# INTELLECTUALLY STIMULATING & SOCIALLY RESPONSIBLE SCHOOL CURRICULA

## CAN TECHNOLOGY HELP US GET THERE?

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Introduction

Societies maintain educational systems for a variety of reasons. These include aiding the personal growth and development of its citizens, preparing people for the world of work and transmitting the culture and values of the society. To be sure different societies strike different balances among these purposes.

It can be argued that the curriculum needed to address these purposes effectively must reflect the evolving nature of the society and the ways in which the society functions. Among the more prominent factors shaping the way a society functions is the technology it uses to address its purposes.

Clearly this argument leads us to consider the way(s) in which the curriculum could and should be affected by the rapidly developing technologies that surround us. Without prejudging if and how mathematics, language, science and arts curricula should change, it is clear that these subjects could change most dramatically and it behooves us to understand the potential consequences of such changes.

This paper will address the following questions - given the reasons that societies maintain educational systems, and the ways in which curricula could be changed in light of changing technologies, what changes might, in fact, be desirable and for whom? Answering these questions will require consideration of the values of the society and its professed goals for both individuals and as members of the larger collective.

## What do industrialized societies expect of education?

To begin our inquiry we must first consider how and why a society educates its young. In the life of any society there are many social institutions that have an educative role. These include the family, religious institutions and the media as well as school. For the most part, schools have curricula that are stated explicitly. In contrast, the other *de facto* educative agencies of the society rarely have curricula that have been deliberately fashioned to address society's needs and goals for education.

Given that different social institutions contribute to the educative function of a society, one is led to the question "What educative purposes do these various social institutions have?" I consider three traditionally cited purposes of education.

### Transmission of the culture

Over the long term probably the most important role that a society expects its various educative agencies to fulfill is that of transmitting the culture and the values of the society. An enlightened society should seek to do this in a way that does not denigrate the heritage and culture of others. Unfortunately, there are too many societies that convey hate and distrust of others in the process of conveying their own values. All the same, all societies find ways to transmit their culture and heritage.

How do modern societies transmit their culture and heritage from one generation to the next? Without trying to argue for the primacy of one institution over another it is clear that school, home, family, religious institutions and the media all play important roles in addressing this goal of education.

### Preparation of people for the world of work

By far the dominant expectation of education in most societies, at least as articulated by political leaders and by the print and electronic press, is to prepare people for the world of work. In the United States, we are subjected to a constant barrage of complaints from public figures pointing to the failure of our educational system to prepare young people adequately for responsible roles in commerce, industry and the professions. I expect the situation is not substantially different in other countries.

The predominance of this expectation of the consequences of education has grown to the point that in many places in the United States serious experimentation is currently going on addressed to the question of the feasibility of replacing public schools with schools run by profit-making organizations. The logic of these efforts lies in the claim that such organizations, by virtue of their experience in "meeting a payroll" are better able to anticipate the needs of the work world and to prepare students to function in it.

### Assisting the personal growth and development of individuals

The third expectation societies claim to have for their educational systems is that of helping young people develop as distinct individuals with fulfilling lives and relationships. To be sure, the balance between the development of the individual *qua* individual and the development of the individual *qua* member of the collective will vary dramatically from one society to the next. In extreme cases, a society may even choose one of these aims *to the exclusion* of the other.

It could be argued that this responsibility is most properly regarded as that of the family and home. But with the rapid disappearance in industrialized societies of the extended family, and even in many cases the nuclear family, the school is the social institution that is being asked more and more to assume the responsibility for this outcome of education.

### How does the school curriculum aid the addressing of these aims?

One may analyze the behavior of any aspect of the educational system through the prism of these three stated purposes, i.e., transmitting the culture, preparing people for the world of work, and aiding personal growth and development. In particular, we may ask how **school curricula** do and/or do not further the attainment of these aims in any society. We do this in full recognition of the fact that such a perspective is but one of many possible.

Nonetheless, looking through the prism of school curricula is particularly central to the understanding of how the various disciplines contribute to the attainment of these three aims. The case of mathematics is, I believe, special because, for the most part, educative agencies of the society other than school, such as the family and the media, play only a minimal role in the mathematics education of the society. We shall first explore the case of the mathematics curriculum and how it does or does not aid in the addressing of society's goals. Following an examination of mathematics from this perspective, we will turn to other subject areas in order to explore the similarities and differences in the ways they advance society's aims.

## Transmitting the culture

We normally assume that by incorporating the study of language and literature into the curriculum, we assure the role of the school in transmitting the culture and values of the society. To be sure, other societal institutions play an important role in this regard - perhaps even a dominant one.

It should be pointed out that the inclusion of music and the visual arts into the school curriculum is often justified on the grounds of contributing to the school's role in transmitting the culture and values of the society.

In contrast, mathematics and the sciences are not, by and large, considered part of the culture of the society and their inclusion in the curriculum is generally justified on other grounds.

## preparing people for the world of work

The presence of the natural and social sciences in the school curriculum of all of our societies is largely attributed to the need for society to prepare the next generation of people to function in the economy of that society. People who function in very diverse sorts of economic positions need to have a sense of place and time as well as some understanding of that which is physically possible and that which is not.

To be sure, the specialized needs for education in the natural and social sciences will vary depending on what role a person plays in the world of work. The engineer is likely to have greater need for a background in physics than the social worker, who in turn is likely to have a greater need for a background in anthropology than the engineer.

Because modern societies are committed to not asking people to make career choices before puberty at the earliest, there is a period of general education which must educate broadly, if not deeply, in the natural and social sciences.

While I believe that mathematics is neither a natural or social science, it is nonetheless thought of in much the same terms, i.e., as being present in the curriculum in order to prepare people for the workplace.

For the most part, the presence of the arts in the curriculum is not justified or explained by saying that it is an important contributor to the preparation of the next generation for the world of work.

aiding personal growth and development

There are parts of the school curriculum that are described as being directly addressed to this purpose of education. School programs in the visual arts, music and crafts of various sorts are largely addressed to helping youngsters develop aesthetic sensitivity and provide opportunity for personal fulfillment.

In addition to these curriculum content areas, since the close of the second World War, and in many instances preceding that, there has been a school rhetoric that calls for the school to play an important role in the social and emotional development of students. With the growth of the conservative perspective in the past several decades the role of the school curriculum in aiding personal growth and development has become a hard fought political issue. Increasingly we find pressures on school and school curricula that press them away from helping youngsters develop intellectual independence and thoughtful, critical inquiring modes of thinking. As we shall see, this pressure can have important consequences for curriculum content.

What role(s) do the disciplines play in the curriculum - the case of *mathematics*?

I turn now to mathematics as part of the school curriculum and address the question of the ways in which mathematics helps address the three purposes of education that I have used to frame this discussion.

## mathematics as cultural heritage

While it is probably universally recognized that mathematics is a part of the international cultural heritage, it is unfortunate that education authorities (at least in the United States) do not regard mathematics as an important ingredient in the body of culture that needs to be transmitted from one generation to the next.

I believe I understand one reason for the dramatically different perceptions of mathematics on the one hand and literature or music on the other as part of a society's cultural heritage. The difference in perception lies in the different nature of the experience of people with these different fields. In the case of literature or music, most people have, at some point in the course of their formal education, and often for many years beyond, some direct personal experience with the making of literature and/or music. People watch drama on television or the stage. Some people act in amateur theater groups. People listen to music. Some people sing in church choirs. People read books. Some people write them. Most people deliberately undertake to partake of literature and music, sometimes more actively, sometimes less so. In contrast, most formal school experience never gives students the opportunity to do anything with mathematics except lean back and let it wash over them, (hoping they don't drown in the process). In short, it would seem that the elements of cultural heritage are those things that most everybody engages in, however pale that engagement may be compared to the glorious achievements of the Mozarts and the Shakespeares of the society.

I don't believe that this situation will change until there are opportunities for young people to participate in the making of mathematics and science in the ways in which they participate in the making of language and music. I want to be very clear that by this I do not mean simply rehearsing the theorems others have devised or the experiments others have performed. I mean that they must also have the tools to devise theorems and experiments of their own. I will argue later that newly emerging technologies can provide an unprecedented set of tools with which to equip our students to do precisely this.

## mathematics as part of preparation for the workplace

*"You need to know how to do long division in case your calculator breaks".*

*"You need to be able to balance your checkbook".*

*"You need to be able to read graphs in the newspaper".*

*"You need to know calculus to study medicine".*

In many ways mathematics is clearly recognized as having a central role in preparing people for the world of work. This recognition is sometimes informed, thoughtful and deep. Often, however, this recognition is the result of tradition that is not reinspected or reconsidered for decades, and sometimes longer than that.

Roughly speaking, the mathematics we say people need during the course of a general primary and secondary education consists of a variety of topics in arithmetic, geometry, algebra, and calculus. In addition, many have argued that a general primary and secondary mathematical education should also include topics in logic, discrete mathematics and mathematical structures.

For example, the curriculum standards of the National Council of Teachers of Mathematics (NCTM) lists the following thirteen elements in a single list that it regards as appropriate for youngsters ages 11 to 14.

- Mathematics as Problem Solving
- Mathematics as Communication
- Mathematics as Reasoning
- Mathematical Connections
- Number and Number Relationships
- Number Systems and Number Theory
- Computation and Estimation
- Patterns and Functions
- Algebra
- Statistics

- Probability
- Geometry
- Measurement

It is not difficult to infer from this list the importance this reform effort places on mathematics as part of the preparation of youngsters for the workplace. The first four entries, however, could refer to **any** body of mathematical content. These elements of the list tell us something about the insights they would like students to have and what they would like students to be able to do mathematically, but nothing about the mathematical content that they are to do it with.

I prefer a different approach to the problem of describing a primary and secondary mathematics curriculum. I choose to ask what kinds of mathematical objects do you want people to be able to use with some agility, and what kinds of actions would you like people to be able to do with these objects?

My *minimal* candidate list of mathematical objects includes

- number and quantity (counted and measured in the world around one)
- shape and space
- pattern and function (relationships among numbers and quantities from one's surround)

My *minimal* candidate list of mathematical actions with these objects includes

- representing, formulating and modeling

- manipulating and transforming

- inferring and drawing conclusions

- communicating

It is not difficult to defend this formulation of primary and secondary mathematics curriculum in terms of a desirable general preparation of people for world of work. Implied in this Cartesian product of **OBJECTS x ACTIONS** is an extensive list of pedagogic objectives. Recognizing that there are many different things that different people may do, it is clear that we would like all people in the workplace to be skilled at

<u>representing, formulating and modeling</u>

- observe and gather data, both qualitative and quantitative (counted and measured)

- make informed judgments about that which should be considered and that which could be ignored in a given situation

- make reasonable estimates of lengths, weights, times, areas, volumes, costs, etc.

- represent relationships among counted or measured quantities graphically and symbolically

<u>manipulating and transforming</u>

- manipulate number & quantity using appropriate arithmetic operations

- transform functional relationships using appropriate symbolic and graphical operations

<u>inferring and drawing conclusions</u>

- make inferences about assumptions and revise models as needed

- understand and utilize the distinction between necessary & sufficient conditions

- compare and contrast

- make inferences about invariance, symmetry, extreme cases, point of view

communicating

- communicate clearly in both oral and written form

This way of formulating the curriculum is influenced by both linguistics and computer science perspectives. Languages, be they human languages or computer languages, have both nouns and verbs. The verbs tells us about the actions done *by* or *to* the nouns. In the design of computer programs, we have more and more come to appreciate the power of thinking in terms of *objects* and the actions carried out by them or on them. Thus this sort of formulation would appear to be a very general one. Moreover, this **OBJECT x ACTION** Cartesian product of the mathematics curriculum has proven to be both parsimonious and instructive to both teachers and students.

It is probably true that other strategies for the organization of the primary and secondary mathematics curriculum may well lead to similarly desirable lists of pedagogic objectives. No claim is being made here for the unique effectiveness of this approach.

mathematics as a tool for personal growth and development

Normally people do not think of mathematics as an arena in which young people can grow and develop self-confidence and self-esteem. Nor do people tend to think of mathematics as an arena in which students come to develop any sense of the aesthetic. It is generally assumed that to the extent that school can play this sort of role, it is going to be in subject areas other than mathematics.

I believe that, given the nature of mathematics instruction and curriculum available to most students in most societies, this is an accurate perception. This recognition is painful to me as a mathematics educator and I wish it were otherwise. In particular I find it painful because it means that most people never experience mathematics as a source of beauty and delight.

Might it be different? I believe the answer is yes. I will argue in the next section that the judicious and thoughtful use of technology can affect both the practice and the perception of mathematics in the schools. I believe this to be true not only with respect to the educative purpose of aiding personal growth and development but also with respect to the purposes of preparing people for the world of work as well as for transmitting the culture and values of the society.

## How might emerging technology affect these roles?

Increasingly, over the last decade, teachers and researchers have found that thoughtfully crafted technology-based expository curricular materials and exploratory tools can have profound effects on both the content of the mathematics curriculum and what happens in the mathematics classroom. These effects, in turn, can, and I hope will, influence the role of the mathematics curriculum in the way society seeks to address the purposes of education.

### deepening and broadening understanding

By virtue of the fact that software environments can make the intangible interactively manipulable, and do so in several different representations simultaneously, the depth and breadth of understanding that can be reached by students (and teachers) is substantially enlarged.

This expanded understanding comes about by virtue of the ability of the user of the technology to manipulate an abstraction in one representation and see the consequences of his or her actions simultaneously in several different representations. To the degree to which understanding is built on an ability to move nimbly across representations, the contribution of the technology here is clear.

It is clear that a deeper and broader understanding of the conceptual structure of the subject can have an important impact on the effectiveness of schools in preparing people for the world of work.

providing a conceptual grounding for students' manipulative skills

Another potential consequence of the use of appropriately crafted technology is a shift in the nature of manipulative skills, away from rote ceremonies and in the direction of procedures that while being exercised mechanically and with some degree of automaticity, are, at a deep level, understood. Given that, at present, many people in the workplace use bits of mathematics mechanically and *without* understanding, this would seem to be a major improvement.

inviting conjecture and exploration

A feature of many of the exciting technological environments for mathematics education that have been developed recently is that of making it easy for users to make and explore conjectures. I contend that the act of making and exploring conjectures about mathematical objects is the *heart-and-soul* of making mathematics.

How do these exploratory environments make it easy for users to make and explore conjectures? Perhaps the easiest way to answer the question is to invoke once again the **OBJECT x ACTION** metaphor. These environments track the user's interaction with the environment and parse that interaction into the **objects** that the user is acting on and the **actions** that the user is carrying out on those objects. This parsing of the interaction makes it possible for the environment to formulate the set of actions as a procedural entity, with a name if desired. This procedure may then be repeated on other objects. Interesting properties discovered to be true in the case of the procedure acting on one object may then be searched for when the procedure is carried out on other objects. Thus the exploratory environment substantially lowers the difficulty of exploring conjectures. In fact, it tends to make the making and exploring of conjectures an inviting activity.

It has been found over and over again, and in many parts of the world, that if students are given tools that make it easy for them to explore conjectures, they will both make and explore conjectures. This means that they will have, in some measure, something of the experience of making mathematics. This, in turn means that mathematics can begin to play a role in the development of self-confidence and self-esteem of the student. If people emerge from the school experience with mathematics as an engaging element of school life that they found satisfying and perhaps even rewarding, then over time it is likely that mathematics will come to be seen as part of the culture *in fact* as well as in name.

## other potential effects of technology on mathematics education

While the focus of this paper in on curriculum, a brief discussion of the impact of technology on other aspects of mathematics education is appropriate.

### on teachers

If exploratory environments of the sort discussed above become commonplace, then the roles of teachers, particularly at primary and secondary level, are likely to be affected greatly. If students are equipped with tools that allow them to make and explore conjectures, then it is likely that they will rapidly press the edges of the teacher's knowledge of the subject. If this happens, then teachers themselves will be pressed to actively seek to expand their mathematical knowledge on an ongoing basis. This would clearly be a welcome change from the *status quo* in most schools.

### on producers of curricular materials

We are already seeing a dramatic change in the way information is distributed around the world. The four-color, two kilogram mathematics text that we in the United States seem to be enamored of is likely to wane in importance as more and more curricular materials become available on the World Wide Web. The stranglehold that a small number of publishers or a Ministry of Education currently may have on a country's mathematics curriculum is likely to be loosened.

on assessment

Although it is not universally the case, it is now common for students whose mathematical knowledge and achievement is being assessed to be allowed to use hand calculators while taking their examinations. In many instances students are permitted to use graphing calculators. In these instances it is clear that the nature of the problems we pose to the students in order to assess their achievement must and does change. As our technological tools grow in sophistication so that mechanical mathematical procedures can be automated and carried out at the user's request by our tools, it is inevitable that the nature of the problems we pose will become both more challenging and more conceptual.

## Should the mathematical content of the curriculum be changed?

If the new technologies offer such promising opportunities for improving mathematics education, it behooves us to ask whether we should continue with the same mathematical content, or, whether we can take advantage of the opportunity to rethink what might be in the curriculum in the light of the new kinds of tools available to us.

The relative importance of any particular piece of mathematical content cannot be decided upon without taking into account who is doing the deciding, what relative priority they assign to the different societal aims of education and what role they see mathematics playing in addressing those aims.

For those who value above all the importance of transmitting the culture and who see mathematics as an integral part of the culture, it will be important that the mathematical content in schools be such as to make manifest rich beauty of the subject in its own right. They will place great importance at elementary level in such topics as set theory and representing numbers in non-decimal number bases. At secondary level, they will place importance on such topics as algebraic structures and non-linear dynamics.

For those who value above all the importance of preparing people for the world of work, the topics just mentioned will seem less important than a rich exposure to modeling the world around one mathematically. This group will want the curriculum, from the earliest grades on, to place emphasis on developing an ability to estimate the magnitudes of counted and measured quantities in the surround. At secondary level, this group will attach great importance to the study of functions as mathematical representations of relationships among attributes of entities in the surround.

For those who value above all the importance of schools aiding the personal growth and development of students, it is likely that the specific mathematical content of the curriculum will be less important than the ways in which that content is engaged. They are likely to place great emphasis on the importance of collaborative learning strategies and project work as vehicles for carrying the mathematical content while enabling students to develop group problem-solving skills.

It is my view that we are far from being able to reach a significant portion of our students with the argument that the subject of mathematics is beautiful and engaging. We are, I believe, substantially further away from being able to reach the general public with that argument. However, the public does believe that mathematics is an important element in preparing people for the world of work. I believe, therefore, that we can best effect significant change in mathematics education if we shape our curriculum so that it clearly maximizes the ability of students to function effectively in commerce, industry and the professions. Moreover, if we do this in a way that engages the students in the making of mathematics, it is likely that over time we will produce generation of youngsters for whom mathematics has been rewarding and fulfilling. As such youngsters become the public-at-large we can and should allow ourselves the luxury or rethinking the question of curriculum content.

## Who decides what should happen to the mathematics curriculum?

As a final step in considering the case of mathematics as an example of a curriculum in interaction with technology, I turn to the question of who will decide how the mathematics curriculum will evolve given the opportunities presented by the new technology. In my view, we must look to four different, and not quite disjoint, constituencies. These are the mathematics and mathematics education community, the community of mathematics-using disciplines (e.g. the physical sciences, economics, engineering), commerce and industry, and the public at large. They will each have views on the subject and in all likelihood these views will be strongly held.

### the role of the mathematics and mathematics education community

In the past the mathematics community, by and large, has acted as if the primary goal of a society's educative institutions was the transmission of the culture and that mathematics was a central and integral part of that culture. The community of mathematicians and mathematics educators now has the option of seizing the opportunity offered by the new technologies to make mathematics a source of personal fulfillment and reward for individual students. If it does so, then I believe it will go a long way toward its goal of making mathematics a real part of the cultural heritage of humanity.

### the role of the mathematics-using disciplines

In many ways, the community of mathematics-using disciplines has already embraced the opportunities offered by the new technologies. It has done this by changing the ways in mathematics is used within the various disciplines, often without waiting for the mathematics community to sanction the changes. The mathematics community needs to begin serious dialog with this community. The price of not doing so is high. There are already universities in the United States which have abolished their mathematics departments and where the responsibility for mathematics instruction is being assumed by engineers and economists, physicists and physiologists.

### the role of commerce and industry

Because this community attaches great importance to the goal of preparing people for the world of work, there is a danger that the pressure for change from this quarter will be instrumental and mechanical and short-term in nature.

### the role of the public at large

The degree to which the public discourse influences the nature of the mathematics curriculum varies from country to country and often depends on the degree of centralization of the system. In highly decentralized systems, such as that in the United States, it is possible for the uninformed and out-of-date views of a mathematically and scientifically ill-educated public to influence curriculum decisions. Note for example the growing inclusion of "creation science" into the curriculum of biology and geology courses, or the widespread enthusiasm for mathematics curricula that emphasize rote skills at the elementary level and formal symbol manipulation at the secondary level.

I expect the attitudes of the public at large toward mathematics will change slowly. Perhaps if the mathematics community and the community of mathematics-using disciplines succeed in mathematically engaging their students in richer and more fulfilling ways, public attitudes may shift noticeably in a mere generation or two.

What role(s) do the disciplines other than mathematics play in the curriculum?

Following the extended analysis of the case of mathematics as part of the school curriculum and how it might and should evolve given the opportunities offered by the new technologies we turn our attention to some of the other disciplines that prominent in the school curriculum. Here our focus will be on the degree of both similarity and difference to the case of mathematics.

In many ways the analysis of the roles of disciplines other than mathematics in the curriculum is much more straightforward. Let us begin with the case of the natural sciences.

8.1 Science

In the United States natural science, like mathematics, is not often regarded as part of the society's cultural heritage. An interesting recent illustration of this phenomenon is the draft of the standards for the study of American history. The word science appears exactly *once* in the document, and there only to say that "...science is a field that has excluded women".

The natural sciences are, however, seen as the intellectual base of engineering. As such they are central to the development of the ever growing parade of consumer goods that are available to the public. In a somewhat more applied vein, the natural sciences are at the heart of much of the vocational training that we offer at the secondary and community college level.

The social sciences also find their major societal justification in the fact that they underlie much of our theoretical understanding of the world of business and industry. Economics, sociology, psychology and anthropology are now everyday tools of the thoughtful and successful manager in a wide variety of industries.

The natural sciences, or more properly the technological applications of the natural sciences, also play a role in helping the personal growth and development of people. There is a tradition of "tinkering" with technological artifacts in many industrialized countries. These artifacts include amateur radio, automobiles and more recently, computers. There is little doubt that those who engage in such tinkering derive a great deal of personal satisfaction and pleasure from these pursuits.

In the case of mathematics, we saw that exploratory environments can offer the opportunity to change in an important *qualitative* way the nature of the mathematics education we can offer our youngsters. In the case of the sciences there are also technology-based tools the offer similar opportunities. Let me discuss two such computer environments.

8.1.1 acquiring, evaluating and analyzing data

We can now offer students tools for acquiring and analyzing data that differ dramatically from those available to the student of several decades ago. In the natural sciences data acquisition is often carried out with the aid of automated instrumentation that can be easily reconfigured and that is not subject to the fatigue of observers and errors of recording and transcribing data. In the social sciences the connectivity of the internet makes it possible to collect data easily and with much less regard to geography than was hitherto possible and with frequencies that would not have been imaginable even ten years ago.

New data tools do more than simply make the acquisition of data easier and more comprehensive than it has ever been before. They also make possible much richer, deeper and broader analyses of data than was hitherto possible. An example to illustrate the point - until the advent of some of the dynamically manipulable visual data analysis tools on the computer, the application of a wide variety of statistical analytic techniques were performed mechanically and with little understanding of, or appreciation of, the appropriateness of any specific technique in a given situation. The new visual statistical tools have allowed for the development of intuitive understanding of the nature of the data sets that are being analyzed and a sense of when a particular analytic approach is or is not appropriate. Further, these new graphic analytic tools allow for the development of intuitions about the nature of the geometry of spaces of more than three-dimensions - such spaces being the mathematical setting for the understanding of multivariate data of any sort.

The dramatic amplification of the ease of acquiring and analyzing data has heightened our sensitivity to an issue that should have been prominent in the study of the sciences all along - i.e. the evaluation of the validity of the data. It is easy to close one's eyes to this problem if there are too few data. However, as more and more data become available, it becomes clear that one must devote more attention to the question of how to design a data collection protocol and how apposite are the data that are subsequently collected.

## 2 modeling one's world

There is a sense in which one can legitimately say that the study of the sciences is not the study of nature, but rather the study of the models of natural phenomena that humans fashion. The building and testing of models is the central tenet of scientific epistemology. Unfortunately, the teaching and learning of science in the schools does emphasize this notion adequately, if at all.

New computer-based tools make it possible to change the place of model-building in the school science curriculum. There are now a variety of environments that allow students to build and explore models of both natural and social science phenomena. Many of these are specially designed software packages with iconic interfaces that make the formulation of models easier to do by virtue of the fact that they take over the building of the mathematical model that underlies the computation once the user has linked the icons representing the levels and rates of change of levels of the elements of the situation being modeled.

Similarly, the generic productivity tool, the spreadsheet, is an important modeling tool in both the social and natural sciences. Its proper use helps the user develop a richer and deeper sense of the phenomenon being modeled and a better appreciation of the limits of the model.

A particular form of modeling environment deserves special attention here. I refer to the computer simulation. A simulation is an expression of the theory the author of the simulation holds of the nature of the elements and their inter-relationships in the phenomenon or system being simulated. As such it is important that a student, or indeed anyone, using a simulation, be able to inspect, and even possibly modify, the assumptions built into the simulation. Absent this ability, my enthusiasm for simulations wanes rapidly. I believe that simulations that do not permit the user to explore, or at least to know, the nature of their underlying assumptions do more intellectual harm than good.

In short, a generation of science students who learn to understand both the power and limits of their discipline will be able to use, rather than abuse, the subject and better able to resist the growing infatuation for pseudo-science and the misleading of the public to which it is put.

### 8.1.3 other effects of technology on the science curriculum

Other effects of technology on the science curriculum that must be considered are the effects on teachers, the effects on the producers of curricular materials and the effects on assessment.

#### 8.1.3.1 on teachers

If both the data environments and the modeling environments of the sorts discussed above become commonplace, then the roles of science teachers are likely to be affected greatly. If students are equipped with tools that allow them to acquire and analyze data and to build and explore models, then it is likely that they will rapidly press the edges of the teacher's knowledge of the subject. If this happens, then teachers themselves will be pressed to actively seek to expand their knowledge of the subject on an ongoing basis. While it is true, as a general rule, that teachers of science at secondary tend to keep up with their fields more than do teachers of mathematics, nonetheless it is the case that for the most part the currency of the science knowledge of teachers is a problem.

#### 8.1.3.2 on producers of curricular materials

As a source of curricular information and material for both the natural and social sciences, even more than in the case of mathematics, the World Wide Web is a growing source of information. The primacy of the text as the final authoritative source is likely to diminish. As a consequence, the stranglehold that a small number of publishers or a Ministry of Education currently may have on a country's science curriculum is likely to be loosened.

#### 8.1.3.3 on assessment

It is hoped that the nature of the assessments we make of scientific knowledge will move further in the direction of probing understanding and away from asking students to demonstrate their knowledge of the "words of science" which is the dominant current paradigm of assessment of scientific attainment of students. Perhaps the precedent of mathematics assessment, with increasing use by students of graphing calculators leading to the asking of deeper and more sophisticated questions, will be followed by similar moves in the assessment of science attainment.

## 8.2 The Arts

There is little doubt that the presence of the arts in the school curriculum is thought of in terms of the transmission of the culture of the society. Certainly courses in art and music appreciation have this kind of rationale behind them. It is also the case, that school curricula often include drawing and singing classes which are presumably intended to help youngsters develop the wherewithal for continued personal growth and development in the arts.

While these two roles of arts education in the school curriculum are clear, it is also clear that these roles are fragile. They are among the pieces of curriculum most likely to vanish from the scene when budgetary pressures in a school system force retrenchment.

Do the arts play any role in helping to prepare people for the world of work? Realistically, I believe, one has to answer "no". Except for the occasional secondary school that focuses on the visual or performing arts, it must be said that the arts are not thought of in any serious way as a way to prepare the generation to take its place on the economic scene.

Nonetheless, accepting the roles of arts education as important in the transmission of the culture and as stimulant to personal growth and development, we are led to ask are there technology-based environments that might lead us to question whether arts curricula might change in order to capitalize on the opportunities for creativity that these tools offer.

8.2.1 tools for artistic invention and performance

I would like to suggest that computer-based tools might have a substantial effect on education in the visual arts in both its appreciative and creative aspects. The archival capabilities of the internet and CD-ROMs make vast libraries of visual material available widely and inexpensively. Moreover, the ability to search such archives in rich ways already exceeds what is possible with pre-computer technology and there is every reason to believe that research into new kinds of indexing and browsing strategies will yield ever-more powerful ways of doing so.

The potential contribution of technology to the visual arts curriculum is not limited to its appreciative aspect. The growing number of graphics packages offer the possibility for a student artists to achieve effects in shape, form, color, texture, and perspective that hitherto they could only envision in their minds' eyes. Artistic creativity need not be mortgaged quite as heavily to as before to a mastery of technique, because the software can serve as a capable assistant, ready and willing to take up the chores of illuminating a scene or restructuring a scene from a somewhat different vantage point or changing the distribution of colors in a palette.

The appreciative and creative aspects of the musical arts are also potentially enhanced by the thoughtful use of thoughtfully built software environments. CD-ROMs that move through a displayed score as a composition plays, software that allows the key of a composition to be changed, or the harmony and counterpoint to be varied all deepen and broaden the musical experience of the student.

The dramatic arts have also been affected in important ways by the use of computers. In the theater this is particularly true in the area of lighting and sound on stage. The automatization of light and sound cues allows designers to direct their attention to the nuance of mood and worry less about the mechanics of dimmers followspots. Perhaps the most affected aspect of the dramatic arts has been film and television. Special effects, hand held cameras, animation - both computer-generated and hand-drawn, new editing techniques have all transformed the making and viewing of productions in these media.

## 8.3 Language

Finally, we turn to the subject of language. There is probably no subject whose mastery is of greater importance in the lives of most people than language. The ability to speak and to listen, to write and to read is by far the most important collection of skills that a human acquires. It is of some interest, therefore, that much of this learning takes place before youngsters reach school, and during the school years well outside of the schoolroom, and continues for many people long after formal schooling is completed.

Indeed, reading writing, speaking and listening are of primary importance from the perspective of each of our three listed purposes for an educational system, i.e., transmitting the culture of the society, preparing people for the world of work, and giving people the tools for personal growth and development.

As in the case of mathematics and the sciences, there is at least one computer-based environment that offers a dramatically different kind of tool for use in the language classroom, i.e., the word processor. Much has been already written and little needs to be added here about the extraordinary expansion of ease of control over written language that this tool offers.

However, the spread of hypermedia, both in documents that reside within a single computer and those that live on a network, gives rise to an entirely new sort of challenge for the language curriculum.

8.3.1 narration, exposition and argument in non-linear media

How can we help people to develop the skill of using language effectively in contexts in which their linguistic productions may not be traversed linearly and sequentially? Traditionally, classes have taught the writer/speaker to structure narration, exposition and argument in ways that depended inherently on the assumption that the reader/listener would begin at the beginning and follow as the author led him or her through to the end. Similarly we have taught the reader/listener strategies for attending to the "story line" of the writer/speaker that relied on the essential linearity of the language offered.

There is an interesting interaction here between the language curriculum and the arts curriculum. As the medium of recorded communication distinguishes less and less between recorded words and recorded images and sounds, we have to anticipate the act of creating a document will involve more than simply the act of putting words to "paper". Images and sounds will become an integral part of what the author composes and inserts into the document. To be sure, the magazine writer, composing an article for a newsmagazine could always rely on the fact that there would be photographs accompanying the story. But it was rarely he or she who chose the photographs and placed them appropriately. There was never a film or sound woven integrally into the fabric of the document. In short, we must anticipate that the notion of literacy will be expanded beyond that of literacy with words to a kind of literacy with images and sound as well. We must not lose sight of the fact that the ultimate intent of a document will always be to tell a story, or to explain something to someone or to make an argument supporting a point of view.

I do not have answers to offer here - only questions. But I do have confidence that as we live with the new capabilities that our technology offers us, we will develop both greater sensitivity to these issues as well as better strategies for engaging them. As we do so, I think it is both inevitable, and indeed desirable, that school curriculum in the area of language change to reflect our evolving needs and capabilities.

## Conclusion

I have tried to show how the mathematics, science, language and arts curricula, as shaped by various constituencies, play a variety of roles in helping society address its aims for its educative institutions. Many will claim that in virtually no instance does the technology offer an opportunity that is not, in principle, otherwise available. Even if one takes this point of view, it must be granted that at some point *changes in degree* become *changes in kind*. The new technologies offer a range of opportunities to shape curricula in new ways so as address society's aims more effectively than in the past. The challenge is great but so is the opportunity.