Dumbing Down Mathematics and Science: Sizer's Essential Schools Proposal

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Abstract

Popular culture contains widespread misconceptions of science and the scientific process. Sadly, these misconceptions are also present in Theodore Sizer's books on high school educational reform. The unfortunate result is that Sizer proposes educational reforms that amount, in the case of science and mathematics, to an elimination of the content and richness of these areas of knowledge.

This article contains some suggestions about teaching science and mathematics at the secondary school level. These suggestions are based on an extended discussion—extended because the issues are rather complex—of what science is and is not, and what scientists see themselves as doing.

These suggestions are not based on the idea that most students will become scientists. They are, however, based on the presumption that having an appreciation for the basic organizing principles of science is both possible and important for non-scientists. The suggestions are contrasted with those presented in Sizer's books.

Introduction

In two books ([1], [2]), Theodore Sizer has proposed a fundamental restructuring of high school education, and he has formed a consortium of "Essential Schools" that are implementing his suggestions. Although his proposed educational model has the stated aim of making education more rigorous, and students more accountable for their learning, I believe that his proposals actually amount to a retreat from the idea that science and mathematics can be taught so they become meaningful to today's students and tomorrow's citizens.

Sizer's books are an influential part of a large debate that has been going on for the last fifteen years (and in some sense, for the last hundred years): a debate on the role and aims of public education. The debate is vast: it encompasses heated arguments on proposals for curriculum reform as well as proposals on the structure of the school day and teaching techniques. Because the debate is so large, it is impossible to characterize simply: there are the inevitable charlatans promising easy solutions at no expense; there is the teacher-bashing contingent that is always popular in certain circles, and there are thoughtful and serious, often incompatible, and often controversial proposals for large-scale change.

Sizer is not a charlatan; nor does he traffic in teacher bashing. Although I believe he is fundamentally wrong, his ideas are honest and have to be taken seriously.

There is, indeed, much that is impressively correct in these two books. Sizer has an eye for what is going on in high schools, and an ear for the nuances of speech of students, administrators, and teachers. He has spent years visiting high schools and his accounts of these visits show real insight into the educational dynamics that drives most schools.

In a nutshell, Sizer is rightly concerned with "students who are drifting anonymously through a friendly but soft school program" ([1], p. 229). He demonstrates convincingly that students don't learn very much because they are allowed to be passive. He wants to change the educational process so that students will be forced to take responsibility for their own education, and thereby truly internalize what they are learning.

I believe Sizer deserves credit for bringing out in sympathetic detail the way in which American high schools fall short of graduating educated citizens of a democratic society. In this respect, his books are significant.

Sizer proposes nine principles on which he believes high school education should be founded. I want to concentrate here on three of these principles:

> 2. The school's goals should be simple: each student should master a number of essential skills and be competent in certain areas of knowledge. Although these skills and areas will, to varying degrees, reflect the traditional academic disciplines, the program's design should be shaped by the intellectual and imaginative powers and competencies that students need, rather than by conventional "subjects." The aphorism "less is more" should dominate: curricular decisions are to be directed toward the students' attempt to gain mastery rather than by the teachers' effort to cover content.
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> 6. . . . The diploma should be awarded on a successful final demonstration of mastery for graduation—an Exhibition. This Exhibition by the student [shows] his or her grasp of the central skills and knowledge of the school's program . . . . The emphasis is on the students' demonstration that they can do important things.
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> 8. The principal and teachers should perceive of themselves first as generalists (teachers and scholars in general education) and next as specialists (experts in a particular discipline). . . . ([2], pp. 207-208)

These three principles—"less is more"; exhibitions as a goal or proof of successful education; high school teachers as generalists—have also been promoted by other educational reformers. There is something to be said for each of these principles. But particularly in terms of science and mathematics, they are either (in Sizer's formulation) inappropriate or misapplied.

In fact, as I read through Sizer's two books, I was continually struck by how shallow his view of science and mathematics is.

This is not in itself surprising. Science and mathematics have a bad reputation in contemporary American culture. Although they are held in a certain amount of awe—not usually for very good reasons, in my opinion—the most common attitudes are negative, in particular:

- Science and mathematics are comprehensible only to geniuses, and therefore need special treatment in order to be brought down to the level of ordinary people. (There is a biology textbook published by a major textbook company titled "Biology: An Everyday Experience". I am continually struck by the defensiveness and pandering of this title.)
- Science and mathematics are dry and sterile, with no inherent interest. (I always have to be careful telling people that I enjoy doing mathematics—most people think it consists of adding up long columns of figures.)
- Science and mathematics are mechanical, hierarchical ways of interacting with the world; they embody an antagonism to the human spirit.

We don't have these attitudes about English literature, say, or about music, or history, or foreign languages. These attitudes about science are so pervasive, however, that they make it difficult to discuss science curriculum without first talking about what science is and what scientists see themselves as doing.

WHAT SCIENCE IS NOT

Unfortunately, we all have a simple little definition of science in our minds. We got it from the first lesson in every science class we took in high school—you know, the one about The Scientific Method—and it goes like this: scientists

1. Collect data.
2. Find some pattern in the data and make a hypothesis.
3. Test the hypothesis.
4. Collect more data.

If scientists and mathematicians actually did this, it would in truth be boring and sterile. Who would want to spend his or her life doing such a thing? This is *not* the way science is done.

Sometimes we see a more sophisticated version of this: scientists

1. Make a hypothesis.
2. Test the hypothesis by collecting relevant data.
3. Make a new hypothesis.

But this is equally nonsensical. Where do these hypotheses come from? Scientists and mathematicians don't just sit around making idle conjectures to test. (And the widespread perception that they do is what lies behind former Senator William Proxmire's "Golden Fleece" awards which were used to ridicule scientists for, say, investigating the mating behavior of arthropods[1].)

WHAT SCIENCE IS

The truth is this: each science has an intellectual core, a set of organizing principles. These principles have been arrived at slowly, with great effort. For the most part, they can be named simply enough, but fully understanding them is the work of generations. Here are a few of these organizing principles (presented in a far too condensed form—shelves of books have been written about each one of them):

Biology

The Cell Theory Living things are made of cells. Cells are the environment in which the chemical reactions of life take place.

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[1] Presumably, most people are much more interested in the mating behavior of presidential candidates.

The Unity of Biochemistry The sequence of DNA in an organism's chromosomes determines the structure of its proteins, which in turn determine the characteristics of that organism.

Evolution Chromosomes in different organisms are related in ways that reflect their common ancestry. Species evolve from each other by natural selection.

The fact that every organism on this planet shares the same genetic code is an example of the unity of biochemistry, and is made understandable by the theory of evolution.

Chemistry

The Periodic Table This table contains a wealth of information about the relationships between the properties of different chemical elements.

One could contrast the periodic table with, say, a list of presidents of the United States. There is an essential distinction between these two tables. A list of presidents will tell the names and dates of the presidents; it is a collection of these facts. But even though the periodic table contains factual information, it is not fundamentally a collection of facts. It is a way of organizing those facts. The position of an element in the periodic table gives a lot of information about the chemical properties of that element. Elements in the same column of the table, for instance, have similar chemical properties. Unless you understand the way the periodic table organizes this information, you can't understand chemistry. A lot of modern physics was developed to try to understand why the periodic table looks the way it does.

Dynamic Equilibrium When I look at a still, quiet pond, I see tranquility. A chemist, however, sees molecules of water continually evaporating from the pond, and other molecules condensing back onto the surface.

In a similar fashion, every bone in your body is being continually torn down and reconstructed—over a period of time, even though a bone looks like it had never changed, it will have been completely replaced.

Chemists look at virtually everything this way—in particular, chemical reactions typically can go "backwards" and "forwards" at the same time. Which way predominates in any instance depends on the environment of the reaction—the temperature, the concentration of the reacting materials and the products, and so on. Such a reaction proceeds until a dynamic equilibrium is reached, at which point the two opposing reactions exactly cancel each other out. Changing the environment of the reaction can change the equilibrium point of the reaction.

The existence of life depends on chemical reactions in cells being driven one way rather than another, and the intricate biochemical processes that are characteristic of living organisms work together to make this come out just right.

Physics

Much of physics can be understood as built around two pairs of complementary but interwoven themes:

Particles and Waves Baseballs, planets, electrons, and roller coasters can be thought of as particles. Particles have mass and are acted on by forces. The forces are often naturally described by force fields, such as electric or magnetic fields.

Water waves, sound, and light are waves. While particles either hit an obstacle or miss it, waves bend around it.

It is remarkable, however, that light also has properties of a particle, and electrons also have properties of waves.

Matter and Energy Matter and energy are subject to many transformations, and physics and chemistry are in large part the study of these transformations: chemical reactions, getting useful work out of heat, creating light from electrical energy, and so on. The laws of conservation of matter and conservation of energy were major unifying principles which tied these transformations together.

More recently, the theory of relativity has shown that there is really one law: matter and energy are jointly conserved but can be transformed into each other.

Mathematics

Abstraction The primary mathematical abstractions are numbers and shapes; and we are so familiar with them that we normally don't even think of them as abstractions. But they are, and it took the human race a hundred thousand years to come up with them.

Two key abstractions that are important at the high school level are

1. Variables. A variable is an abstraction of a number. With variables, we can make models (i.e., abstractions) of real problems, and solve them mathematically.
2. Functions. A function specifies how two quantities vary with respect to each other. Common ways of representing functions are as tables of values, graphs, and formulas. Learning how to translate between these three kinds of representations is an important part of high school mathematics.

There are many other abstractions in mathematics.

Deductive Reasoning Formal deductive reasoning originated with Greek mathematics. Students first tend to encounter it in high school geometry. The power of deductive reasoning made such an impression on people that mathematics became a standard model for centuries of what reasoning and knowledge should look like.

The Synthesis of Algebra and Geometry In the early seventeenth century, Descartes showed that algebra and geometry were in a sense equivalent—anything you could express in one you could express in the other. This made it possible to use algebra in geometric reasoning, and conversely to use geometric intuition in algebra.

What Does it Mean to Do Science?

The scientific enterprise—doing science—has to be understood in terms of a tension, or an interplay, between theory (such as these organizing principles), and experimental fact.

We can see this in the work of Galileo, who lived at the beginning of what we now refer to as the Scientific Revolution, and who was the first person to investigate the motion of falling bodies in what we recognize today as a scientific manner.

Ideas of motion before Galileo were very different from those we hold now. It was believed, for instance, that an arrow shot through the air was kept moving by the air pushing on it.

It was also believed (and stated by Aristotle, who was regarded as an authority) that heavy objects would always fall faster than light objects. Now actually, there had been cogent arguments put forward for some time that this might not be correct; that objects of different weights would fall at the same rate. But as far as I know, no one had actually performed an experiment to determine the truth of this.

There used to be a widely believed story that Galileo went to the top of the Leaning Tower of Pisa, dropped two objects of different weights, and showed that they reached the ground simultaneously. The moral drawn from this story is that Galileo overthrew Aristotelian physics by performing the first physics experiment, thus grounding physics in experimental fact for the first time.

This, however, is not what happened. Galileo never performed that experiment, and never claimed to. It would have failed in any case, due to the effects of air resistance; and Galileo was well aware of air resistance. What he actually did was astonishing and profound.

Galileo in effect asked the following question: how does the velocity of a falling body vary with respect to time? It was remarkable that he even asked this question, for a number of reasons:

1. This was the first time that anyone had suggested that there could be a quantitative, mathematical relationship between velocity and time. The question as Galileo posed it is far more sophisticated than simply asking whether heavy bodies fall faster than light ones. With Galileo we enter a new conceptual universe.
2. It was not obvious that the velocity actually *did* vary with time. It was commonly believed that the velocity of a falling body was constant: if it fell fast, then it *started out* falling fast. In fact, it was difficult to understand just what it would mean for the velocity to change in a continuous manner.
3. Given the technology of the time, it was hard to see how this question could be addressed. Modern clocks were just beginning to come into existence. Falling bodies simply fell too quickly to measure anything very well. And there was the problem of air resistance to deal with.

The way Galileo solved the third problem was to vary it in such a way that he slowed down the descent of the falling body. Instead of dropping a metal ball, he let it roll down a groove in a board. By decreasing the steepness of the board, he slowed down the rolling ball so that its position could be measured at various times, even with the primitive time measuring instruments he had available to him. And since the balls were rolling relatively slowly, air resistance could be ignored.

He found that the velocity was not constant; that it was proportional to the time elapsed since the ball was let go (that is, the acceleration was constant); and that the velocity did not depend on the weight of the ball.

Galileo was the first person to give a clear description of uniformly accelerated motion. In doing so, he laid the groundwork for the grand synthesis of Newtonian physics a generation later.

He went on to explain how the velocity of a thrown object could be regarded as the composition of its horizontal and vertical velocities, and that based on this, it could be expected to travel in a parabola.

To summarize what Galileo did:

1. Instead of trying to explain a complicated phenomenon directly, he created an experiment that exhibited this phenomenon in a simplified, measurable, form.
2. He looked for a mathematical description, or model, of this experiment.
3. He used what he found to deduce what must happen in more complicated situations.

But, brilliant as this technique was, it would not have been possible without the theoretical insight to look for mathematical relations in simple situations. *Galileo was not simply collecting data and looking for patterns.* If that was what he was doing, he probably *would* have gone to Pisa and dropped weights from the tower; and he would have found nothing.

Facts in science by themselves mean very little. They need theory to give them meaning. It was because of the theoretical basis of Galileo's work that he was able even to look for the facts that would turn out to be useful.

On the other hand, theories can also be cheap. Unless they are ultimately grounded in observational fact, they have no value.

So science does not consist of collecting idle facts and making theories out of them, nor is it spinning idle theories without any factual basis. The hardest thing in science is often not a matter of answering a question—it is finding the right question to ask. Finding the question is the irreducibly hard task that the greatest scientists devote their lives to.

Galileo's greatness lay in his discovery that while the world as it is presented to our senses may be complex, simple phenomena of motion can be described by regular physical laws expressed in the language of mathematics. We have learned this lesson so well that this seems obvious to us today; it can be hard to realize just how strange and remarkable this idea was when Galileo first came to it.

This viewpoint of Galileo led to science as we understand it today: It made the world more understandable, and more awesome and wonderful than had ever been imagined. In Galileo's own words,

> Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood until one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics...

What Does It Mean To Teach Science? (Less Is Not More)

There is a difference between an organizing principle on one hand and a fact, or even an application, on the other. *A science or mathematics course that is not built around the organizing principles of science does not teach science.*

That may seem like an extreme thing to say, and many people would disagree with it. We have all heard of cute "physics for poets" or "science for the right-brained" curricula. These may be one step up from biology as an "everyday experience", but they feed into the same destructive cultural stereotype. By way of contrast, a course entitled "poetry for physicists" would rightly be regarded as a joke.

Science courses must be built around the major ideas of science; this cannot happen unless students are also exposed to enough of the richness and detail of scientific factual knowledge to make these ideas—these organizing principles—real. The idea that "less is more" is misconceived when it comes to science education. Of course if a biology class were to consist solely of a year of classification of plants and animals; or if a mathematics class consisted primarily of mindless symbolic manipulations, there might be a point to this. But the problem we have is not that our students are being taught too much, but that, really, they are being taught too little: that science and mathematics are not being taught as the central intellectual human achievements that they are. One cannot convey this by extracting a small part of chemistry, say, and "having the students learn it really well". Students must have a view of the subject as a whole; they must see the broad scope of the subject. This cannot happen without learning a lot of details in the process.

Appropriate Science Work For High School Students

Every so often you see an article in the newspaper about a school science fair. In many such articles, students are portrayed as solving serious scientific problems, often problems that their teachers "don't understand". This is certainly unlikely; and in fact these articles depict a form of gee-whiz science having little relation with the real thing. But what about science fairs themselves? Are they really a good use of student time?

I know some people who as high school students had very positive experiences in science fairs. I think it's fair to say, however, that these people are quite unusual. In many cases they are now professional scientists, and as students they had access to advice and mentoring from scientists. This seems to be the necessary criterion for a successful science fair project—you need to have serious contact with a real scientist to make it worthwhile. Projects created under these conditions are often wonderful; they provide real learning experiences that may well be the high point of a student's high school career.

The vast majority of students, however, simply do not have such contact, and it's hard to see how they could. Furthermore, classroom teachers do not have the time to provide the kind of individual attention over an extended period of time that would be needed. For this reason, most science fair projects are at best a waste of time, and are often much worse than that. Middle school students love to make papier-maché volcanos for science fair projects, and high school students are often quite fuzzy on what it means to run a controlled experiment. But even students who have some idea that a project should ask a serious question and attempt to answer it are put in a nearly impossible position: they are really not prepared to know what a good question is. After all, real scientists typically get to that point sometime in graduate school.

This is why, unfortunately, very few science fair projects contain any real science. While there have been some notable exceptions, most science fair projects misrepresent science and scientific creativity.

Doing science consists of applying the organizing principles of science to new situations, examining their foundations, extending them, even trying to contradict them. This is work that high school students are not prepared to do. What they *can* do is see, recreate, and critically question the experiments and reasoning that have led us to our current state of knowledge; this is what is done, in a guided fashion, in good science and mathematics classes by means of homework, laboratory experiments, class discussions, and outside reading.

Science and mathematics have a different quality from many other subjects, and that is that they are inescapably linear. You really can't get far in mathematics without algebra and geometry; and you really can't get far in science without mathematics.

This linearity affects both how we teach students and how we assess them. It's possible for high school students to read 20th century literature, perform 20th century music, learn 20th century history. But if we do an exemplary job teaching mathematics in high school, we will have brought our seniors up to where mathematics was about 300 years ago—and that's no mean achievement.

It is for this reason that it is unrealistic to expect high school students to do original scientific work; they do not yet have the background, and it would be doing them a disservice to pretend they do. That is not to say that science and mathematics courses cannot be stimulating, exciting, and relevant; they should be. But it is important to keep in mind that we are *not* turning out high school scientists: we are turning out people who have an appreciation for the way science is organized and who have an ability to read about it and learn more about it. We're turning out people who at some level understand the basic organizing principles of science.

EXHIBITIONS AND "AUTHENTIC ASSESSMENT"

In contrast, Sizer believes that public demonstrations or "exhibitions" provide the most authentic way of evaluating high school education, and should serve as the goal of high school education—in fact, as the exit requirement—even to the extent that they displace formal instruction:

> If a student can convince himself, his community, and those whose approbation he needs (college admissions officers and employers) of his intellectual merit, who cares whether he has attended school for 180 days for each of thirteen years? No one—assuming the authenticity of the Exhibition. While ways of assessing the student's intellectual habits over time would be required, serious Exhibitions, ones with integrity, would make more sense as a qualification for a valid diploma than mere school attendance. ([2], p. 198)

What do these exhibitions consist of?

Science fair projects are given as examples in Essential Schools Project literature.

Sizer also gives quite a few examples in [2]. Here is the one I think is most interesting:

> Estimate the number of rubber molecules peeled off a tire at each revolution on an asphalt surface. Be prepared to explain both the procedures you selected and the variables attendant on your solution. ([2], p. 100)

Sizer says this requires "a knowledge of chemistry and considerable ingenuity." Well, perhaps. The problem is really not well stated, because rubber is not a simple molecule but a polymer. I assume that to make sense, the problem then is really asking how many rubber *monomers* are peeled off a tire at each revolution. In addition, there are a number of different rubber polymers that are in common use. Referring to an organic chemistry text, I couldn't tell which kind of rubber was used in automobile tires. Presumably students could find this out somehow. Then they could look up the density of rubber, and from the chemical formula for the rubber monomer they could get the volume of the monomer. Finally, they could compute the volume worn off a tire in its expected lifetime, which taken together with the circumference of a tire and the number of miles of expected wear, would give them the volume worn off in 1 revolution of the tire. Dividing that by the volume of a rubber monomer gives the number requested.

What is this problem good for? Probably a day of class discussion and homework, or perhaps an independent assignment. But it does not cover very much of chemistry, or of mathematics, and I can't see how anyone could say that this kind of thing demonstrates a broad knowledge of science.

And this, I think, was the best science problem in the book—not really a bad one at all; but not an "exhibition".

Another example asks the student to come up with a set of menus for school lunches which will then be served in the school cafeteria. Again, it sounds like a biology term paper on an important but narrow subject, not a final exhibition of knowledge of biology.

Some exhibitions are bizarre:

> A. Describe how you would measure the distance between your ears without using calipers. B. When you are satisfied with the method you have devised, compare the result with that obtained by using calipers. Discuss what you would need to do to make your method almost as reliable as using calipers. C. Carry out your plan and describe the results. D. Critique your work, describing what, if anything, you might do differently in the first three parts of this task. ([2], p. 99)

Some are trivial, as in the following “levers and pulleys” problem:

> Devise a way to remove a heavy, bulky object now lodged in a building’s exposed cellar; defend your solution on the basis of specific physical laws. ([2], p. 106)

And finally, here is an exhibition for advanced “early college” students:

> B. ENGINEERING, SCIENCE, AND MECHANICS
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> The engine and drivetrain of the 1983 Chevette before you has been “sabotaged” by us in a number of ways. Please troubleshoot the problems and repair them in the shortest amount of time and with as few new parts as possible. Draw up a description both of the problems and of your specific remedies; include a bill for the owner. (You should assign your labor time at the rate of $28 per hour.) Be prepared to defend your troubleshooting strategy, to explain why the sabotage caused flaws in the engine’s functioning and to tell us whether there were remedies you considered and then discarded. ([2], p.118)

I think the most charitable thing that can be said about this is that it confuses science with auto mechanics.

The very best of Sizer’s exhibitions could be used for homework problems or reports. The scientific content of most the exhibitions is thin or non-existent. They tend to confuse science with public affairs (more on this below). None of them can serve as an exit requirement for a high school diploma in the field of science.

And if they are really just class projects, then I think we have to allow for the discretion of the teacher. Mandating teaching styles is something that has never worked well. Some teachers find some projects useful; others do not. And projects take time. While some projects can be useful, I can’t see how projects covering a year’s curriculum in any science could be scheduled in a year.

The thing that bothers me most about these exhibitions, however, is that they simply do not reflect the integrity of the subject as a whole. When you come down to it, how could they? How can the conceptual basis of a year of serious study of a science be encapsulated in an exhibition?

INTERDISCIPLINARY STUDIES IN THE ESSENTIAL SCHOOLS

Sizer doesn’t actually talk very explicitly about interdisciplinary studies, or about teachers as generalists. In his books this idea comes up in two contexts:

a) He wants to make the teacher-student relation less impersonal, and to that end, have each teacher be responsible for more aspects of a student’s education. He is of course aware that there will be resistance to this idea:

> At a meeting at a city high school a cherubic-looking white-haired chemistry teacher kept nodding and agreeing with the argument I made in my presentation to the faculty that the number of students assigned to each teacher had to be radically reduced. She balked, however, at any compromise on her wish to teach nothing but chemistry, at least as she defined chemistry. I reasoned with her: this is too poor a school to more than double the teaching force. Couldn’t she teach some mathematics to kids who were her chemistry students? *I’m not a mathematics teacher*, she replied. I countered, I’m not suggesting that you teach advanced math, just algebra. *I’m not a math teacher.* Can you teach chemistry to any standard without math? *That’s different.* How? She broke into tears. *I would rather teach two hundred students chemistry than teach anything else.* But you can’t know that many kids at all . . . *I know, I know, I know.* ([2], p. 43)

The phrase "just algebra" gives this away. Does Sizer really think that you don't have to have a good understanding of mathematics (enough that you could teach "advanced mathematics") in order to be able to teach "just algebra"? There is no way we are going to improve education by having a good chemistry teacher function as a mediocre mathematics teacher. Sizer is motivated here by the need to keep costs down while installing some kind of advising system. I don't think he solves the problem.

b) Some of his exhibitions purport to mix science with other disciplines. Here is one example:

> Recycling of all sorts of waste will be organized and supervised by a schoolwide committee, reports on its effectiveness regularly issued, and analyses of and comparisons with similar efforts elsewhere published. ([2], p. 133)

In one of the schools in the project, a biology class spent some time debating the ethics of refusing employment to a person with a chronic disability or disease.

Maybe these are legitimate topics in a public issues curriculum—perhaps in social studies—but the science in each of them is negligible.

There is a great deal of pressure from some quarters nowadays to restructure science courses in order to make science "real", to try to show how science is important by basing science courses on public issues.

We do need scientifically literate citizens—people who can appreciate the relationship of science to public issues. But science per se is not public issues. Attempts to build science courses about matters of public policy (acid rain; destruction of rainforests; nuclear energy) fail because they do not really teach the core content of science.

It's as if one learned about France in a French class without learning the language—for the usual reasons: language is boring, only geniuses can understand it, unless you are going to be a professor of French you don't really need it, and it's basically inhuman and mechanistic (all that vocabulary and those irregular verbs, and who can pronounce it?). Of course you learn about France in a French class. But unless the course is built about learning the French language, it can't really be called a French class.

Displacing the scientific curriculum by a discussion of social issues does not empower our young people. It actually disempowers them, because it creates the pretense that they are dealing with scientific ideas without giving them any of the content that would enable them to understand what they are talking about.

The Importance of Science in Intellectual History

Lest it be thought that I am arguing for a narrow view of teacher specialization, I want to make it clear that I think that science, and the influence of science, is not well enough appreciated, even among teachers. I believe that if more people were conscious of the centrality of science to our view of the world, we would all be more deeply educated and more thoughtful people.

Let me give just a few examples:

The deductive method, as exemplified by Euclidean geometry, had an effect on Western thought that extended far beyond Greek mathematics.

Why, for instance, did philosophers in the Middle Ages from Maimonides to Aquinas think that it would be necessary, or important, to give proofs of the existence of God? Certainly the Biblical text itself is not at all concerned with such proofs—the very idea of a proof would have been incomprehensible to people living at the time the Bible was first written down. And these philosophers were quite conscious of the debt they owed to geometry: Aquinas' *Summa Theologica* was known as the "spiritual Euclid".

Similarly, when the authors of the Declaration of Independence wrote, "We hold these truths to be self-evident . . . ", they were quoting Greek mathematical philosophy; they were appealing explicitly to a Euclidean deductive model based ultimately on "self-evident" axioms[2].

The Scientific Revolution that we associate with Copernicus, Kepler, Galileo, and Newton was another primal event in Western thought.

The word "revolution" itself came into use as a political term only after it had been used by Copernicus to describe the revolution of the Earth around the Sun. This was not an accident of etymology. If the earth could move, perhaps also other things could change. The religious and political implications of the Copernican world-view were immediately seen to be profound.

Here is another example, again from the Declaration of Independence:

> When in the course of human events, it becomes necessary for one people to dissolve the political bands which have connected them with another, and to assume among the powers of the earth, the separate and equal station to which *the Laws of Nature* and of Nature's God entitles them, . . . [my emphasis]

The Laws of Nature—who before Galileo or Newton would have spoken in those terms? The very idea that there were Laws of Nature that could be comprehended by people and used to understand and predict the workings of the physical world—this was a liberating idea, not just in the world of science, but in Western intellectual and political history.

Nowhere in Sizer's books is there an indication that science is an important component of our common cultural heritage, that it has a lot to do with how we think of ourselves and the world, that its ideas are profound and need to be wrestled with over a long time.

Rather, his program reduces science to fragmented bits of odd knowledge, discussions of public issues, and cute but superficial exhibitions; it ignores the central significance of science in human history and culture. By trivializing the scientific part of the curriculum, it omits half of the richness of the human imagination.

References

[1] Theodore R. Sizer. *Horace's Compromise: The Dilemma of the American High School.* Houghton Mifflin, Boston, 1984. [LA222.S54].

[2] Theodore R. Sizer. *Horace's School: Redesigning the American High School.* Houghton Mifflin, Boston, 1992. [LA222.S544].

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[2] We no longer regard axioms as self-evident, but that is due to later developments in mathematics in the 19th century.