence the goals and curriculum, come from, our purpose of fully individually adaptive education will require certain special considerations. The standards efforts will establish outcome goals for schooling. From these goals, a curriculum can be defined. A curriculum is a roadmap of the path to attainment of educational goals. Historically, these roadmaps were organized and structured according to the perceived structure of the discipline, as in the case of mathematics, for example, where a strong split was originally made into different areas of mathematics, such as geometry and algebra.

Unfortunately, the order in which topics of a discipline are listed in a taxonomy is not necessarily the best or only order in which those topics might be mastered. Indeed, some outcome goals might be satisfied by any of several alternative sets of subject-matter competences. The curriculum that we have in mind would be fully aware of alternatives for meeting the various standards. For example, suppose there were a standard that a student should be able to write an expository report of 25 pages on a major issue in current international affairs and should also be able to write a one-page executive summary of the paper and prepare visual aids for a 10-minute briefing on the topic. One student might develop all of this capability in a journalism class, while another might develop it in a social studies class. A third student might practice writing papers in English class but acquire the summarizing and presentation graphics skills as part of a summer apprenticeship in an advertising agency. The specification of curriculum, the roadmap for schooling, must be organized to permit such variability. This means that it must be a process, not a list.

The process we have in mind is one of noting students' current competences and then developing alternative clustering schemes in which to-be-acquired competences are covered by various combinations of long-term learning tasks. The range of ways in which the curriculum can be organized for a given student will be a function of the kinds of learning opportunities available. To a large extent, the clustering will be informed more by past cases—success stories of learning tasks that produced particular competences in the students who attempted them.

Developing a Software-Courseware Infrastructure

Educational Administration Software

As suggested above in our discussion of curriculum, it is impossible for a teacher to remember the present status of the cognitive map of each student, and thus to make reasonable decisions based on it, when each student is following a different trajectory in the universe of knowledge. Fortunately, present computer technology provides us with the tools to track student status and to make this information accessible to teachers.

It is within the state-of-the-art to develop a computer program in which all the requirements of the common curriculum will be registered as nodes of a complex structure and in which each student will have a personal copy of this curriculum, annotated with his or her performance on each node of the structure. The mastery accomplishments may be registered in different ways:

- automatically, when a student is working in supervised mode on library courseware;
- as a result of the teacher reporting completion of a project (the computer system will automatically translate project mastery into mastery of all the nodes covered by the project or will provide a rubric that permits the teacher to analyze student products with respect to specific learning goals);
- as a result of a teacher's direct annotation over a curriculum structure;
- as a result of school testing; and
- in recognition of externally-accredited knowledge.

Based on these data the computer program may answer specific teacher queries, such as the following:

- Who are the students satisfying the prerequisites for project *X*?
- Which are the projects that student *Y* is ready to tackle?
- Which are the topics more appropriate as a next stage for student *Z*?
- What are the topics I should teach to students *V, W, X, Y,* and *Z* if I want them to tackle project *A*?

Using this information, and interacting with the students, the teacher will be, for the first time, in a privileged position to assume responsibility for educational decisions. It is a debt long overdue that we owe our teachers.

Pedagogical-Instructional Courseware Support

We will expand in a later section on the necessity of providing a variety of instructional resources, trying to optimize the matching with each student's learning style. Of these resources, those which are computer-based are particularly important, in that they may allow for downloading part of the instructional teaching load to the computer.

For a general coverage of this topic, see Venezky and Osin (1991). For artificial intelligence–based applications, see Lesgold (1988). Here it will suffice to say that we distinguish between two modes of student-computer interaction: supervised and unsupervised.

In supervised mode, the computer program which manages the interaction includes a knowledge model, a student model, and a pedagogical model. The student model may be divided into three layers:

(1) the relatively fixed psychological parameters relevant to the instructional process;
(2) the cognitive map described in the previous section; and
(3) the short-term information related to the achievements and problems encountered in the interaction within the specific instructional unit being studied.

Based on these data, the pedagogical model will adopt instructional decisions whose objective is to optimize (as well as we know how) the learning process.

The experimental data on student progress when well conceived courseware is used are very encouraging (Becker, 1992, 1994; Osin, 1984). For example, Osin, Nesher, and Ram (1994) showed that the groups which benefit more from computer-assisted instruction are the extremes of the class distribution, that is, the high achievers and the low achievers. These results exemplify how the computer can supplement the teacher activities, in the areas more difficult for him or her to reach.

Learning time, a very valuable resource, may be optimized as shown by Lesgold (1994b; Gott et al., in press). Trainees in an electronics fault diagnosis training program acquired the equivalent of about 4 years of on-the-job experience from a 20- to 25-hour interaction with an intelligent learning-by-doing computer environment.

In unsupervised mode there are no models, either student or pedagogical. The computer is a resource in the student's hand. Nevertheless, this mode is equally valuable, because the computer is the tool of the information era, and mastering its utilization is a fundamental component of education for the future. Furthermore, there are many simulations, microworlds, and exploratory tools, designed in unsupervised mode, of high educational value. A well designed educational administration package will include the facilities for providing advice to any student on which of these educational computer programs match more closely his or her cognitive profile, within a certain area of knowledge, using the data stored in the student record (Osin, 1992).

Allowing for Dynamic Student Grouping

Conventional schools group students of the same age for fixed periods of time. There is no educational reason that can justify this approach. The diversity of individual learning rates, discussed above, shows that it is absurd to expect all students in a same-age cohort to learn the same content in the same amount of time.

Trying to solve this problem by what is called *ability grouping*—that is, separating high achievers from low achievers—is pedagogically and socially unsound. These labels are assigned on the basis of data that are sensitive to maturity, transitory motivation, and teacher quality. Ability grouping tends to perpetuate these labels as self-fulfilling prophecies, by providing the so-called low achievers a low-level educational environment that will inhibit their real possibilities of intellectual growth. We propose to group the students dynamically, according to the similarity of coverage of the curriculum, as reflected in their individual cognitive maps, irrespective of age and learning rates.

Flexible Classes

We start with an organization that keeps many of the formal aspects of the present school structure, while avoiding present pitfalls. Possible alternatives will be presented in a later section.

A class consists of a group of students who are ready to pursue most of the learning goals for a particular grade, under the guidance of a teacher. Classes would not be age constrained. A student would enter a class when he or she is cognitively ready for it—that is, when allowed to enter a first-grade class (more or less determined by age) or when he or she has learned the previous grade curriculum, as shown by the personal record. A student would leave (graduate from) a class upon completion of the curriculum requirements for the corresponding grade. Satisfaction of the curriculum requirements does not necessarily imply mastery of every topic in the curriculum. This is done to take into consideration that a student may have different aptitudes, and different learning rates, in diverse areas of knowledge, so that it would be too rigid to expect a lockstep progress in all the curriculum areas. Criteria will be established to determine the most convenient moment or circumstance to move a student from one grade to the next. Although the teacher, supported by the educational administration software, would try to keep a relative balance, avoiding the concentration of a student in the study of one specific area to the detriment of the others, the system would allow for a student to pass a grade with debts in certain subjects that would need to be learned in the next class. This means that a teacher responsible for a grade must master the curriculum of at least the adjacent grades also. This is important not only because of our expectations in terms of teacher knowledge, but also because changing grades should be done, for administrative and instructional reasons, at the end of a session (e.g., trimester or semester); a student who has satisfied the requirements of a grade before the end of the period should be able to continue progressing in his or her educational process, in the class where he or she is, until the end of the given period.

Another element worth mentioning is that the emphasis is not on complete encyclopedic knowledge, so that the curriculum requirements for a grade may very well allow for some flexibility of learning goals for different students.

The net result of this approach is that every student has the right to remain in a class for as many sessions as it takes him or her to satisfy the curriculum requirements, and also the right to progress to the next grade as soon as he or she has satisfied them. The immediate consequence is that, particularly as we advance in grades, the age range within a class will increase. There is nothing wrong with this, but it may take a while for society to get accustomed to it. We think that multiage grouping is a better model of the real world, where people are not segregated according to age. Having to get used to it is a small price to pay if it solves a major problem of the educational system. Strong arguments in its favor were presented earlier in the section entitled "The Multiage Classroom."

With our proposed organization, testing of seventh graders, for instance, would not show a performance distribution ranging from second grade to eleventh grade (Tyler, 1962), but rather a relatively homogeneous population of precisely seventh graders. It is this cognitive coherence in class which allows for efficient use of time and resources, transforming the learning process into a fruitful experience for every student.

None of the problems of ability grouping are present in this structure. The educational system offers to all students the same enriching environment. The average and below-average students will have the activity of the brighter students as a model, and, furthermore, by doing cooperative learning where they can also contribute their part, they will not have a feeling of rejection or isolation.

A practical problem that this "conservative" approach to reform helps to address is that many teachers do not master the curriculum of all the grades in equal form. There is enough change regarding teachers when we ask them to switch to project-based education and to individual monitoring of student learning, so that we feel that keeping them working with the curricular materials in a grade they are familiar with may help in the adaptation process.

Variable Groups

A variety of instructional activities will be available within a class: project-based education, cooperative learning, computer-assisted instruction, audiovisual resources, didactic presentations (expository presentations, demonstrations, discussions), individual tutoring, self-study, laboratory experiments, and assessment activities. Focusing now on the grouping strategy to be used in defining a project team or a cooperative learning group, we suggest the following heuristics:

- heterogeneity of intellectual capabilities,
- varying partners from project to project (at least partially),
- matching of student aptitudes to task requirements, and
- striving for a good working relationship within the group.

In a different dimension, we must consider the number of learning tasks to be assigned to a student. This is the parameter that distinguishes between fast and slow learners, and it constitutes an important distinction with conventional schooling. In conventional methods all students are assigned the same tasks, and what distinguishes between them is the quality of their learning. Our proposal expects all the students to reach mastery in each and every one of the learning tasks they are assigned. The way to give expression to different intellectual capabilities is to allow for a difference in the number of topics a student may be learning simultaneously. Thus, a very fast learner may be participating in three projects, two cooperative learning groups, and a computer-assisted instructional activity, while a slow learner may be participating in one project, one cooperative learning group, and an individual tutorial activity. This is how a fast learner may finish a grade in much less time than a slow learner, even though both students interact and study together in a socially convivial environment.

A critical element that permits this differential progress is the mapping of the linear curriculum onto projects; it is possible to work on different projects simultaneously, while in the present linear structure every student is forced to progress step by step over a rigid sequence. In other words, we can preserve learning as a social activity and allow for a different learning rate, because the projects are not sequentially ordered. On the other hand, the classical scope-and-sequence structure forces a rigid order that has to be followed step by step, and we cannot expect all of a group of students to reach mastery of every step at exactly the same time. This may be one reason why students in nongraded or adaptive schools still exhibit a rate of progress which is very much in lockstep with their age cohorts.

Inter-Class Activities

Although the class is the center for the student's cognitive development, the school as a whole serves as an environment in which social, emotional, and physical development takes place. The school should organize activities in which different kinds of groupings take place, crossing class boundaries. Social activities will tend to group students by age, sport activities will tend to group students according to physical or skill development, and artistic activities will tend to group students by temperament or special abilities.

Additional Possibilities

According to school preferences, it is possible to define multigrade classes and use a team teaching approach. There may be a disadvantage of additional complexity, and an advantage of less frequent class changes for fast learners.

The Accreditation of Externally Acquired Knowledge

One of the most irritating aspects of conventional schools is the waste of time suffered by the students who already know the topic being taught by the teacher. The recognition of the fact that students may actually come to school with knowledge of their own will significantly increase the efficiency of the educational system, and will help assure that all children are challenged in school. Students should be able to satisfy curriculum requirements by presenting a portfolio and/or taking an examination. In addition, a school should recognize instructional credits (records of standards mastery) and register them in a student's personal record when the corresponding mastery is accredited by a state-recognized educational institution.

Allowing Each Student the Time Required to Learn Each Task or Topic

Probably the major source of student failure in the present educational system is incomplete learning. As mentioned earlier, the learning curve has three phases: (a) an initial zone of very slow growth, in which initial understanding and skill are developed; (b) an intermediate zone of very fast cognitive growth; and (c) a final zone of asymptotic—almost flat—approach to practiced perfection. This final zone is the *overlearning* zone. In a conventional class the teacher will assign each topic a certain amount of time, defined by his or her experience and by the division of the required curriculum over the available school days. Minor deviations may occur, but when the teacher declares that instruction is finished and a new topic is about to start, the situation of the different learners is as follows. The fast learners are in the final zone, and their overlearning will ensure a high rate of retention. The average learners are at the end of the intermediate zone or in the beginning of the final zone, and most of them will remember, though some will forget. The slow learners are in the initial zone or in the beginning of the intermediate zone; they will forget the little they learned. The lack of internalization of the slow learners is an accumulative problem. Not knowing the prerequisites precludes the comprehension of following topics, and a student may spend years of frustration in school without any real learning taking place.

The most important social aspect of our proposal is to fight this syndrome. All students should be given the right to fully understand and internalize the topics they have to learn, and this is translated into the need to allow them the time needed for this processes to take place. There is also the other extreme. Once a fast learner has mastered and internalized a certain topic, he or she should be allowed to progress in the educational process without being forced to wait for students characterized by a completely different learning rate.

There is another dimension, of pedagogical importance, that should be mentioned in this context. For a fast learner, participating in a project may be enough to learn a topic. To reach the same mastery level, a slow learner may require additional cooperative learning, tutorial guidance, or additional practice in supplementary projects.

School Organization

In order to allow for a certain separation of ages in educational institutions, while at the same time allowing for the crossing of grades irrespectively of age, we propose the creation of two school levels prior to university studies: (a) primary school, providing education in Grades K–8, and (b) secondary school, providing education in Grades 6–12. The overlap between the two levels allows for the adjustment of the transfer from primary to secondary school, taking age into consideration. The following cases may exemplify the idea.

(1) An average learner may finish seventh grade at age 13 and start the eighth grade in secondary school. Alternatively, if he is of small build, for instance, he may prefer to stay another year in primary school.
(2) A fast learner may finish eighth grade at age 12 and start secondary school in the ninth grade, where she will be 13 years old.
(3) A slow learner may finish fifth grade at age 13 and start secondary in the sixth grade.

In each case, each school level will have a population with a normal (gaussian) distribution of ages, so that everybody will be able to maintain social contacts appropriate for his or her age.

The Implications

Educational Implications

Clear Benefits for High and Low Achievers

The present educational system is built on the assumption that all the students that belong to the same age cohort have a similar intellectual development, and thus all curricula, materials, and teaching practices are tailored for the "average" student. Our proposal, by recognizing the existence of large individual differences within the same age cohort, provides equally tailored education to all the levels of the cognitive spectrum. It is clear that the main beneficiaries will be precisely those that received the poorest service from the conventional system. In a conventional school, the farther a student is from the "ideal" average student, the more his or her educational needs are ignored. This is why low and high achievers will be the major beneficiaries of our proposal. Low achievers will be spared failure, while high achievers will have the possibilities for fully developing their intellectual potential.[10] In addition, it is our educated guess that by changing drastically the present school climate, by creating an atmosphere of challenge and intellectual activity, the "average" students will benefit also, and the baseline of educational achievement will be raised at all levels.

An Improved Model of Social Interaction

The scenario in which a teacher in front of a class distributes knowledge to rows of learners not only is false but is a very bad model for the real-life situations the students will encounter. By creating their own knowledge, and by cooperating to do so, the students will get used to the environments found in productive activities, and will develop, by practicing it, the cognitive style required in a modern society. Furthermore, by integrating the students in groups of diverse intellectual capabilities, and various ages, we are again providing a better model for their adult life. Last but not least, the fact that this integration is done with students who are all mature and able to tackle the tasks assigned allows the students with lower intellectual capabilities to feel productive also, and reassert themselves, while providing the high achievers with concrete examples that students at a lower intellectual level than their own may, nevertheless, be partners in fulfilling a task or creating a product.

The Need for a Coordinated National Effort

Although our proposal may be implemented at a regional scale, the real benefits, and the utmost efficiency (in investment terms), would be obtained in a statewide or even nationwide sharing of many implementation chores. For instance, a rich database of instructional resources (including newly defined projects), carefully indexed in terms of conventional topics, although a relatively large investment, would result in a very low per capita cost if amortized over a very large student population. These savings can be achieved whether or not the entire population is expected to meet the same standards (i.e., different states with different standards might still benefit from common development of the needed information bases for adaptive education).

For example, if 1,200 projects were to be developed for a national database (and this would provide an average of 100 projects to select from for every school year), with an estimated cost of $50,000 per project, this would be an investment of $60 million. For an estimated student population in the United States of 50 million students, who could use these projects during a minimum of 3 years, we would have a cost of 40 cents per student-year.

Another dimension where the national implementation would be very important is that of the transferability of educational credits. A student learning at the fourth grade level, irrespective of age, should be able to move to another school, maybe in another state, and continue to be in the fourth grade. Ideally, if all schools were working according to our proposal, the transition would be very smooth, because the student would continue to learn enjoying the same instructional methods and the same type of educational environment.

Changes in the Teaching Profession

The requirements to be a teacher in the more open and creative educational system we propose are different from those implicitly defined by the conventional system. Nevertheless, we believe that a majority of present teachers are intellectually able to perform the change, if appropriate training and support are provided. During a transition period, some teachers will require the advice and maybe the help of teachers with higher qualifications. In some cases, schools may decide to form classes with higher numbers of students and assign two teachers to each such class in order to distribute the instructional load in a way compatible with the preparation of the existing teachers.

In the long term, this more challenging type of teaching will attract highly intellectually endowed individuals, in larger quantities, to exercise this profession. A hierarchy of levels and special tasks will be created, as more experience is developed and a variety of requirements is discovered.

Special Education

While we expect our proposal to make education more efficient and effective, there may well remain situations in which students need special resources. Currently, the process whereby students are designated for special education has clear weaknesses. It depends upon legal requirements that map poorly onto our knowledge of learning. However, many issues in special education are being rethought, and we would surely want our approach to be compatible with emerging approaches to special education.

As a check on the adaptability of our proposal, we consider how it might handle an emerging approach to special education, namely, curriculum-based measurement (see Fuchs & Fuchs, 1995). Such approaches look at student progress under a variety of conditions to see whether that progress is so low as to justify providing special resources beyond those normally available. In the system we envision, some specialization would happen automatically, simply by matching students to tasks for which they are ready. However, one could imagine situations in which access to more labor-intensive instructional formats might depend not upon absolute level of learning achievement to date but rather on rate of progress. A simple example is self-management training, which might be made available, independently of current curriculum level attained, to a student who fails to show much learning over time altogether. Another example would be to provide access to alternate sources of information for students with specific dyslexias.

To see how our approach can handle this kind of need, we compare it to the approach put forward by Fuchs and Fuchs (1995) for traditional schooling arrangements. Their approach involves three phases of decision making. First, the question is whether the child's rate of learning matches that of peers. If not, then a second question is addressed: whether regular education can be "strengthened" sufficiently to permit an adequate rate of learning. If not, then, finally, a check is made to assess whether alternative special education is leading to an improved learning rate. Fuchs and Fuchs suggest that each of these phases requires a tracking of the competence of the student over time. The appropriate competence measure will depend on the particular area of learning, but each of the three questions posed in the decision process just mentioned is a question about rate of improvement in knowledge or competence.

Of course, our proposal would replace the first phase with an automatic calibration of learning opportunities to the student's current level. From that standpoint, the question posed would be a stronger one: Is the student able to make reasonable progress when provided with learning opportunities appropriate to his or her current level of knowledge? It is in the next phases that the situation becomes more complex. For Fuchs and Fuchs, "strengthening" a curriculum involves adding such additional opportunities as specific self-management training. This, again, would come from a finding of inadequate learning progress. The system we propose would provide the basic rate information without any difficulty, so long as there is a reasonable ordering of learning goals for which it monitors. With such an ordering, information about what a student knows can be supplemented by first-derivative (rate of acquisition) information, which is needed for the Fuchs assessment scheme. Further, the recordkeeping that is possible with an individualized learning approach can include qualitative information that might better inform the choice of interventions. For example, by automatically tracking the amount of time spent in various learning tasks and recording the actual outcomes of those tasks, a good recordkeeping system can help distinguish between situations in which focusing attention or persisting in effort is the problem and other situations in which specific cognitive deficits, such as phonological awareness or phonological representation capability, might be more likely candidates.

University Adjustments

The success of our proposal would imply two changes from a university standpoint. First, the incoming student population would have a much lower dispersion in their cognitive capabilities, because these students would arrive at the university after having mastered the high school curriculum requirements, instead of just after having finished high school, as it is today. The universities will be very grateful for not having to provide all the "buffer courses" they provide today, in order to bring many entering students to the level where they can understand what is being taught in the real university courses. The length of baccalaureate education would likely also shrink to more like the 3 years common in Europe, since American colleges spend up to 2 years covering content that European students receive in college-bound secondary schools, such as the German gymnasia.

Second, the age range for incoming students would be much higher than today. This may require some changes, particularly in dormitory organization, but we think these changes will be minor. In particular, several universities (e.g., Johns Hopkins, Northwestern, and Bard College) are already receiving very young students (sometimes only those who live nearby with parents), with remarkable success. A summer program conducted for "gifted" children by Johns Hopkins

University easily manages to maintain courses for students 11 to 17 years of age, on campuses where adult students are also pursuing summer courses.[11] No problems of consequence have occurred.

Social Implications

Educational Gains for Low-SES Groups

Although we have claimed that our reform will raise the achievement level of all the student strata, from a social standpoint the most important gain is that of changing the educational achievement, and the corresponding self-image, of the low achievers. In American society, low achievers are found in much higher proportions in groups of low socioeconomic status (SES) than in groups of high SES. The consequence is that by providing high-quality education, the key for social progress, to low-SES groups, we will be bringing a high factor of improvement to one of the major problems this society is facing.

A Recognition of the Right to Intellectual Diversity

The explicit messages of equality of the American ("all men are created equal") and French ("liberté, égalité, fraternité") revolutions have been taken too literally by many groups in society, and, instead of being understood in their true meaning of equality of rights, they have been transformed into a false ideal of uniformity. In different periods these feelings have been expressed in the rejection of minorities, even the denial of their rights, and in xenophobia in diverse manifestations. The conventional teacher presenting a unique message and expecting a unique response to every question is not the key to solve this problem. On the other hand, the search for creative solutions, the group discussion of open possibilities, and the rewarding of original thinking, all part of the methods we propose, will be of help in developing a society of individuals who will recognize the rights to independent ideas, to diverse ways of thinking, and to various styles of argumentation to defend one's ideas in a rational dialog.

Economic Implications

Highly Improved Cost Effectiveness of the Educational System

Cost effectiveness is determined by comparing the value of the products or services generated by a system with the system cost. We claim that our proposal requires no increase in the educational budget. Second, the "product" of the educational system will improve in the form that we have described—that is, the instructional failures of the present system will be avoided. If we were to attend to the needs of the below-average students within the present system, a much higher budget would be required for tutorials, additional instruction, and so on. Thus, our proposal provides a system with much higher cost effectiveness than the present one.

Superior Workforce for Industry and Services

In the era of information and high technology, the instructional level required for the workforce is much higher than in previous eras. This point has been made in several ways, most forcefully in the report *A Nation at Risk.*

The high standards defined in the common curriculum result in a population able to cope with the requirements of the most sophisticated industries. Otherwise, the uneconomic trend will continue of industries having to educate their workforce according to their requirements, which are not satisfied by the graduates of the present educational system. Another important dimension is time. By accelerating the better learners, we allow for their incorporation into the workforce, with or without a university degree, in a much shorter time than in the conventional system.

Zero Increment Over the Present Educational Budget

The most "original" point in this proposal is to allow each student to progress according to his or her learning rate. As learning rates are normally distributed, this will result in the above-average students leaving the system in less time than it presently takes them. Of course, this will free educational resources, personnel, materials, and space. We can use the resources that have been freed to take care of the below-average students, who will require more teacher attention, more materials, and more time to stay in school. The symmetry of the distribution of learning rates allows us to say that, in general terms, the savings generated by the acceleration of the above-average students will compensate for the additional expenses required by the slower learners.

Notes

[1]Alfred North Whitehead used the term "inert knowledge" to refer to knowledge that had been learned and demonstrated in school but that failed to come to mind when relevant in the outside world.

[2]To say that meaning is "stored in our culture" is certainly a gloss. By this, we mean that a given piece of knowledge can come to mind either because we have learned to use it in culturally relevant situations (like a conversation with another person) and/or because the artifacts in the world our culture shares can trigger its retrieval.

[3]Many years ago, the second author observed human performance in diagnosing students. This was in a computer-equipped classroom in which each student received tailored assignments based upon teacher decisions about the student's placement in each subject-matter curriculum. What was notable in these unpublished observations is that the trajectories of students through the curriculum did not stabilize for about 3 months. That is, students did not receive consistent progressions of assignments until well into the third month of each academic year. Presumably, this long period of noisy and inconsistent placements reflected teacher uncertainty about student knowledge levels.

[4]The policies of the Johns Hopkins University Center for Talented Youth confirm this figure. In their screening for gifted children, a student who requires an SAT verbal score of, say, 430 by age 12 to take a course would need a score about 35 points higher for each year after 12 the test was taken.

[5]Prussian education was not always as the stereotype would have it. In particular, the Kriegesakademie (school for officers of the military) was a place of collaborative and highly individualized learning. Students would put forth ideas which would then be critiqued and discussed by both faculty and other students. This approach was intentionally copied in the U.S. military war colleges, and even today the U.S. military looks back to the German military educational system between the first and second World Wars as an example. Further, Mann himself later headed an extremely individualistic educational establishment, Antioch College.

[6]By results, we mean the results of student work. Sometimes, a major piece of sophisticated effort may be needed to rule out a possible product component, so the performance of that piece of work may not be manifest in a formal product of the project. For example, students carrying out a math project may initially explore several theorem-proving approaches they end up discarding. The record of this work—what was done and where the work led—can be thought of as a product, too, for the sake of this presentation. In contrast, incomplete work, or work that represents great effort but no learning, tends not to be considered in evaluating what students have learned from a project. This is a subtle distinction at times, but an important one.

[7]Whether each student is evaluated separately or the team is evaluated as a whole depends on the purpose of a given evaluation. This is an area of active research, which we do not presume to prejudge.

[8]When we criticize the failings of traditional education, we must bear in mind that teachers are a group of people who did what was expected in traditional classrooms.

[9]We take no position on the general issue of prerequisites. Some scholars have suggested that prerequisites often serve to keep students from confronting hard cognitive tasks, and we agree. However, it will often be the case that a project will have a very different character unless some or all of the project team have certain skills. For example, a project in a calculus course may have very different outcomes depending on whether at least some team members have had some exposure to basic mechanics in a physics course.

[10]Actually, the educational system is only partially blind to the dispersion of student aptitudes. If the student is really way out, the educational system will do something, and thus we have the programs for the gifted and for the retarded, but the system prefers to ignore that there is a continuum between these two extremes.

[11]The children have high SAT scores at young ages. However, we believe that in the kind of system we propose, substantial numbers of students would achieve the levels of these students, many of whom seem to benefit primarily from educated parents, an intellectually rich home life, and sufficient income to afford a $2,000–3,000 summer program.

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