CHAPTER 3

DESIGN BY ASSEMBLY

One can argue that making a series of small improvements in existing curricula will eventually add up to new curricula that accomplish what is desired of them, including producing graduates who are literate in science. That seems an excessively optimistic view. Decades of making incremental adjustments in K-12 curricula have not resulted in much advance toward universal science literacy.

If incrementalism has not worked, what will? Surely not instant revolution, since the record of radical curricular reform is no more impressive than that of gradual curricular evolution. The central issue is not speed, but how to get a broadly beneficial transformation to occur at all, however long it takes. The traditional way we go about curriculum change is simply not up to the job. Present curriculum design fails to focus on the attainment of specific learning goals, is piecemeal, expects teachers to design curriculum materials, pays little attention to validating learning, and is technologically archaic.

Typically, what *is* done in the name of curriculum design is to modify slightly the large elements that are already there—by adding units and topics to existing courses (sometimes subtracting, but not often), changing teaching materials and teaching methods, and altering the rules governing the paths that students take through the curriculum. Thought of as adjustments made to improve a curriculum, such changes may make good sense individually, but they still leave unattended the need to create a basic configuration of subjects and courses in the first place.

There must be alternatives to the piecemeal approach. The one presented in this chapter is to design curriculum by selecting and configuring large curriculum components called blocks, almost necessarily with the aid of computer software.

The Idea in Brief

Imagine there exists a large and diverse inventory of “curriculum building blocks” and a database describing each of these blocks in detail. Given explicit learning goals and constraints and a conception of what the curriculum *as a whole* should be like, a school district could create its curriculum by choosing and configuring sets of appropriate blocks chosen from the inventory. The developers of the blocks would bear the responsibility of building in sound goals and instruction, and the makers of the database would bear the responsibility of studying and describing blocks well, leaving local educators with the responsibility for making good choices.

A Familiar Analogy

By way of comparison, imagine designing a sound system for your home. In the early days of radio and records, the choices were simple: Depending on your pocketbook and whether you wanted a floor model or tabletop model, you bought a single piece of furniture and plugged it in. If you also wanted to play records, you got a separate phonograph. But then “high fidelity” and “stereo” arrived and with them the notion of buying individual audio components; hook the right components together in the right way and you had a sound system tailored to your personal tastes and circumstances.

The drawback of this technological advance was that there were now more choices to be made, more things to be considered in making those choices, and more ways of going wrong. To deal with this new complexity, some people would simply pick a recommended set of supposedly matched components sold together by a catalog or audio store, letting someone else make most of the detailed decisions. But others, rising to the challenge, would decide to design their own sound system.

Today, stores and catalogs are crowded with audio components—many different makes and models of loudspeakers, amplifiers, tuners, disc players, and tape decks, each with its own specifications and cost. To design a system, you need some rules for making choices. Most of the rules are simple. You must have a least one signal source (radio receiver, disc player, tape deck, etc.), or you may have several. You must have an amplifier and speakers (or headphones) if you prefer. You must pay attention to technical details like the relationship between the power output of the amplifier and the power needs of the speakers. In deciding what components to get, you also need to take into account the kinds of recorded material you expect to play, what physical constraints there are (such as the size of the room and who else lives nearby), how much you are willing to spend, and how you want the system to look (how it looks, after all, is an important source of motivation and satisfaction—given that it produces good sound). For example, some people want a separate preamplifier, power amplifier, and tuner, whereas others prefer a receiver that combines all three functions in one box.

Once you have all the components at home, you must connect them properly. Beyond selection criteria, you need rules regarding connections. You follow instructions, hook up the system, plug it in, turn on the power—and likely as not it doesn't work. You consult the instructions and diagrams, change some connections, poke some controls, and eventually it usually does work. You like the sound at first, but later you realize that although it works, you are not satisfied. You seek advice from audio magazines or experts or friends, upgrade some components, and add video components to create a complete home entertainment system. And it is a very different system indeed from the radios and phonographs of yore.

Technology moves fast. Today, video and computer components are often part of a "home entertainment system" which may be more than a "sound system."

In principle, there is an even more challenging alternative to using a set of components. With the right technical knowledge and skills, you could create a sound system from transistors, resistors, wire, transformers, and other electric, electronic, and mechanical parts. (A generation ago, some people bought do-it-yourself kits to undertake this time-consuming challenge.) Few of us today have the technical expertise or time for that, especially with the advances that have been made in electronic technology, including the incorporation of a great many small components into integrated-circuit chips. So our realistic choices come down to either obtaining a preassembled sound system or assembling a system from major components.

The design–by-assembly process for developing a curriculum has much in common with designing a sound system. Both enterprises involve selecting components that are already available and putting them together in a particular way. Both require that the decision makers choose from a variety of existing components on the basis of what the completed system will be expected to accomplish, as well as the performance characteristics, reliability, compatibility, and cost of the individual components. And both make success contingent upon the decision makers' abilities to make good choices.

An Education Analogy

To focus more particularly on education systems, think of a university and ask yourself what its undergraduate curriculum is. Your answer may well be that it has many curricula because each undergraduate designs an individualized curriculum from a huge collection of courses. The university catalog tells what courses are available and specifies the selection rules for particular programs.

Selection rules provide first-year students with essential information, such as: (1) each course carries a certain number of credit units; (2) to graduate, students must accumulate a certain number of credit units; (3) these units must be distributed over time within some predetermined constraints; (4) students must select a major and meet its course requirements; (5) students must pay attention to course sequence, for some courses cannot be taken until prerequisites have been satisfied; and (6) students must also pay attention to weekly and daily class schedules, so that their courses don't overlap. (For examples, see the excerpts from a Harvard University course catalog shown opposite.)

In choosing courses, savvy undergraduates do not depend altogether on the selection rules given in the catalog. They seek out student opinion on who are the best teachers, which are the tough courses, and the like. Gathering relevant information, official and otherwise, is part of the design process. In short, students design their individual undergraduate curricula by selecting instruction blocks (courses, seminars, independent study) from a defined set according to some explicit selection rules, taking into account what is known about the available courses. Even then, most students find through experience that they have to modify their initial choices. They usually do so by changing single courses or course sections, but they may make more radical changes, such as choosing a new major.

This analogy is not intended to suggest that elementary- and secondary-school students should design their own curricula, but to show that the process of curriculum design based on assembling the right components in the right order is not, after all, a novel idea.

TYPICAL DESCRIPTIONS FROM A HARVARD UNIVERSITY COURSE CATALOG

Earth and Planetary Sciences 6
Introduction to Environmental Science: The Solid Earth
Catalog number: 2694
Primarily for Undergraduates
Half course, Fall, Tuesday and Thursday, 10-11:30; lab and section require one afternoon per week.

An introduction to geology, with primary emphasis on those aspects of continental near-surface phenomena whose understanding is particularly relevant to environmental problems and hazards. Environmental effects of natural subsurface processes (plate tectonics, earthquakes, volcanoes) and surface processes (erosion, deposition, mass movements); resource use (water, soil, minerals, fossil and alternative fuels); waste disposal. Labs and field trips familiarize students with minerals and rocks, geological structures, and maps, and the interpretation of field observations.

Note: EPS 6 may not be counted for a degree in addition to EPS 7.

Engineering Sciences 50
Digital Electronics in Scientific Experimentation
Catalog number: 4499
Primarily for Undergraduates
Half course, Fall, Tuesday and Thursday, 10-11:30.

Intended to give students in laboratory sciences and students contemplating a concentration in electronics a thorough grounding in the concepts and language of digital electronics as well as some experience applying these concepts in practice. Topics include analysis and design of combinational logic circuits, sequential logic circuits, state machines, programmable logic devices, and the essentials of analog signal conditioning techniques. "Hands-on" experience in the use of integrated circuits is provided by a combination of experiments done with a take-home lab kit, and some exercises using laboratory equipment and computers. A miniproject is assigned during the reading period.

Note: Some experience in a laboratory science is helpful but not required.

Enrollment: Limited to 36.

Mathematics Xa
Introduction to Functions and Calculus: A Year-long Course I
Catalog number: 1981
Primarily for Undergraduates
Half course, Fall, Section I: Monday, Wednesday, and Friday, 10:00; Section II: Monday, Wednesday, and Friday, 11:00; Section III: Monday, Wednesday, and Friday, 12:00; twice-weekly lab session to be arranged.

Fundamental ideas of calculus are introduced early and used to provide a framework for the study of mathematical modeling involving algebraic, exponential, and logarithmic functions. Thorough understanding of differential calculus promoted by yearlong reinforcement. Applications to biology and economics emphasized according to the interests of our students.

Note: Students taking Mathematics Xa should plan to take Mathematics Xb immediately afterwards. (The sequence Xa, Xb is equivalent to the Mathematics Ar, 1a sequence.)

Enrollment: Limited to 15 students per section.

Anthropology 97x
Sophomore Tutorial in Archaeology
Catalog number: 0400
Primarily for Undergraduates
Half course, Spring, hours to be arranged.

The sophomore tutorial provides a background in archaeological method and theory, particularly focusing on small-scale societies. Specific topics include the origin of anatomically modern humans, the peopling of the New World, and the nature of small-scale societies in both modern and ancient contexts. Weekly readings (drawn from the current journal literature), discussions, several short writing assignments.

Note: Required of all concentrators.

THE IDEA IN MORE DETAIL

The most open-ended strategy for designing a K-12 curriculum would be to select instruction blocks one after another solely on the basis of their supposed success in achieving benchmarks (or other agreed-upon specific learning goals). This pure "benchmark-maximizing" strategy would seek simply to hit all benchmarks as often as necessary. Yet, because the blocks themselves carry requirements for prerequisites and resources, the choice of each block would depend to some extent on what blocks have been chosen already and, in turn, would influence subsequent choices. This is a complex demand of design by assembly. Fortunately, it seems likely that there will be computer software for the task (as for almost every task). When proper computer software for curriculum design is developed, it can be used to display a running account during selection of how well the full range of benchmarks is being targeted. Even better would be software that could also identify at each step the next blocks that would most improve the overall benchmarks profile.

Project 2061 is attempting to develop a prototype of such software.

Computer-assisted design by assembly requires three specific and essential resources. First, there has to be a set of related information banks—or, as they are called at this turn of the century, databases:

- A database of learning goals and the connections among them. This database would include *Science for All Americans*, *Benchmarks for Science Literacy*, the national standards and frameworks for the various subject domains, and state frameworks. It would also include the comparisons in *Resources for Science Literacy* that show the connections of *Benchmarks* to national standards in science, mathematics, technology, and social studies (and eventually to the standards for other subject-matter domains).
- A database containing descriptions of a large number—certainly hundreds and perhaps thousands—of commercially available curriculum building blocks. Some proportion of these instructional blocks should aim at specific learning goals, and critical evaluations should be available to indicate that they are instructionally effective. Equally important, the specific goals, effectiveness, and other properties of each block must be described honestly and well.
- A database of curriculum-design concepts, including some fairly elaborate ones that provide considerable guidance for design, along with exemplary designs that have already been worked out in detail.

Second, there has to be user-friendly computer software available to search these large and complex databases and keep track of options and decisions. Third, there have to be qualified design participants—whether teachers, administrators, school-board members, or citizens—who understand the process of curriculum design by assembly and have the skills and resources to implement it. With the necessary databases, software, and expertise at hand, the design process would consist of five steps:

> Step 1: Work toward agreement on a coherent set of specific learning goals to be reached by the K-12 curriculum. The learning-goals database should help here. Avoid taking a cafeteria approach to selecting specific learning goals. The goals should be a related set like those in *Benchmarks* and other major sources. Substitutions can certainly be made, but how they affect the rest of the set needs to be taken into account.
>
> Step 2: Identify and record constraints. Curriculum design is always constrained by policies, resources, schedules, and so forth. It is important to ferret out those constraints, whether explicit or not, that appear to be the most limiting. Of course, all the design principles related to benefits, risks, and trade-offs would apply here.
>
> Step 3: Come up with a design concept that captures what the curriculum should be like or that at least suggests what its main features ought to be. Although different design concepts could address a given set of learning outcomes, some may seem more effective or more motivating than others and also more likely to gain wide acceptance. Scan the database of curriculum-design concepts for ideas. Record the selected or invented design concept, indicating its implications for selecting blocks.
>
> Step 4. Look in the database of completed curriculum designs to see if there are already worked-out K-12 curricula designs that are consistent with the selected design concept and that prescribe an actual array of blocks. If a suitable design is found, then print out the details and begin collecting the specified blocks. If not, use the method described in Step 5.
>
> Step 5: Guided by the design concept, begin selecting blocks. Start by selecting a few blocks that everyone can easily agree upon. Now add more candidate blocks that have some appeal, one at a time. For each block, consider how the goals it targets compare to the slate of goals that are still missing from the collection chosen so far (including specific learning goals and others deemed desirable by the design

Designs on Disk demonstrates a utility for dragging blocks from a database into a curriculum "space" and keeping track of the benchmarks that have been collectively targeted.

Ideally, curriculum-block descriptions should provide information in these categories:

- **Title**
- **Overview**
  - Intended Students
  - Subject Area
  - Format
  - Time Frame
  - Prerequisites
  - Rationale
- **Content**
  - Stated Goals
  - Main Topics
  - Activities
  - Options
  - Connections
- **Operation**
  - Human Resources
  - Material Resources
  - Assessment
  - Teacher Preparation
  - Cost
- **Credibility**
  - Empirical Evaluation
  - Benchmark Analysis
  - Reviews
  - Users
  - Development

Although most of these categories are familiar, their content is sometimes novel. See CHAPTER 4: CURRICULUM BLOCKS for more details.

concept). Keep a record of deliberate trade-offs made or considered along the way, so that both the participants and other people can follow the reasoning, especially if decisions are later to be revisited. Continue adding blocks until the design is complete. Early in the process, choices can be fairly free, because there is so much curriculum space open and so many goals to be targeted. But as the curriculum space fills up, meticulous attention has to be paid to the time requirements of additional blocks and how well the blocks contribute to the still-unsatisfied goals.

Searching, keeping track, and documenting these five steps can be daunting tasks. It may be possible to do the job with pencil and paper, but it would be vastly easier to undertake by using sophisticated and user-friendly computer software. Such software could be helpful in Step 1, searching the goals database and comparing different sets goal by goal. Searches would be facilitated also for design concepts and for complete designs (Steps 3 and 4). To facilitate keeping track and sharing work among participants, files would automatically be set up for considerations made and conclusions reached on local goals (Step 1), constraints (Step 2), and design concepts (Step 3).

It is in Step 5, however, that the greatest benefits of computer assistance would probably be realized. As a new block is tentatively added to the growing array, the computer would compare the goals it targets well to the goals still unsatisfied by the collection. The computer would search for candidate blocks, perhaps even suggest blocks that would make needed contributions to the emerging curriculum. By keeping track also of the resources that selected blocks require, the computer could provide advice on whether candidate blocks meet constraints that had been entered. The computer could even advise on cost-effectiveness—comparing a candidate block's contribution to goals with its demands on time (students' and teachers'), facilities, equipment, and money.

The crowded endgame, when there is too little space in the curriculum and too many unsatisfied goals left, would benefit in particular from computer searching and fitting. Even with computer software to display a running account of targeted and still-to-be-targeted benchmarks, a stepwise series of choices could still lead to a situation in which no set of available blocks that would serve the remaining benchmarks would also fit in the time still available in the schedule. So, as many people experience in packing a suitcase or van, some backtracking may be necessary. Revising some earlier choices would be facilitated immensely by having the computer juggle and compare multiple alternatives and justifications. Curriculum design by assembly as it is envisaged here hardly seems practical without the use of sophisticated computer programs.

SETTING THE STAGE

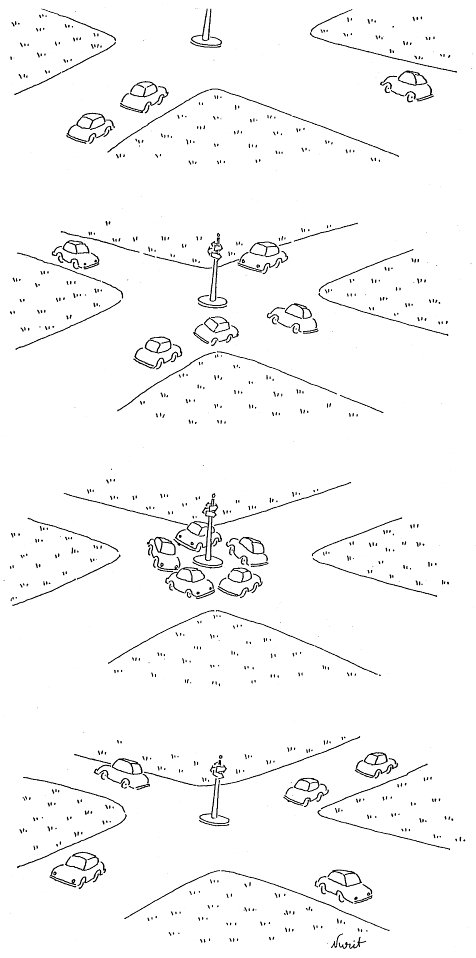
The curriculum-design system proposed in this chapter is intended to enable educators to design alternative K-12 curricula, ranging from the traditional to the radical, that will all lead to the same desired goals for student learning. The previous section sketched some technical resources that would be required for carrying out computer-assisted design. There are, however, other related conditions, as discussed in the next three sections, that have to be met as well:

- There is widespread agreement among teachers, other educators, and the public on the need for reform, the character of learning goals, the acceptability of curriculum diversity from district to district, and other issues.
- The content knowledge and craft skills of beginning teachers and administrators are far more extensive and sophisticated than was previously the case—and teachers and administrators alike expect to build their skills systematically over their careers. This would imply that the professional preparation of teachers has been thoroughly reformed to be targeted and coherent, rather than piecemeal, hit-or-miss, or driven by instructional fads.
- Educational policies have been adjusted as necessary to support or at least permit this new approach to curriculum design. Accordingly, such curriculum-related matters as assessment, graduation requirements, licensing, the locus and limits of decisionmaking, and funding have been changed where necessary. Perhaps most important, school districts have found a way to make much more time available to enable teachers and administrators to engage in creative and essential activities such as curriculum design.

A dozen aspects of the education system important to curriculum reform are explored in *Blueprints for Reform,* which is available in print and on the Project 2061 Web site at www.project2061.org.

Shared Beliefs

Widespread public readiness for daring curriculum changes designed to improve student learning is not sufficient to guarantee successful reform. There must also be a consensus on what students are intended to know and be able to do—and the recognition that students are not achieving those goals now. At the most basic level, this requires agreement on the balance among the several subject-matter domains and, within each domain, on the balance between the common core of studies and the electives available for students having special needs, interests, and talents. Specifications of the core for the domain of natural-science education are provided by *National Science Education Standards* and *Benchmarks for Science Literacy* (and the strength of those specifications is underlined by



their being almost completely consistent with one another). *Benchmarks* also contains specifications for social science, mathematics, and technology. Although there is not yet a coherent picture of what students should learn across the entire spectrum of subjects, preliminary efforts are under way to link the standards in a rational whole.

One of the premises of the curriculum-design system proposed here is that there is no one best way for students to learn. Thus, different school districts may have very different curricula, despite having the same set of learning goals: common ends, diverse means. The notion of curriculum diversity among and within school districts is not necessarily attractive to everyone. Diversity may be resisted by those who believe that there is one inherently best curriculum design or those who believe that a common curriculum, however imperfect, is necessary to accommodate student migration or varying college-admission requirements. However, where curriculum diversity is tolerated or actively sought by communities, the need for a design system to create serious curriculum architecture becomes clear.

Professional Development

In addition to professional development aimed at building curriculum-design skills, teachers will need opportunities to strengthen and expand their instructional skills. The connection between curriculum design and instruction points both ways. A curriculum sets possibilities and limits on what teachers can accomplish, and teachers determine the degree to which a curriculum's possibilities can be realized. If a curriculum changes radically, so must teachers; if teachers change radically, so should the curriculum. A mismatch between teacher capabilities and curriculum capabilities is a formula for failure.

Effective use of the building blocks of the curriculum of the future will require teachers whose preparation in content is different in breadth and depth from today's norm. Consider, for instance, the content demands of blocks that will be chosen to reach the learning goals recommended in *Benchmarks*: the nature of science, mathematics, and technology and their interconnections; key concepts from the biological, physical, earth, and space sciences; scientific insights concerning human society and the mathematical and designed worlds created by the human species; historical and thematic perspectives that cut across and connect science, mathematics, and technology; and the possession of certain scientific habits of thinking and doing. Those blocks will require that teachers possess knowledge surpassing the level of science literacy outlined in *Science for All Americans*—which may imply extended professional development throughout teachers' careers.

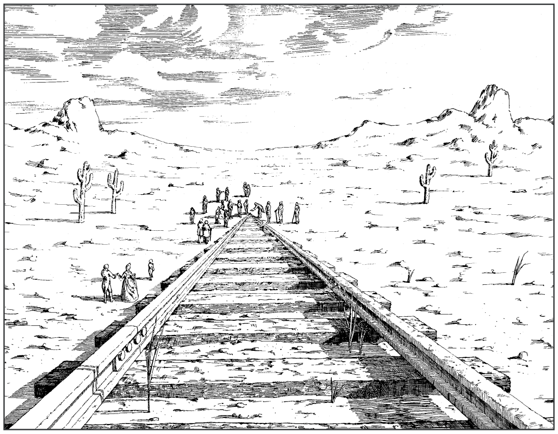
On the other hand, the specificity of science literacy, as defined by Project 2061, makes it possible to focus teachers' own science learning. An elementary-school teacher of science, for example, would not be obliged as an undergraduate to take general courses in biology, chemistry, physics, earth sciences—and, in the Project 2061 notion of "science," courses in engineering, mathematics, history and philosophy of science as well—in the hope that they could sift out and retain the basic literacy ideas. Rather, undergraduate study could be tailored to focus on those basic ideas. (The prescription is made here for prospective teachers in particular, but most undergraduates may best be served in the same way. And some undergraduates may decide only later to be teachers.)

For a list of recommended trade books selected for their focus on basic literacy, see *Resources for Science Literacy: Professional Development.*

High-quality curriculum blocks could also make teacher preparation more efficient. Say, for example, that the intent is to integrate mathematics and natural science for a semester in middle school. An integrative block that has been developed thoughtfully with ample resources in time and expertise (and that directs the teachers to the particular background knowledge they need) would relieve teachers of having to become broad-based experts in mathematics and science generally.

There are also craft skills to be mastered. In the future, teachers will have to enter the profession with teaching skills that are more sophisticated and more diverse than those that have until recently been considered sufficient. Being able to pace students briskly through a monolithic textbook will no longer suffice in an age rich in multimedia materials, well-developed individual and group methods of instruction, sophisticated assessment approaches, calculators and computers, information networks and multimedia, and steadily rising expectations.

In modern professions, progress seems to lead to and be a consequence of specialization. Teaching has a long history of specialization by grade level and, in the upper grades, by subject matter. It may be that content specialization in some fields like science and music ought to be introduced earlier, but that need not be the end of it. To take full advantage of the curricula of the future may well require the services of teachers who have developed teaching or technical competence of one kind or another beyond that of general practitioners, which they all share. The issues involved in specialization are admittedly many and subtle, but the explicit attention to requisites that good block descriptions will provide ought at least to bring more clarity to the debate.



"Locating the Vanishing Point"

Education Policies

If different school districts are to take advantage of a resource system that enables them to design different curricula, then state and local policies must permit them to do so. The very essence of design is to find an imaginative accommodation between goals and constraints, making trade-offs between them as necessary, modifying one or the other or both in the process. Here are some examples of curriculum-related policy questions that are especially relevant to the curriculum-design system being proposed:

- Where are decisions made? How much freedom does a school district have to design its curriculum? Are learning goals set by the state in detail, in general, or not at all? Are they required or only recommended? Who decides whether a given curriculum design is acceptable—the local school district or the state? And on what basis?
- What regulations are there to ensure accurate and valid descriptions of curriculum blocks? What evidence is required that a proposed curriculum block is likely to result in the claimed learning? For curricula in place, when are assessments required to show that learning goals are being met? What assessment techniques and instruments must be used?
- Do state and local policies (fiscal and operational) permit the adoption of a curriculum design in which some faculty members specialize in research and development, curriculum management, or assessment, and have limited teaching assignments?
- What latitude is there to include blocks that call for teaching by people who are not licensed K-12 teachers, such as students who teach younger students, or scientists from the community who serve as associate or adjunct teachers on a part-time or limited basis?
- Can students receive credit toward graduation by examination in lieu of taking specified courses?

Clearly, there are certain answers to such policy questions that would make it difficult for curriculum-design teams to come up with designs very different from what is now traditional. Other answers would be conducive to the design of more inventively effective curricula and to creating a design-by-assembly system.

Even if these three conditions discussed above were to be met, the proposed curriculum-design system would also require a more reliable and relevant body of high-quality research on which to base curriculum-related decisions. In addition, strong demand for curriculum building blocks would be needed to encourage developers to create many new blocks, describe them fully and objectively, and subject them to field-testing for workability and effectiveness.

ASSEMBLY STRATEGIES

As the five steps proposed earlier make clear, curriculum design in the future would be more efficient, more soundly based, more congenial, and ultimately more successful if undertaken with the assistance of electronic databases and specialized software.

The Idea of Computer-Aided Design

These days, if we want to build our own kitchen, garden, or boat, we are likely to do one of two things. We could search for a ready-made design that seems to be what we have in mind. Alternatively, we could buy a computer program to guide us through the process of creating our own design. Using computers for such design projects is relatively new, although they have been used in industrial and many other contexts since the 1970s.

In education, computers are used mostly for record keeping and student instruction. Both of these applications are important, but both have a long way to go before their potential is fully realized and they become integral to the education enterprise, rather than hit-or-miss add-ons. But computers are rarely used for helping to create and operate curricula.

Different components that could be part of a computer-aided curriculum design system can be found in *Benchmarks on Disk, Resources for Science Literacy: Professional Development*, and *Designs on Disk*. The chief purpose here is to describe how a full-fledged computer-based system could be used in curriculum design, but some attention also is paid to the system's potential use in curriculum resource management, curriculum operation, and curriculum-related professional development.

One caution: Computers and computer programs cannot replace human inventiveness and vision. No matter what instruments are used—legal pads and #2 pencils or sophisticated computer programs—the curricula that are created can be no better than the thinking that goes into them. The subject here is computer-*aided*, not computer-*generated*, curriculum design and management.

Searching for Candidate Blocks

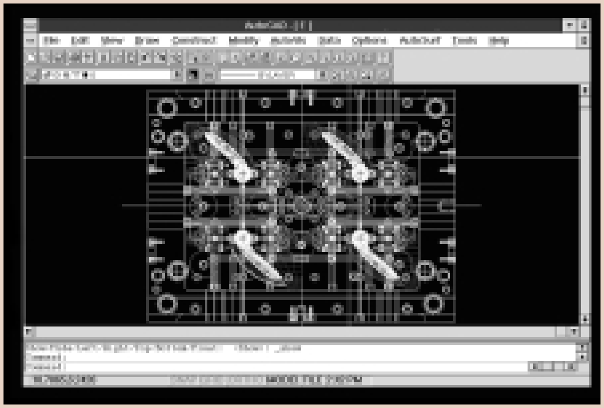
In the design-your-own-sound-system analogy used earlier, a person shops in stores or catalogs, or both, to find out what is

CAD/CAM

One of the first large-scale uses of computers in industry was in designing products and systems and guiding manufacturing operations. Hence the acronym CAD/CAM: Computer-Aided Design/Computer-Aided Manufacturing.

The construction and assembly of products is a complex undertaking, from the ordering and flow of raw materials or parts to the sequence of connecting them. How it is carried out can make a great difference in the efficiency and cost of production.

Manufacturing considerations also have implications for the design of products, since small changes in design may also make large differences in the efficiency and cost of construction. The design of products and the design of constructing and assembling them are therefore closely linked. It has turned out that CAD/CAM has useful applications in a wide variety of contexts, including the design of research investigations, traffic patterns, buildings, computer chips and computers, magazine layouts, weapons, parks—and in other situations that require extensive data to draw on, careful tracking, and a variety of alternative models to explore.



Some day there could be an on-line "curriculum store" that includes not only the block descriptions asked for in Chapter 4, but also video demonstrations of what blocks look like in action.

available and to compare the options in terms of expected performance, appearance, and cost. Then, taking certain constraints into account (such as budget and space limitations) and applying certain selection principles (such as which kinds of components are desirable and compatible), selections are made. In that analogy, on-line guided selection could have substituted for the store and catalog.

There is, of course, no such thing yet as a comprehensive "curriculum store" where one can examine an array of curriculum blocks critically and get precise information on their properties and costs. The jumble of materials on display at education conventions and on the Internet, even the displays of the major textbook publishers, provide very little information of use to curriculum designers. But if one assumes that in time many hundreds of good curriculum blocks will exist, the question arises, How can we possibly deal with such a vast amount of information?

A design team (whose membership might differ greatly from one district to another) begins a search for suitable blocks by selecting the categories of variables it wishes to have taken into account in the search. The box on the opposite page, A Variety of Block Shapes, illustrates a wide range of temporal dimensions of blocks. A template for essential block information is described in detail in Chapter 4: Curriculum Blocks.

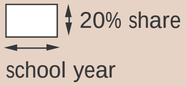
Although a computer makes it possible to search on the basis of any of the variables in the block description, an efficient search technique is to build a pool of candidate blocks based on overview properties. Using the AND's, OR's, and NOT's of search logic, the team uses the curriculum-design software to have the computer find all of the blocks that meet its audience, subject-matter, coherence, format, and time requirements. Here are some examples of block properties a team could ask for:

- Project blocks emphasizing observation and collection by K-2 students
- Any blocks with especially rich options for advanced students
- One-semester integrated science/mathematics blocks organized primarily around measurement for all students in grades 3-5
- Quarter-long, discipline-based, grade 6-8 mathematics core courses featuring the use of statistics in demographic and economic applications
- Any blocks that claim to target goals from Chapter 11: Common Themes of *Benchmarks for Science Literacy*
- One-semester integrated science/history seminars for all grade 9-12 students
- Any blocks for which there is empirical evidence of student learning
- Year-long courses in calculus for students in grade 12 who plan to major in science and mathematics

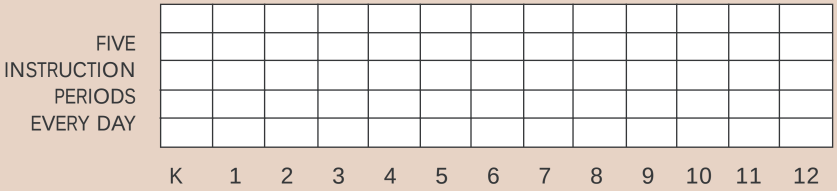
Using blocks with a variety of shapes obviously might cause severe scheduling problems, unless the blocks and the school are suited to “modular” scheduling, in both daily and calendar time dimensions.

A VARIETY OF BLOCK SHAPES

Because of the demand of filling 13 years of curriculum, and the desire for more coherent instruction, blocks are likely to be fairly large units, certainly larger than “activities” and probably larger than most “units”—probably more on the scale of courses or half-courses. In this scheme, a block’s length represents its calendar duration and its height represents what share of time it gets on the scale of minutes per day or days per week. A conventional high-school course would correspond to a block with a “width” of a school year and a “height” of about 20 percent of instructional time (one period a day, five days a week):

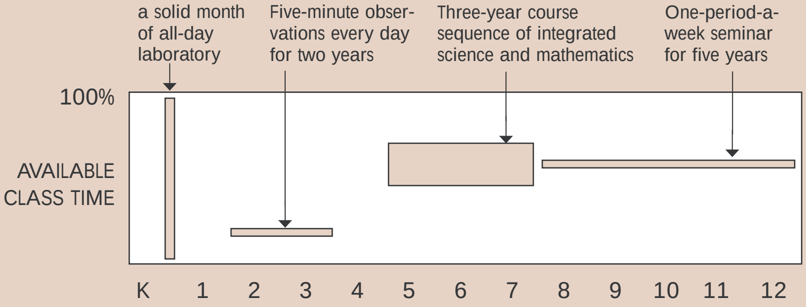


A curriculum made up of nothing but such courses (call them subjects in the lower school) would look like a wall of uniform bricks:



But there are many other possibilities. Even keeping the same total hours, a block might be greatly compressed or extended: at one extreme, an experiment block could fit into a month of all-day sessions; at the other extreme, a seminar block could require only one period per week for five years. Blocks could be still more different in “shape,” say a weather-cycle block that would take only five minutes a day over several years, or a course-sequence block that would occupy all of the middle-school years. These possibilities would correspond to the block shapes drawn below.

Some extreme examples of possible instructional blocks:



There already exists curriculum-accounting software that helps to lay out chunks of time for every element of the curriculum framework. What happens in those chunks, and whether they are enough, is another matter.

A search of the curriculum-block database will turn up only those blocks having the requested combination of properties, displaying the titles of candidate blocks. If the search turns up too few or none, some of the constraining specifications may have to be removed from the search request. If a daunting number of blocks turn up, more constraining criteria may have to be added. Clicking on a title in the database brings up a brief summary, the equivalent of a college-course catalog description. On the basis of the summaries, some blocks can be eliminated from further consideration, thereby reducing the size of the candidate pool.

Configuring Curriculum Blocks

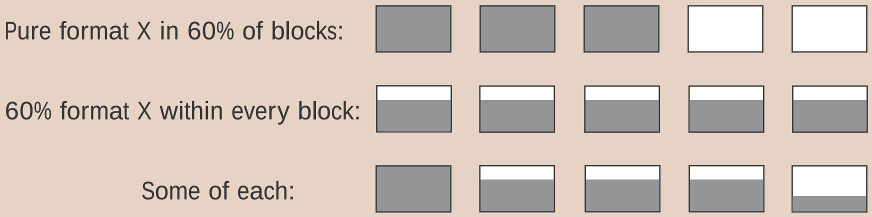
Choosing among candidate blocks to be considered for inclusion in the curriculum involves making two kinds of decisions. First, each block in the candidate pool must be evaluated on its individual merit. How many specific learning goals does it target? How appealing is its instructional strategy? How does it compare with its competitors? Does it fit the overall design concept? (The box opposite illustrates how the same design concept could take different forms.) Second, since the block will end up as only one part of the curriculum, it must be evaluated in light of its special contribution to the whole array of chosen blocks. Does it target goals still unserved in the collection of already chosen blocks? Does its format provide needed balance to the different formats in other blocks? Does it supply timely prerequisites for later blocks, and are its own prerequisites met by earlier blocks?

As the configuration grows, serious analysis of profiles, patterns, and trade-offs can begin. Are some goals targeted again and again while others are ignored? Is the redundancy needed or wasteful? How difficult is it to find blocks to fill the gap? Are we getting the balance we want among block types? Where are we weak? Are there slots for which better candidates should be found? What if we added these two blocks in place of that one? What would be the consequence for the block’s own grade level and for those it connects to? And so forth.

As this analysis proceeds, the design team can follow up on references and other elements of a block description. References to published reports, research, or reviews that support them (and possibly the documents themselves) can be obtained through the Internet and then studied as decisions are being reached. The block descriptions also cite schools or districts where such blocks are in use, so members of the design team can talk with or even visit educators who have experience with a block in which the team is interested. As decisions are made, a satisfactory design finally will emerge, but keep in mind

A design concept can be realized in a variety of different patterns, some applying to *every* block, some to the whole pattern of blocks. For example, a design concept that focuses on using a particular instructional format 60 percent of the time could specify that 60 percent should use only that format or that a certain *proportion* of the blocks should use only that format. Alternatively, the concept could specify that there should be a certain *proportion* of that format within each block or that there should be a balanced *variety* of instructional formats, either across or within blocks.

Three ways in which a distinctive curriculum feature X could be distributed among blocks to achieve 60 percent X:



that in design “satisfactory” means “adequate for the purpose,” not “perfect.”

This process sounds long and complicated in the telling, but there is nothing about it that educators could not do using today’s computers, if only the blocks existed. The diagram that follows illustrates the kind of information that a computer-assisted block search could present to the designer as a candidate block is added to a partially filled curriculum design space. When an icon for a new block is dragged into an unscheduled opening in the design, its dimensions show how much time the block would take, and bar graphs show how many new benchmarks it would target.

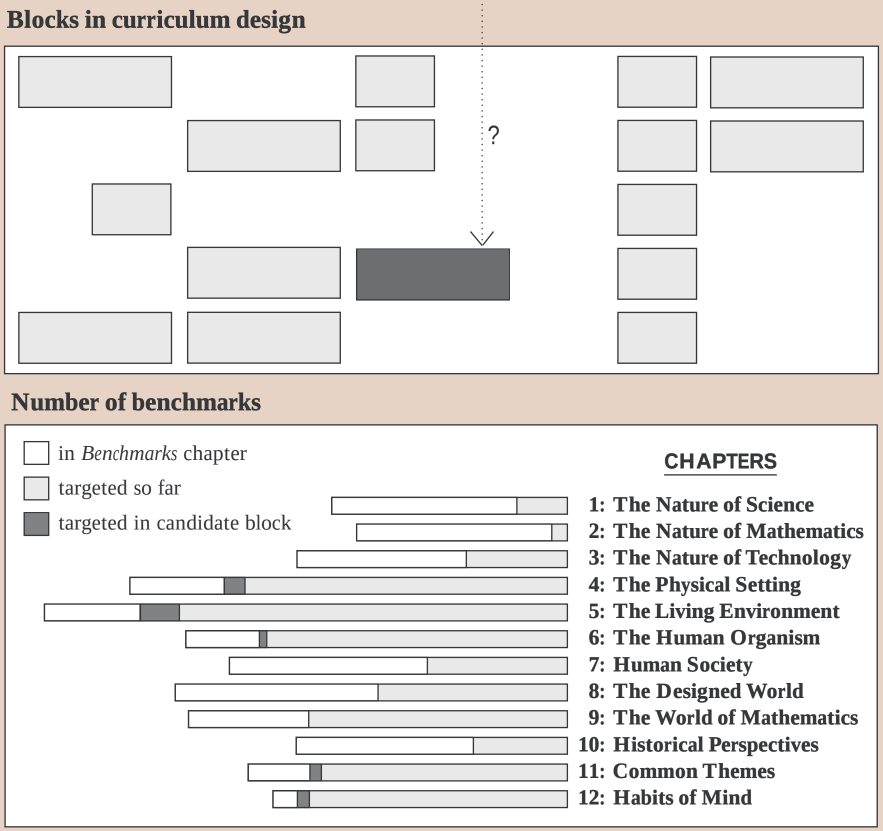
The diagram, hypothetical as it is, shows only two kinds of blocks—one period a day for one or two years. A much greater variety would be possible, as illustrated in the box on page 115, which offers an impression of the diverse array of blocks that could fit into just the 6-8 grade range. The result of applying this process is a curriculum that has been thought out top to bottom by the educators who are going to implement it and by the community it will serve. Nevertheless, the parts will have been created by experts with time and resources unavailable to teachers.

In configuring the curriculum blocks, the selection inevitably gets more difficult as the curriculum space fills up. Blocks to fill in missing goals may not be found or may not fit in the remaining time. Learning goals still left to target could be from scattered content domains. (For example, the design team could end up needing a single

The consequences of adding a block to the curriculum might be displayed this way with block-assembly software.

BLOCK-ASSEMBLY SOFTWARE

Dragging and dropping a rectangle that represents a candidate block produces a display of bar graphs showing how many still-untargeted benchmarks the block aims at for each chapter of *Benchmarks for Science Literacy*. The bar graphs also show how many total benchmarks there are for each chapter and how many have been targeted by other blocks already selected. Additional block characteristics can also be displayed. If the candidate block is added, the benchmarks account is updated. Even if the block is not selected, a record of the attempt can be stored for later review.

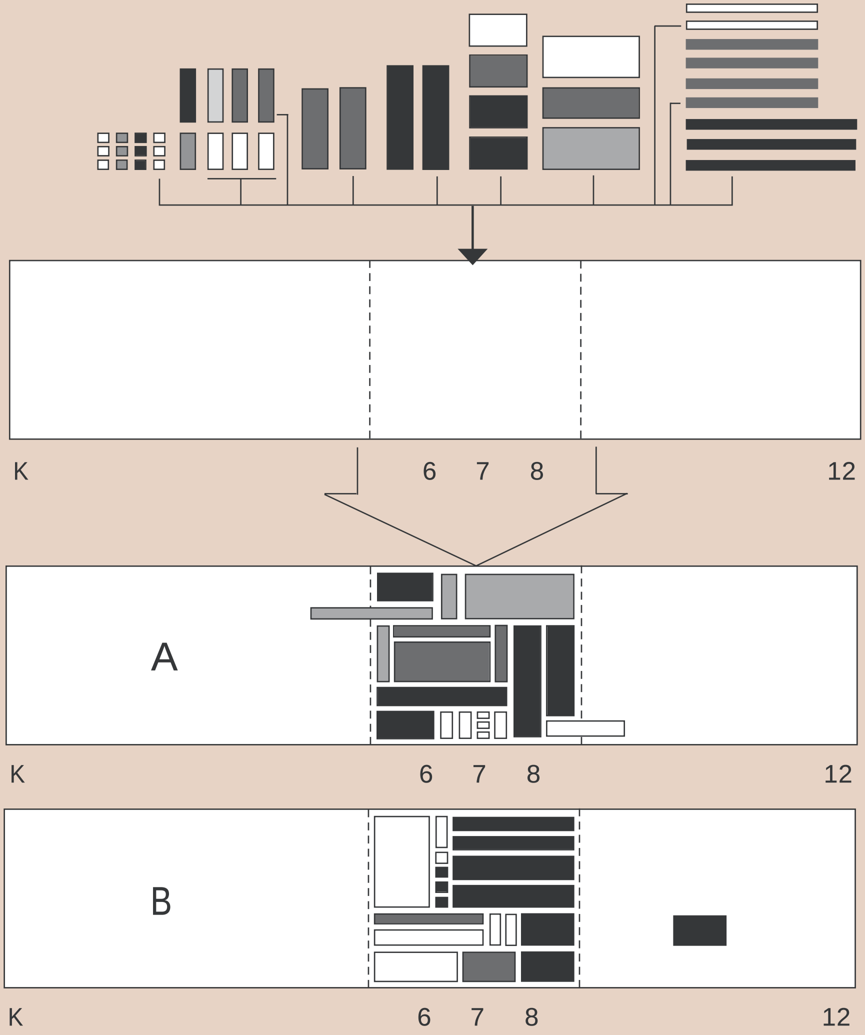


Candidate block
☐ OK to add
☐ Get more information
☐ Don't add, but log idea
☐ Cancel addition

Display other properties
☐ Core/elective balance
☐ Instructional formats
☐ Discipline/integrated balance

FITTING BLOCKS INTO CURRICULUM SPACES

Given a pool of curriculum blocks (top) and the task of selecting them to fill a grade 6-8 curriculum space, the diagram shows two possible configurations. Among their other differences, configuration A would have extensions of blocks into lower and higher grades, whereas configuration B implies a specific follow-up block in grade 10.



final block that targets benchmarks from the nature of the scientific enterprise, agricultural technology, relativity, and cells.) Furthermore, the remaining benchmarks could be remaining, not just because of the luck of the draw, but because they are particularly difficult to learn or otherwise troublesome to develop instruction for.

It is entirely possible that no acceptable configuration of blocks will satisfy all of the goals in the allotted 13 school years of 180 days each. One reaction to that outcome would be to go back and identify some blocks that were selected for reasons other than their effectiveness in serving specific learning goals and to replace them with blocks that are more targeted to benchmarks. Other possibilities could be to lower the priority of some learning goals, squeeze more blocks into the same time frame, or shift the balance of time for different subjects within the school day. A more extreme reaction might be to lengthen the school day or year. On the other hand, it is also possible, if block development has really been successful, that there would be time left over. Depending on where the free time shows up, some school districts could choose to fill out the last years with electives, whereas others could choose to spread the core curriculum out more thinly over all 13 years and provide electives each year.

A Nutritional Analogy

We can get an idea of the kind of help computer-assisted curriculum design could provide by considering an existing example of design-by-assembly software from outside education. The next box is based on an on-line analysis program for selecting a day's menu of food items. The nutrition-analysis software tabulates a cumulative profile of nutrients for the food items that have already been selected. But it is the user's responsibility to scan the profile and notice where it still falls short of recommended nutrient totals. Having noticed a shortfall in, say, calcium, the user can request the program to display of a list of food items that are high in calcium—and then choose one from among those candidates to add to the menu. A more helpful computer program would be one that can point out shortfalls itself, then display a list of candidate food items that would contribute well to filling in all of the missing nutrients (while not greatly exceeding other requirements that were already satisfied). The user, of course, would still make choices among those candidates according to individual preference.

One can even imagine that the program could be used to proceed step by step to design a complete diet on its own. In its simplest form, that would mean first choosing the single food item that would satisfy the most nutrient requirements, then choosing the next item to best satisfy the remaining requirements, and so on. If the

AN EXAMPLE OF COMPUTER-ASSISTED DESIGN: DAILY DIET

On-Line Nutrition Analysis Tool

Step 1. The dietary suggestions for men, women, and various age groups are different. Please select your appropriate age and gender categories.

Step 2. In the accompanying list of the most common nutrients in the USDA database, click on any nutrient for an explanation of what it is, what it does in the body, and some common foods in which the nutrient is found. Click on each nutrient you want to include in the analysis.

Step 3. Add foods to your personal diet list. From the lists provided, click on a food name, a particular form of that food, and the number and size of servings. The list will keep track of this information and also the total weight of that food.

Step 4. Inspect the nutrient analysis table to see an account of the nutrients in each food choice and the total for the entire daily diet selected so far. The table will show both the amount of nutrient and what proportion that amount is of the recommended daily total.

Step 5. Identify nutrients that are still undersupplied and click on Suggested Foods to see list of foods rich in those nutrients. Select new food items to add to diet list (or increase amounts of some food items already selected that are rich in that nutrient).

Example table:

Food Item	Serving Size	Servings	Calories	Protein	Fat	Carbo-hydrates	Vitamin C	Calcium
Porterhouse Steak, Choice	4 oz.	2	692	56.3g	50.1g	0 g	0 mg	18.14 mg
Potato–baked with sour cream, chives	1 potato	1	393	6.6g	22.4 g	50.1 g	33.8 mg	106 mg
Apple–raw	1 apple	2	81	0.3 g	0.6 g	21.1 g	7.9 mg	9.7 mg
Daily Total			1166	63.2g	73.1g	71.2 g	41.7 mg	133.8 mg
Daily Recommended for female aged 25-50			2200	50 g	73.3 g	---	60 mg	800 mg
Percent of Daily Recommended			53%	126.4%	99.7%	---	69.5%	16.7%

Adapted from *Nutritional Analysis Tool, v 1.1* (http://spectre.ag.uiuc.edu/~food-lab/nat/) Department of Food Science and Human Nutrition, University of Illinois at Urbana-Champaign.

food-item database included additional variables such as the weight and cost of food items, the program might be able to design diets that would be optimally lightweight or cheap, while still satisfying nutrient requirements. (Instead of favoring food items that provide the most nutrients, it might favor those that provide the highest ratio of nutrients to weight or nutrients to cost.) There is no guarantee, of course, that such an optimum diet would be palatable to any particular user (or to anyone at all). Desirability would require user preferences to be invoked at each step—say, no broccoli. Straightforward user preferences that could be clearly specified (for example, for vegetarianism or food allergies) could also be entered and taken into account by the program, but it seems likely that many preferences would be subtle and interdependent, always requiring user involvement to get satisfactory diet designs.

The analogy to curriculum design is fairly obvious, with nutrient requirements becoming specific learning goals and food items becoming curriculum blocks. Some user preferences that could be readily specified could be entered into the block-selection program, whereas others would require close involvement of the users in choosing among candidate blocks found by the program. The total cost in material and human resources would be an important variable to keep track of, as would the total time. (The block that targets the most benchmarks, even with demonstrated success, may also take up a great deal of curriculum time.) And, given the severely limited time frame for the curriculum, the raw number of benchmarks targeted might not be as important to consider as the ratio of benchmarks to the time required for it. Curricula designed this way can be described as "benchmark-efficient" or "learning-optimizing" curricula—although at the cost of not having any other unifying character.

The discussion of specific learning goals here is presented in terms of "benchmarks." In principle, any coherent, progressive set of specific learning goals can serve as benchmarks. Project 2061 tools include utilities for translating other sets of national, state, or local goals into benchmarks, which may serve as a common currency for curriculum analysis.

CURRICULUM-RESOURCE MANAGEMENT

The design-by-assembly process will result in a curriculum design, but such a design is not a curriculum. Clearly, implementation of the design to create an actual curriculum that works as intended requires appropriate human and material resources. Computers can aid in meeting those requirements as well.

Material Resources

Today, much of the burden of locating resources falls on teachers. If the subjects or courses to be taught are based on a textbook, suggestions on resources may be given in the accompanying teacher guide. That helps. Often, however, the guidance is scanty and limited to apparatus and kits supplied with the textbook—databases, computer programs, and so on. On the other hand, sometimes the teacher guide is huge, with information on myriad extra (but not always relevant) activities—to the point of discouraging teachers from using it. Thick or thin, however, the amount of material is not so important as how explicitly and well it is tied to specific learning goals.

The process used to create a curriculum design can also be used to identify the resources of all kinds needed to implement the curriculum. The block-description templates list all of the materials needed for each block. As a result, the computer can keep track of the total resource requirements (and cost consequences) as each new block is added to the configuration and the design unfolds.

Once the design is complete and has been approved, computers can be used to help organize, monitor, and operate the business aspects of resource management. Accounting software will coordinate with block-selection software to provide a summary list of all the materials needed, when, in what quantities, and at what estimated cost. If major budget constraints loom, the design team can recommend alternative blocks.

The curriculum-design approach sketched here calls for a much greater diversity of learning materials than in the past, and the materials themselves are less likely to be aggregated or even available on-site. The Internet seems likely to become an increasingly important instructional resource, and a way will have to be found to apportion access to it fairly. In the future, school-district computer centers will be able to deliver instructional materials to the classroom on demand or just in time. With such complexity, computer assistance will be essential.

So much management responsibility can surely seem intimidating to teachers today, but remember that we are imagining situations 10 or 20 years in the future. By then, teachers will have grown up with the kind of technology we are talking about and using it to plan instruction will be a key part of their professional preparation.

Even if all that occurs, teachers will be responsible for managing the process wisely. To that end, they will need analytical tools, probably the more integrated the better. The analytical and record-keeping parts of *Designs on Disk* will become part of the curriculum CAD/CAM system. (Here “CAM” stands for “Computer-Aided Management.”) As a result, teachers will be able to examine new materials critically and enter their findings in the resource database. That will allow them and others to update and refine the resource inventory, substituting better materials as they come along. This electronic "review journal" will encourage teachers to share their analyses and conduct discussions about them on-line.

Human Resources

Curriculum resources are not limited to materials. The single most important resource, no matter what the curriculum, is the teacher. In curricula of the future, teachers will continue to be the most important resource, but their roles, techniques, and training will change. And as the curriculum, instructional materials, and teachers change, so too will the management of students.

Diversified teaching roles. As the curriculum becomes more complex, teaching roles will diversify. Think of a curriculum made up of courses, seminars, projects, and independent study—some plainly discipline oriented, some integrated to a greater or lesser extent. In these blocks, time may be configured in many different ways, and distinctions between grades may be blurred. In such a curriculum, different teachers will specialize in different aspects of the work. Some may teach blocks that cut across subject-matter domains, some may teach straight discipline courses, some may specialize in monitoring independent study or organizing and supervising seminars, still others may train and supervise students in peer teaching, and so forth. Keeping track of such a variety of assignments will be much more complicated than in traditional curricula. In addition to having individual skills, of course, teachers will need to be skilled in working in teams in which they make specialized contributions.

This picture will become more complicated as the teaching responsibilities in future curricula become diversified. In addition to a central core of highly trained certificated teachers, future curricula will very likely depend on peer teaching, on the use of adjunct teachers (especially for beyond-the-core blocks), and on access to remote teachers by means of computers and telecommunications (as virtual classrooms become part of the curriculum). To organize and monitor such an enterprise will require computer applications that combine appropriate spreadsheet, database, and design functions.

For some examples of the kinds of functions the curriculum design software will be able to carry out, see *Designs on Disk.*

Student programs. By the same token, students of the future will follow more varied routes than is now the case. There will be the core program, in which students may or may not follow a common sequence of studies, and the beyond-the-core elements, in which student programs are likely to differ greatly. Moreover, to the degree that a curriculum bases student progress on what students have learned rather than on what they have "taken," record keeping will take on a new dimension. Student programming and student record keeping will necessarily have to become computerized, a trend already under way. We assume that in the dozen or more years before all this is likely to come to pass, administrative policies, teacher preparation and career development, and public expectations and support will rise to the challenge and make it feasible. Such functions should be closely tied to the curriculum, and so an effort is being made by Project 2061 to include those management functions in software it is developing for computer-assisted curriculum design.

CONTINUING PROFESSIONAL DEVELOPMENT

There is no substitute for strong preparation in the content of one's field or for a similarly strong preparation in the techniques of one's craft. This is no less true of teaching than it is of engineering, medicine, or any other advanced field. Throughout one's career, knowledge and skills must be continually updated.

For teachers, preservice preparation can be generic in that it need not be specific to any particular curriculum, although it should include the intimate study of and practice in applying the relevant standards. Then, once actual practice begins, there is much to be gained by focusing professional growth on the demands of the curriculum at hand. In the future, the curriculum building blocks will make it clear what they require to be taught properly and will indicate sources for gaining the requisite knowledge and skills. In addition, the professional development material—including suggestions for workshops and study groups within the district or school, and for carrying out a program of self-directed study—now found on *Resources for Science Literacy: Professional Development* will become part of a complete CAD/CAM system and be continually improved.

See Chapter 6 for a more in-depth discussion of professional development activities that focus on science literacy goals.

Although there will still be a need for teachers to take formal advanced refresher courses from time to time, the bulk of continuing education will take place as part of an individual's regular work. In addition to the guidance that can be provided by a sophisticated, computer-based multimedia system with telecommunications links to information, instruction, and experts, the curriculum itself will have to provide time for professional growth. The traditional preparation period does not accomplish this, and occasional half-day training periods hardly do better. The curriculum structure of the future will open up the way and provide more opportunities for study, and the curriculum blocks themselves will engage the teacher in a way that will make the teacher's own learning integral with, or at least parallel to, that of the students. There will also be other conditions needed for effective professional development to become a reality: an office, a telephone and a computer in one's office, a budget for professional development, and, above all, the establishment of appropriate professional expectations and attitudes.