Technology in the schools

James Rutherford *

1809 Eighth Street, Berkeley, CA 94710 USA

Abstract

Some progress is being made in the use of computers in K-12 instruction, but not in ways that take full advantage of them as part of a technological system that incorporates the analytical power and memory capacity of information technologies, the interactive and mobile potential of communications technologies, and the presentation capabilities of print and audiovisual technologies. Nor are computers being used as design instruments for modeling curricula. Most worrisome, however, is the failure of the schools to establish technological literacy as major goal by treating the study of technology as core subject matter for all students. © 2004 Elsevier Ltd. All rights reserved.

Keywords: Technology education; Technological literacy; Curriculum design; K-12 education; Education standards

Ask K-12 educators about technology in the schools and you are likely hear about computers. Somehow “technology” and “computers” are, in the minds of many, one and the same. This is perhaps appropriate, since computer technology is surely the most powerful instructional tool to emerge in a century.

But there is another way to think about the place of technology in the schools, namely, as essential curriculum content. This view looks at technology rather as one of the liberal arts than as a tool. As stated in an education report of the American Association for the Advancement of Science (AAAS):

Technology—like language, ritual, values, commerce, and the arts—is an intrinsic part of a cultural system and it both shapes and reflects the system’s values. In today’s world, technology is a complex social enterprise that includes not only research, design, and crafts but also finance, manufacturing, management, labor, marketing, and maintenance [1].

* Tel.: +1-510-898-8009.
E-mail address: jrbr@erols.com (J. Rutherford).
These two representations of technology both belong in K-12 education.

In what follows, I first comment briefly on computers as devices for teaching and for designing curricula, and then turn to my main concern: the place of technology content in K-12 education.

1. Technology and teaching

Few American schools are without computers. They are found in classrooms from kindergarten through high school, in so-called computer labs, and in the offices of school administrators. It is not uncommon for them to be put to good use. Moreover, incremental advances can be expected: educational journals are filled with articles on how to better realize the instructional and administrative uses of computers; computer workshops for teachers are ubiquitous; schools of education are teaching computer skills; and the large investment in classroom computers brings with it a growing demand for their effective use.

Still, questions remain about the degree to which schools have yet to exploit the potential of computers for transforming instruction. Computers have helped teachers and students do somewhat better pretty much what they were doing before. It can be argued, of course, that incremental change is all that schools need, or at least is the only change that teachers, parents, school boards, and the general public want or will tolerate. But there may be more to the modest impact of computers on K-12 teaching than disinterest in radical change. It may be due, at least in part, to the general failure of educators to realize that the computer revolution has made possible a revolution in teaching and learning.

Missing may be the recognition that computers have properties that set them apart as a different species, not just a different breed, from earlier teaching and learning devices used in schools. They constitute the “front end” of a technological system that incorporates the analytical and memory functions of information technologies, the interactive and mobile capabilities of communications technologies, and the presentation capacities of print and audiovisual technologies.

Other reasons are practical, and have to do with the failure of schools to back up teachers with sufficient equipment maintenance and training. Computer systems are incredibly complicated and tend to frequent malfunction and rapid obsolescence, and therefore they need lots of technical support to keep operating. Teachers’ experience with simpler instructional machines tells them that maintenance of equipment is often spotty, and so depending on the use of computers could become a handicap.

Still another practical issue is preparation. Classrooms can be loaded with computers, but most teachers are unlikely to realize their full potential without help. It is more than knowing how to word process, use spreadsheets, keep calendars, and access Internet. Among other things, they must learn how to locate appropriate sources of information and link them effectively to the topics being studied; how to help students use computers and the Internet effectively in the context of course content; how to deal with the difficult and sensitive matter of security; how to use
computers on behalf of their own continuing education; and how to become a participant in an active network of professional colleagues for sharing experiences on the use of computers in instruction.

This explanation for the rather slow exploitation of computers in the K-12 system is not offered as justification. The barriers noted are mostly attitudinal and financial and can surely be overcome in time. Perhaps the larger point is that we have a prime example, which affects millions of teachers and students, of the engineering principle that the rate at which technologies get accepted in any given occupation and effectively used depends on more than their intrinsic usefulness.

2. Technology and curriculum design

This may not be the time for a radical redesign of the K-12 curriculum. Perhaps curriculum stability is desirable: publishers can create appropriate textbooks, teacher colleges can prepare students for the actual work they will do, adults will know what their children and grandchildren are facing, and policymakers can estimate year-to-year progress. It may well be that today’s curriculum, having evolved over the decades, is both robust and open to modest incremental improvements. It is noteworthy in this regard that the “No Child Left Behind” Act calls for the US Department of Education to carry out a national study of conditions and practices necessary for technology to be used effectively to improve teaching and learning, but does not call for a national study to see how technology can be used effectively to improve the design of curricula.

But suppose the time comes—as some of us think it should—when such change is seen to be necessary. How might it be accomplished? In past decades, a technical capacity for radically reforming curricula may not have existed, but that is surely no longer the case today, for such capacity now exists.

An answer to that question has been proposed in Designs for Science Literacy, a report from Project 2061, the long-term reform undertaking of the American Association for the Advancement of Science [2]. Referring to the way curriculum design is currently carried out, Designs notes that the 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. This, then, suggests a strategy based on two assumptions: the design practices of architects and engineers can be applied to the creation of new curricula, and computers can serve as powerful aids in designing them.

2.1. The curriculum design process

Several steps are needed to achieve a successful design process:

1. establish design specifications
2. clarify curriculum constraints
3. conceptualizing the design to capture the character of a new curriculum
4. selecting content and organizing it coherently.
2.1.1. Establish design specifications

As in engineering design, the first step in designing a curriculum is to establish the design specifications. What exactly are the curriculum goals? Although elementary and secondary schooling has many purposes—preparing young people to live healthy, interesting, and socially responsible lives, for one, and encouraging the development of individual talent, for another—promoting learning is its most fundamental purpose. For design purposes, learning goals must be specific; grand generalizations are not helpful in curriculum design any more than, say, in aircraft design, and they must take the development realities of students into account.

2.1.2. Clarify curriculum constraints

Of course, identifying explicit goals is only one aspect of the process of setting design specifications; clarifying curriculum constraints is its close companion. In any design undertaking there are always constraints, and education is no exception. Such constraints often have to do with cost, state and federal legal requirements, facilities, time availability, faculty preparedness, college admissions requirements, and local traditions, among others. Whatever they are, they need to be made explicit if they are to influence curriculum design. As learning goals and various constraints accumulate, the memory, sorting, tabulating, and graphic capabilities of computers enable designers to organize them in ways—by grade level, subject, connectedness, and priority, for example—that will help all interested parties examine them as a set. The idea is to reach an initial consensus on specifications before beginning to craft a curriculum design.

2.1.3. Design conceptualization

The next step involves conceptualizing a curriculum design that will capture the character of what the new curriculum will be like. According to Designs:

Some overarching idea about the curriculum is a starting place for the creation of a design concept. It may be impressionistic rather than definitive, but no less valuable for that. It provides a point of reference as alternative designs are debated and negotiated. The possibilities are endless, but a curriculum concept commonly includes the instructional contexts to be emphasized, the teaching methods to be used, and the resource to be exploited. [2] p. 56.

By way of illustration, there are two curriculum design concepts from Designs that are pertinent to the topic of this special issue of Technology and Society:

- **A high-tech curriculum** that, from the first year on, exploits the power of state-of-the-art technologies so that all students can become proficient in finding, gathering, organizing, analyzing, and communicating information, which in effect would put them in a virtual classroom of worldwide learning.
- **A science and technology applications curriculum** in which all subjects are studied in the context of agriculture, materials and manufacturing, energy sources and use, information and communications, health, transportation, and such categories of human endeavor [2], p. 57.
To be sure, such brief thematic concepts do not treat all the aspects of a curriculum that must be taken into account, but they are helpful in narrowing the nearly endless curriculum possibilities. In practice, the design group would expand its preferred design concepts into a few paragraphs that set out the main ideas and features that should be included in the finished curriculum design.

2.1.4. Design development

In the light of specified learning goals, identified constraints, and selected design concepts, the next step in K-12 curriculum design has to do with selecting content and organizing it into a coherent whole across grade levels and subjects. It must take into account such matters as child development research findings, effective teaching practices, the capabilities of learning technologies, and the need to monitor student progress. In so doing, curriculum design must, as in any design undertaking, make tradeoffs based on estimates of benefits and costs, and consideration of the risk of failure and undesirable side effects.

*Designs for Science Literacy* summarizes its design strategy as follows:

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 describing blocks well, leaving local educators with the responsibility for making good choices. [2], p. 98

Some of the possible categories of curriculum blocks suggested by Project 2061, which bear on technology and society (many of which can be developed for different student developmental levels), are:

- **applications blocks**, emphasizing the uses of science, mathematics, or technology
- **case-study blocks**, in which the content is organized around one or more case studies that focus on historical episodes, social issues, or technological problems
- **design blocks**, organized around challenges for students to respond to individually or in groups
- **cross-cutting blocks**, which link science, mathematics, and technology to other domains
- **exploration blocks**, which examine a place or time from the perspective of science and technology, and
- **issue blocks**, usually seminars that engage students in an examination of issues involving science, technology, and society.

In order to select blocks from a large pool, their properties must be fully and accurately described. *Textbox 1* shows a sample template, derived from *Designs for Science Literacy*, listing the properties of curriculum building blocks.
Textbox 1
A template for describing curriculum blocks

**Title**

**Overview**
- **Intended Students**: grade range and special groups
- **Subject Area**: area of study (e.g., chemistry, geometry, social studies)
- **Format**: how instruction is organized (e.g., traditional, seminar, independent study)
- **Time Frame**: options for calendar duration, meetings/week, and time/meeting
- **Prerequisites**: prior knowledge and skills for student success in block
- **Rationale**: ostensible purpose for study (e.g., explains phenomena, follows a social issue, design a product)

**Content**
- **Stated Goals**: specific learning outcomes that developer claims block serves
- **Main Topics**: what will be studied (e.g., nutrition, recycling, maps)
- **Activities**: typical student experiences (e.g., measuring rainfall, debating policy)
- **Options**: alternative materials, activities, or organization for teachers or students
- **Connections**: relevance to subsequent or parallel parts of the curriculum

**Operation**
- **Human Resources**: professional or lay staffing needed of instruction or support
- **Material Resources**: needed equipment, supplies, sites, and transportation
- **Assessment**: tasks, scoring guides, and schedules for assessing student progress
- **Teacher Preparation**: needed knowledge and skills in subject and teaching
- **Cost**: time and money needed

**Credibility**
- **Empirical Evaluation**: scientific studies of what students actually learn from block
- **Benchmark Analysis**: evidence-based estimate of which goals are served
- **Reviews**: published expert opinion on the quality of the block
- **Users**: places (and contact people) where block has been implemented
- **Development**: how, when, and by whom block was created

*Source: [2], p. 129*
The curriculum-block assembly process begins by selecting candidates from the pool that appear to meet specified content and structural properties, and adding them graphically to the defined “curriculum space.” The intent is to fill the virtual space with virtual blocks that individually and collectively make sense given the goals, constraints, and design concepts that it must taken into account.

As blocks are added, the computer curriculum accounting software keeps track of all the variables of interest, making it possible for serious analysis of the emerging design to take place. Questions such as the following, posed in Designs, can then be addressed and tradeoffs made:

Are some goals targeted again and again while others are ignored? Is the redundancy needed or wasteful [of time]? How difficult is it to fill [a] 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 those connected to it? [2], p. 112

A design-by-assembly process such as this takes time, not just for the design work itself but also in order to reach a consensus among the many interested groups. Computer networking enables a community to follow the process and provide responses along the way. This leads to the acceptance of a fully worked-out curriculum design. The process used to create the design can also be used to identify needed material resources, including teaching materials, databases, virtual classrooms, professional training, and outside experts.

Computers are not magic tools that can cure all the shortcomings of the K-12 curriculum, but they can provide a technological resource such as educators have never before been able to call upon for designing and managing curricula. So far, however, computer design capacity has been mostly ignored.

2.2. Technology as subject matter

Technology has long been a subject in K-12 education, especially in comprehensive high schools. However, for some time now, views on what the content of technology education ought to be and where, if anywhere, it should fit into a curriculum, have been undergoing change. The nature of that change will be discussed below, followed by suggestions with regard to the content of technology education and its placement in the curriculum.

2.3. The changing view of technology education

At one time, technology had a substantial presence in the schools, particularly in the upper grades. Its orientation, however, was strongly vocational. In recent years, “industrial arts education” has been reconceived as “technology education.” The name in fact signaled an actual change in perspective. This change first became apparent in a report of the International Technology Education Association, Technology for All Americans: A Rationale and Structure for the Study of Technology [3], and then affirmed in its follow-up reports, Standards for Technological
Literacy: Content for the Study of Technology [4] and Advancing Excellence in Technological Literacy [5].

What those reports had in common was a new emphasis on technological literacy and less emphasis on technical competence. Seeking to have all students understand the nature of technology was clearly beginning to overtake the limited goal of training some students for jobs in the trades.

The National Academy of Engineering (NAE) evidenced its support for the transformation of technology education in the schools by undertaking “to develop among relevant communities a common understanding of what technological literacy is, how important it is to the nation, and how it can be achieved” [6, p. vii]. Its report, Technically Speaking: Why All Americans Need to Know More about Technology], argues that “American adults and children have a poor understanding of the essential characteristics of technology, how it influences society, and how people can and do affect its development” [6], p. 1. A higher level of technological literacy is needed, it continues, because “people at all levels of society would be better prepared to make well-informed decisions on matters that affect, or are affected by, technology” and because “as citizens of a democratic society, individuals are also asked to help make technological choices for the country as a whole or for some part of it” [6], p. 3.

Support has also come from the scientific community. In Science for All Americans [1] and its companion, Benchmarks for Science Literacy [7], the AAAS argued that science literacy must necessarily include an understanding of the nature of technology and its ties to science and culture. That claim derived from the broad view it takes of technology that emphasizes its cultural nature rather than its vocational ones:

As long as there have been people, there has been technology. Indeed, the techniques of shaping tools are taken as the chief evidence of the beginning of human culture. On the whole, technology has been a powerful force in the development of civilization, all the more so as its link with science has been forged.

We use technology to try to change the world to suit us better. The changes may relate to survival needs such as food, shelter, or defense, or they may relate to human aspirations such as knowledge, art, or control. But the results of changing the world are often complicated and unpredictable. They can include unexpected benefits, unexpected costs, and unexpected risks—any of which may fall on different social groups at different times. Anticipating the effects of technology is therefore as important as advancing its capabilities. [1], p. 25

It follows that for society to reap the potential benefits of technology while avoiding as many of its negative effects as possible, technological literacy must be widespread. Only well-designed K-12 technology education can provide the next generation with the needed knowledge and outlook. Additional support for the inclusion of technology content in science education can be found in the National Science Education Standards, a report of the National Academy of Sciences [8]. Its
science content standards include a recommendation that “all students should develop abilities of technological design and understanding about science and technology.”

2.4. The content of technology education

The ITEA, NAE, AAAS, and NAS reports cited above differ from one another in language and organization, but they are in accord in believing that technological literacy consists of understanding—at a level appropriate for non-specialists—the nature of technology, the relationship between technology and science, aspects of major technologies, and the relationship between technology and society. The reports agree, for example, that all students should learn the following:

The nature of technology. Technology can be thought of as a process that designs tools and systems intended to serve human purposes. Design includes clarifying specifications, identifying constraints, considering feedback, and making tradeoffs that take cost and risk into account. No matter how well the resulting technologies are designed, they always require human control at some point, and all of them are subject to unintended side effects (which may be positive or negative, and may be different for different individuals or groups), and to the possibility of failure.

Technology and science. Science and technology are not the same. The purpose of science is to increase our understanding of the natural world, whereas that of technology is to solve practical problems and extend human capabilities. Nevertheless, science and technology are strongly interdependent: technology draws on science to invent new technologies, and the tools and systems of technology are necessary for scientific advancement. For its part, modern engineering combines both scientific inquiry and the use of technologies.

Technologies. The world has been shaped—and will continue to be shaped—more through the development, modification, and use of technological systems than by individual inventions. Agriculture has made it possible to feed and clothe a large world population; manufacturing and new materials, along with energy technologies, have changed how we travel, shelter ourselves and, alas, wage war; communications and information technologies have enabled us to tackle problems of enormous complexity, and have connected us to one another and to world knowledge; and health technologies have prolonged life expectancy and improved human well-being.

Technology and Society. Technological and social systems interact strongly: technology has cultural, social, economic, political, environmental, and aesthetic effects; in turn, society both fosters and inhibits the development and use of technologies. Historically, technology has been the driving force behind great social revolutions, all the more so since it developed its close relationship with science. These include not only the Industrial Revolution, but also the several radical transformations in agriculture, disease control, and access to nuclear energy.
2.5. The place of technology education in the curriculum

In thinking about the placement question, the possibility of adding a required academic technology course is not encouraging because of strong resistance to the introduction of any new courses to the curriculum. But such an addition would not be sufficient for fostering technological literacy in any case. Technology needs to be integrated into the curriculum across grade levels and within other academic subjects.

The science case has already been discussed. The outlook is positive because key organizations are in accordance with the importance of including technology content into the K-12 science curriculum. In addition to the ones cited earlier, the National Science Teachers Association (NSTA) has strongly supported the views on technology literacy outlined in the AAAS and NAS reports, and has endorsed the science/technology/society approach to science teaching [9]. Also, the NSTA has collaborated with the AAAS in the publication of the Atlas of Scientific Literacy, a resource that maps, among other things, how technology learning goals can be distributed across the grades to foster understandings of major technological ideas [10].

What, then, about the other school subjects? In lieu of a survey of current practices, one can turn to the national standards recently developed in various school subjects. The standards may be far from current reality, but at least they are useful in discerning the direction leaders want the curriculum in their field to move.

Judging from the standards documents, there is little interest in welcoming technology content in the Arts [11], Civics [12], English Language Arts [13], or, surprisingly—or maybe not—in Mathematics [14].

On the other hand, the situation is not nearly so bleak in the other subjects. In the History standards, politics, economics, and wars are still front and center, but technology enjoys substantial attention in both world and American history. Recommendations by the National Center for History in the Schools [15] include technology-related ones such as these:

- Assess the usefulness of the concept that the revolutions of tool-making, agriculture, and industrialization constituted the three most important turning points in human history.
- Explain how new inventions, including the railroad, steamship, telegraph, photography, and internal combustion engine, transformed patterns of global communication, trade, and state power.
- Describe major medical successes in the treatment of infectious diseases and analyze the causes and social costs of the world influenza pandemic of 1918–1919.
- Analyze how global communications and changing international labor demands have shaped new patterns of world migration since World War II.
- Describe the worldwide implications of the revolutions in nuclear, electronic, and computer technology.

Half of the Social Studies standards are located in thematic categories, namely, “Time, Continuity, and Change,” “Production, Distribution, and Consumption,”
“People, Places, and Environments,” “Global Connections,” and “Science, Technology, and Society,” which provide ample opportunities to deal seriously with technology related issues, though that point is not always made [16]. The Geography standards refer to technology explicitly in several places, for example, calling upon students to be able to “analyze the ways in which technology influences human capacity to modify the physical environment and identify the consequences of the modification” [17].

3. Conclusion

From the perspective of the schoolroom, the impact of technology has been glancing. Progress is being made in using computers to expedite learning, but only modestly, since many educators still regard computers as the newest teaching tool but not part of an information and communications system that makes possible dramatic changes in teaching and learning. Nor have computers yet been used as a sophisticated tool for redesigning and managing the entire K-12 curriculum, although they are certainly capable of being so used. Although technology education has to yet take its proper place in the K-12 curriculum, the new standards suggest that advances are possible.

To reach the teaching, design, and curriculum content goals that modern technologies make possible will likely take decades. But no matter, the stakes are high, for individually and collectively our future depends on achieving widespread technological literacy. In this, the role of K-12 education is crucial. A start has been made, and we must not back off just because educational reform is excruciatingly difficult to achieve.

Acknowledgements

The author would like to note with appreciation that many of the ideas expressed in this paper were developed in collaboration with his decades-long colleague and friend, Dr. Andrew Ahlgren.

References

James Rutherford recently retired as chief education officer of the American Association for the Advancement of Science and founding director of Project 2061. His career also included high school teaching, professorships at Harvard University and New York University, and government service as assistant director of the National Science Foundation and as the first assistant secretary for research and improvement of the US Department of Education. During these years, he initiated and directed several major projects, including Harvard Project Physics, Project City Science, and the Carnegie Science-Humanities Education Project, and served as president of the National Science Teachers Association.