ON THE RELATIONSHIPS BETWEEN MATHEMATICS AND SCIENCE IN SCHOOLS

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1. The current scene

In our elementary schools, mathematics and science play completely different roles. Mathematics is established as the second most important subject behind reading. It is taught in virtually every classroom almost every day. It is tested. In many areas of the country, mean mathematics achievement scores for each school are published, and the quality of a school's program is judged in some way on how well the students in that school perform on the test. In some states of the country, there are state-wide tests for graduation from 8th grade that include mathematics. Now there is the possibility of a national test at 8^{th} grade.

None of this is true of science in elementary schools. Science is not taught everywhere, and even where it is taught, it is seldom taught daily. Although it appears on test batteries, few schools are judged by how well their students do in science, and seldom do mean science scores in science appear in newspapers. Though it is certainly possible that somewhere a state-wide science test is required for graduation from 8th grade, I know of no state in the country that has such a requirement. However, recently a number of states, including Virginia, have instituted tests in science and other disciplines at the eighth grade level that are to be used in making promotion decisions.

It is sometimes said that mathematics in our schools is in bad shape – I have been among those who have said this – but mathematics in our elementary schools is in great shape compared to science. Except for health, science in our elementary schools is a catastrophe. That on international tests compared to other countries we have performed better in science than in mathematics can be interpreted as evidence that science is in even worse shape in other countries.

Perhaps the best piece of evidence we have for the current condition of elementary

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school science is to look at what the high school science curriculum expects students to know upon leaving elementary school. Ninth grade science can assume almost nothing, and so it does assume nothing. Even in places where science is taught for 8 years, the senior high school tends to ignore what their entering students know. High school science teachers do not trust even middle school science teachers trained in science to teach anything; it all is retaught. In contrast, 9th grade mathematics is able to assume that most students know addition, subtraction, multiplication, and division with whole numbers, fractions, decimals, some percent, some basic measurement, some formulas, even a little bit of graphing and algebra and geometry in many school systems. High school mathematics teachers are often like their science counterparts in that they do not trust middle school mathematics teachers to teach some content – they think only they can teach algebra and geometry – but they do trust these teachers to teach arithmetic, and in fact they want all arithmetic taught before students get to high school. As far as I know, there is no counterpart in science.

The situation in science education is, fortunately, a little better in grades 9-12. Science is taught everywhere. Biology is taken by virtually all students. Earth science or general science or environmental science courses exist in almost all schools, and virtually all schools that do not teach chemistry or physics at least know that they should be teaching those subjects. A student who takes all the science that is offered in most high schools today can learn quite a bit of science. In some places in the country, that student will have biology taught by an individual with a bachelor's degree in biology, chemistry taught by someone with a bachelor's degree in chemistry, and physics taught by someone with a bachelor's degree in physics. No other subject area in the high school can boast that each year it has specialists teach its courses.

This specialization has caused problems that are known to us all. Biology classes have almost no chemistry in them, even though today no one can be up to date in biology without a reasonable knowledge of chemistry. Chemistry courses have almost no physics in them, but they could use some physics. The same situation used to exist in mathematics. There used to be very little algebra in geometry and very little geometry in algebra, but that has evolved over the century so that now the courses are not air-tight. Part of the reason that this could be done in mathematics is that every mathematics teacher is supposed to be able to teach both algebra and geometry. Unlike science, no mathematics teacher comes to a school with a B.A. degree in geometry, or a B.A. in algebra, or a B.A. in calculus.

Even though science at the secondary level is in better shape than it is at the elementary level, science at the senior high school level still does not have the status of mathematics. The requirements for graduation in science are about a year less than those for mathematics. Mathematics comprises one-half of the SAT exams; science plays only a cameo role in some of the verbal portion. High schools have far more mathematics teams than they have science teams. Though at least as many students enroll in biology as in algebra, one of the most fundamental concepts in all of biology - evolution - is ignored in order to avoid controversy, and I do not know how one can do earth science without tackling the age of the earth. But perhaps this is only analogous to doing mathematics without using calculators and computers, in the sense that there are people who wrongly believe that knowledge does not change and techniques do not change, and refuse to enter the 20th century.

There are some positive trends. In the National Assessment of Educational Progress *NAEP 1994 Trends in Academic Progress* [1], it is reported that over half of today's 17-year-olds report having taken chemistry, about the same percent as report having taken a second year of algebra. The percent of 17-year-olds taking physics increased from 11% in 1986 to 18% in 1994, paralleling an increase from 6% in 1978 to 13% in 1994 in the 17-year-olds taking precalculus or calculus. But there is a fundamental difference in the subjects that masks these similarities. A large percentage of the students who are not in these standard college-prep mathematics courses are still taking mathematics, some a couple of years behind their peers, others in consumer mathematics courses. In contrast, those that are not taking higher level science courses in high school are likely to be taking no science at all. There may be a few places that offer physics courses and chemistry courses that are meant for all students, but they are not in the majority. Again, the situation is bad in mathematics but it is worse in science.

I have gone to great pains to indicate that, at least in schools, mathematics and science are quite different animals. (Perhaps I should add that there used to be another difference. It used to be that science departments in middle and senior high schools had a budget, whereas mathematics departments did not. But computers have changed that, and at the expense of science. It is more glamorous to have a computer terminal than a microscope.)

Despite these differences, which I feel are major differences between the ways in which the subjects are treated, the two subject areas are often treated in the same breath as if they were alike and as if their problems were alike. In announcing Goals 2000 [2], President Bush asserted that the U.S. should be first in the world in science and mathematics by the year 2000 as if it would be as easy to be first in one as in the other. Eisenhower funds have been available in science and mathematics but not other subjects. There are programs for recruiting science and mathematics teachers in some states; seldom do these programs want one without the other. And, of course, there is the School Science and Mathematics Association, not the School Science and Social Science Association, or the School Mathematics and Other Languages Association. No other pair of subjects in our schools are so often grouped together.

It is interesting, then to ask: If these subjects have developed to be so different in our schools, why are they so aligned in people's minds? Are the schools correct to treat the subjects differently, or should they treat them alike? Should the subjects be taught together? Many national groups, including the School Science and Mathematics Association, have emphasized the integration of science and mathematics. That is why in this article I focus on the relationships between mathematics and science, or between science and mathematics, if you prefer that order, and spend some time also examining the question of integrated curricula.

2. Science in mathematics

In my undergraduate education as a mathematics major, I saw very few applications to science, and none after calculus. I was, after all, a mathematics major, and that meant – in the early 60s when I went to school – that I was a "pure" mathematics major, not an applied mathematics major. There were no majors in applied mathematics then.

Not until ten years later, in the early 70s, did I get converted to the belief that applications were important. I shall tell you how that happened. I came to the University of Chicago in 1969. My colleague, Max Bell, was one of the few people who during the height of the new math era felt that there needed to be applications in the curriculum, and he first convinced me of one thing – that the word problems then found in books were not applications of mathematics, and in fact that they hindered the learning of applications of mathematics because they implicitly taught students that mathematics had no applications. I mean, who really wants to know the age of Mary who is half as old as her father will be when she is as third as old as her mother was?

In 1973, Max asked me if I would teach a course in applications of mathematics because he did not have the time to teach it. I responded positively, but only if someone else could teach it with me, for that is how uncomfortable I felt with this material at the time. But when I went to devise a reading list for the course, I was astonished. There were the "mathematics for carpenters and nurses and biologists and technicians...books", the statistics and other applied mathematics books, the collections of applications, some standard science books, and a good number of nice articles. Without a great deal of trouble, the reading list grew to 86 items, and it was clear how narrow my education had been. It is sad that only through this exercise did I learn that applied mathematics was as large a field as pure mathematics.

It then became clear that if one was to enlarge the number of students who learned a significant amount of mathematics, one had to incorporate this huge domain into the curriculum in some way. It began for me with a vengeance in 1974 with a course entitled *Algebra Through Applications* [3], later distributed by the National Council of Teachers of Mathematics, and has continued until the present day with the work of the University of Chicago School Mathematics Project.

But there was a significant aspect to the incorporation of applications of mathematics into the mathematics curriculum that is of particular relevance here. The best applications for the mathematics students were *not* those to science, but to everyday events. Given a choice between half-life and compound interest as an example of exponential functions, there was no question: choose compound interest because students care more about it, and they have more knowledge of the context, and so they are more interested in it. If you want to apply trigonometry to the finding of inaccessible distances, then use the distance between two mountain peaks rather than the distance between planets, because if you use astronomy you will have to teach astronomy, but you do not have to teach students what a mountain is. If you wish to discuss trajectories, use a basketball, baseball, or football, not an arbitrary projectile or a rocket.

Of course, in our materials we do discuss astronomy, and half life, and rocket trajectories, but not as the first examples. I would imagine that those of you who teach science have learned the same thing. For instance, in chemistry an internal application of chemistry is not as appealing to students as the applications to things we eat, or to purification of water or air, or to plastics we use. It is natural that the best examples are those that shed new light on something familiar to us, because we are free to concentrate on the new light rather than on learning the context of the example.

Some of you may think that we became very constrained because we tended not to use science examples, but that was not even close to the reality. Pick up a newspaper and examine the number of numbers on a page. In various countries, I have found invariably the *median* number of numbers on a newspaper page is somewhere between 120 and 150. The *mean* number of numbers is far higher – the last time I calculated it for a Chicago newspaper, the mean number of numbers on a page was over 500, due to sports pages, want ads, the weather page, and business pages.

These numbers are used in many ways. For instance, on the day I completed this paper, there were 77 numbers on page 1 of the *Chicago Tribune*, with the following kinds of uses: *counts*, with a wide variety of counting units, and often large, such as: 1.3 million member teamster's union, 75 high schools, two taverns; *measures*, and there are more of them than counts: many ages, such as a 66-year-old woman; money, often in large amounts: including a $28,570 inheritance, $383 million deficit (a negative number), 50 minutes, 100 miles, two weeks ago; uses we call *locations on a scale*, including: many dates; section 2, page 9; temperatures, such as 76 degrees; ordinals such as first; uses we call *ratio comparisons*, such as: a 27 percent reduction over last year's school funding; uses we call *identifications or codes*, including: Interstate 80, bar code number, Local 743 of a union. And there are *estimates* of counts and measures: hundreds of little towns, thousands of farmers, the 1950s (an interval).

Inside the pages, there are more numbers. The second page of the Tribune has an index and a list of phone numbers and subscription rates, and a table of lottery numbers from four states, and even the competitor Chicago Sun-Times' second chance lottery! All articles in the business and sports sections are filled with numbers. There are many stock averages --

actually rather complex weighted averages, not to mention the stock prices themselves. There are the various statistics used in sports, ranging from simple scores to earned run averages and quarterback ratings that are most easily analyzed using algebra. There are all sorts of advertisements with discounts given as percents and there are annual percentage rates for investments. Some of the advertisements contain dimensions of the articles being offered, some contain computer specifications, powers of zoom lenses, power capacities of stereo systems, and other technical information. There are advertisements discussing mortgage payments, capacities of wine bottles in liters and milliliters (sometimes with the units missing!). There is the extensive weather page, with wind directions and precipitations and barometric pressure and all sorts of other statistics.

I have not attempted to be exhaustive in my listing of numbers in the newspaper. I do not think it is needed to make the point. To read a newspaper today requires that the reader be able to process mathematical information to an extent far beyond that required even one generation ago. It is often said that we are in an information age; it is the case that much of that information is numerical or pictoral, and thus is mathematical. *But the mathematical information is usually not related to science.*

It is often said that mathematics is the language of science. This is true but mathematics is now an important language of communication in many disciplines, including economics and sports and consumer products and services. I am not sure that mathematics ever was the handmaiden of science; if it was, it certainly is not today.

3. Mathematics in science

Now let me consider the other direction. How much mathematics is there in our science courses? Here the situation is spotty. In good science curricula at the elementary and middle school levels, there is usually a lot of mathematics related to data gathering and presentation, often including far more graphing than mathematics teachers realize. Where elementary school science is taught well, the mathematics in that science at a particular grade level is often at a level quite a bit beyond that in the corresponding mathematics lessons at that grade level. I have seen graphing in 2nd grade science that is at a level that some 8th grade mathematics teachers think is beyond their students. This practice demonstrates that material learned in context is usually far more accessible than material learned in the abstract.

Enter high school, however, and the situation is different. There is very little mathematics in some earth science and environmental science and general science courses. Nor is there much mathematics in school biology. Indeed, there seems to be a general policy of not using mathematics in the science courses taken by the vast majority of students. Surely there is almost no algebra - no formulas, no mathematical generalizations. And there is very little geometry. In chemistry, finally, students see algebra and a little bit of geometry. In physics, of course, the mathematical content runs throughout. The upshot of all this is that the student is told that you need mathematics for all of science, but the current science curriculum suggests you only really need mathematics beyond arithmetic in the *physical* sciences.

Is there science in newspapers? On page 1 of a recent issue of the Chicago Tribune there is mention of the first symptoms of Alzheimer's disease, and there is a weather forecast. These represent two of the oldest interests in all of science, medicine and weather. On page 2 there is an article about a 53-year-old woman who is pregnant with the sperm of her husband and the eggs of another woman. On page 3 is an announcement of the next shuttle flight from Cape Canaveral. There are two articles dealing with abortion on the first five pages.

In the second section, there is a lead article on angioplasty. On page 3 there are articles about the two beluga whales that had recently died, and about a dispute over dredging in the Chicago river that might have caused the flood in the Chicago loop. On the weather page are the phases of the moon, the rising times for the planets, all the weather statistics we have come to expect, and a couple I had never noticed before: an aviation forecast that includes turbulence (reported as moderate) and icing (freezing level near 12,000 feet).

In the business section, there is an article on supercomputer software and all sorts of data on the values of metals and livestock and grains and other commodities. In the sports section, there is no article that I would say could be identified as science, though there are articles and data on horse racing and greyhound racing. In Section 5, called Tempo, there is a review of *The Eye of the Elephant: Life and Death in an African Wilderness*, and an article entitled "2 mathematicians explain the function of sea foam". In Section 6, the want ads, there is occasional science required: what is meant by dogs being wormed or being allergenic, various kinds of woods in furniture, land descriptions, and so on. In the last section there is an article that claims that a new sweater "repels electro-magnetic energy, shielding your body from electric shocks, bad vibes and nasty moods". It costs only $425 to $1,275, you'll be happy to know. Another article speaks of the effects of wearing red lipstick. There are all sorts of articles on fashion, in which it would be helpful to be up on natural and synthetic fabrics.

Advertisements tout luggage as water resistant, promote furs and diamonds (which I view as part of our natural world), and speak of quartz tuning of TVs, bass boast, mega bass in a CD-player and "surround sound" in speakers, laser-quality output from a printer, energy saving dishwashers, humidity controlled crispers in refrigerators, and resolution of TV screens.

So there is quite a bit of science lurking in a daily newspaper, just as there is a huge amount of mathematics. Indeed, the amount of science surprised me about as much as the amount of mathematics surprised me when I first analyzed it. But the science as presented in newspapers does not involve mathematics beyond arithmetic, beyond the understanding of measurement and scales and all sorts of units.

The separation that occurs between the subjects in the newspaper mirrors what happens in teaching. I have gone into a geometry class on the day of an eclipse of the moon, and found it to be ignored. No one can condone such artificial separation.

So we have the following situation: If we view the newspaper as being representative of what is important to people, or what they need to know in their daily lives, most of the mathematics does not involve science and most of the science does not require mathematics beyond simple arithmetic. One of the reasons that there is so little mathematics beyond arithmetic in newspapers is that journalism is one of the few college majors that requires almost no mathematics. Journalists also tend to take very little science.

4. Connecting mathematics and science

Gauss wrote, "Mathematics is the queen of the sciences." What does this mean? One interpretation begins with the fact that mathematics is the language of *generalization* of patterns, both numerical and geometrical. The sciences study the patterns of things, both animate and inanimate, in our world. So you cannot get along without mathematics.

Science is one of the targets of the language of mathematics; science studies the contexts. This is the reason that there are so many more stories about science in the newspaper than there are stories about mathematics. Who wants to read about a language? To carry the analogy perhaps farther than it should be carried, it is far more interesting for most people to learn about the Russians than to learn Russian. But if you want to *really* learn about the Russians, you need Russian! Mathematics is, of course, more powerful than Russian because it is a worldwide language, and it seems to be a natural language. As Galileo stated (in his essay *Il Saggiatore*, 1623): "The universe...cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering about in a dark labyrinth." Or as Sir James Jeans wrote (in *The Mysterious Universe*, 1930), "All the pictures which science now draws of nature and which alone seem capable of according with observational fact are mathematical pictures...From the intrinsic evidence of his creation, the Great Architect of the Universe now begins to appear as a pure mathematician."

Because you do not need much mathematics to understand the contexts of science, there have been dozens – perhaps hundreds – of superb science programs produced and aired on television. Thousands of articles have appeared in *Scientific American* and other magazines that attempt to explain science, with very little attention to mathematics. With regard to reaching the general public, science is far ahead of mathematics, and it has not needed mathematics to do so.

There is a fundamental reason why science does not always need mathematics. Science studies things that we can see (perhaps with the help of special tools), or things whose effects we can see – physical things even if the science is not a physical science. Thus, a visual medium, such as motion pictures or television or computer screens, is a natural medium for the transmission of science ideas, for the seeing of patterns. Even people who do mathematics today can get along with a little less knowledge of the traditional written mathematics than they used to – functions can be seen and analyzed using a graphing calculator.

Another reason why science does not always need mathematics is that the concepts of science are not, in their roughest state, mathematical any more than they are English. Mathematics is a language we often use to describe science, but it is not itself science. Concepts such as entropy and many ideas in genetics can be described in mathematical terms, but they begin non-mathematically. We may define work in physics in terms of other quantities, but before we start we have a non-mathematical idea of what we want work to be. The energy of an atom bomb may be explained in part by the equation $E = mc^2$, but energy is a far broader concept than is suggested by the variable E in that formula.

5. Should mathematics and science be integrated?

By "integrated", I mean "Should they be taught together?" –at any level. Should children in primary school receive their science instruction along with mathematics? Should older students learn physics and calculus together? What about middle school, where there is a movement to integrate many things?

It is interesting that the journal *School Science and Mathematics* began in 1901 with the title *School Science*. In 1903, George Myers, a professor at the University of Chicago, was asked to be the departmental editor for Mathematics and Astronomy for the Mathematical Supplement to *School Science*. Ultimately, this supplement became integrated into the journal and the title was changed to what it is today.

Myers worked hard, however, to break down barriers between geometry and algebra. Many of the things algebra teachers take for granted today, such as the use of graphs, number lines, and area diagrams in algebra, were innovations in his work. He also used equations in geometry, which also was novel. It could be argued that his books *First Year Mathematics* and *Second Year Mathematics* were the first unified school mathematics series published in the United States. In both courses he used applications, again an innovation for his time.

But Myers did not believe that science and mathematics should be taught together. He encouraged the correlation of work in science and mathematics. So even the person who may have, more than anyone, been responsible for the name School Science and Mathematics, was not in favor of their integration.

Yet there are still some who think that they should be taught together. I assume that there are people who are members of the School Science and Mathematics Association for this very reason. Didn't Gauss say that mathematics was the queen of the sciences? In the writing that I have seen from American Association for the Advancement of Science Project 2061, it certainly seems that the authors are recommending that mathematics and science be taught together, particularly at the elementary school level.

But they shouldn't, and here are the reasons:

- Integration takes time from one for the other. In fact, a skeptic might argue that the reason Project 2061 recommends teaching math and science together is that the authors don't think as much arithmetic needs to be taught in the elementary school, so combine it with science, and at least get some science there.
- Integration requires that teachers know both mathematics and science, when we often have trouble finding teachers who know one of these areas.
- Integration makes it more difficult to have sustained treatment of the big ideas – proof, evolution, etc. – and always is frustrating to the teacher who cannot spend time on one for too long.
- Mathematics and science utilize fundamentally different modes of thinking, views of valid reasoning. For science, the scientific method is preeminent, with knowledge created through experiment and induction. For mathematics, the logical method is required, with knowledge created through deduction and proof.
- Integration has virtually never worked, despite the good intentions of many bright people.
- Integration is not good for science, because many of today's scientific issues are very much connected with social sciences and politics and ethics, and to have mathematics as a requirement for discussing those issues is a barrier.
- It is good to have the same ideas taught in different places. If spheres are taught in mathematics and sphere packing is discussed in chemistry, students appreciate the utility of mathematics in science. If trajectories are taught in both mathematics and physics, students get two chances to appreciate that science.
- Integration is not good for mathematics, because the preponderance of today's applications of mathematics are not to science, and the important concepts are far more general than their scientific applications would suggest.

6. Should there be more connections between mathematics and science in schools?

YES, fundamentally because it is dishonest to do mathematics without science or science without mathematics.

It hurts science when mathematics is purposely ignored, because it keeps from students a language that could enhance their understanding of the field – if they had more experience with it. This does not mean that mathematics should always be there, but that it should not be kept from being there.

Similarly, it hurts mathematics when science is ignored, because it keeps from students some of the most important reasons for having mathematics, and some of the great advances in history. Students of mathematics should learn of both of Galileo's new sciences – not just the dropping of objects down an inclined plane or from the Leaning Tower, but also the second new science, which showed the effects of changes of scale on objects; students of calculus should learn of Newton – not merely as mentioned in the margin but in specific terms of the problems that led him to develop calculus.

Should they be correlated, as George Myers recommended? This question does not have a simple answer. There are a number of ways to correlate. One way is to use the same language. I recall one time teaching the wrapping function approach to sines and cosines in an advanced algebra class. This is an approach where triangles are not used; a number line is wrapped around the unit circle and sines and cosines are defined in terms of arc lengths, not angles. It must have been three or four weeks before we showed the applications to right triangles. Two students came up to me after class and said – you mean these are the same sines and cosines we have been studying in physics all year! I never used the wrapping function approach again. The languages of science and mathematics are often different, and we should not make school an artificial place where they are the same, but we should be careful that our students see the connections.

A second way to correlate is to examine curricula of both mathematics and science together, and to make certain that ideas are taught in one area at about the same time as the same ideas in the other, and that the prerequisites are there when needed. No chemistry teacher wants to teach first-year algebra, but they often have to. Similarly, no mathematics teacher wants to teach students what is meant by velocity or acceleration. It is very inefficient to do this. But I must say that, except for broad ideas, it does not bother me that vectors are taught in physics and in later high school mathematics, that probability may be found in biology and in junior high school mathematics, that systems of linear equations are solved in chemistry and algebra, that data collection and analysis might be both curricula. These ideas are always approached differently in the two areas, which enriches the ideas and gives students a greater appreciation of their importance.

A third way to correlate is to have a unit which involves both areas. This can be very effective, particularly at the elementary school level when the same teacher may be teaching both, or in grades 6-8, when in some schools interdisciplinary activities are not rare. But it takes time - not only time for the science and for the mathematics, but time to connect them. Unless that connection time is available, the result is often frustration on the part of teachers that they cannot get through their own agendas.

I would much prefer a unit which involves more than just mathematics and science - one that involves all the subject areas - but this is very difficult to manage and takes even more time. Before high school, the time should be taken not from science or from mathematics, but from language arts or English, because one thing that needs greater attention in schools is the use of nonfiction in the teaching and learning of reading and writing. Another reason for my preference for a total experience over one that merely combines science and mathematics is my hope that we can bridge the gulf identified by C.P. Snow (*The Two Cultures and the Scientific Revolution,* 1959): "Literary intellectuals at one pole - at the other scientists...Between the two a gulf of mutual incomprehension."

7. The role of mathematics and science in social science

Finally, I would like to make a few comments on the relationships between mathematics and science and the social sciences.

When mathematics and science are discussed together, it makes it too easy for people to think that math/science types are different from other types of people, and that these areas are arcane, not of relevance to the average person. Yet we all know that both areas have much to offer the social sciences, and we need a concerted effort to inform our colleagues in those areas of the importance of our disciplines.

The place to start is not in their courses, but in ours. How can a knowledge of science and mathematics help voters and government officials make wise decisions regarding the ozone layer, or regarding pollution control or waste cleanup or population growth, to mention some of the major issues of our day? How can a knowledge of mathematics or science help a student understand his or her stereo, or computer, or kitchen appliance? How can a knowledge of mathematics or science help people to make wise consumer decisions? Why are mathematics and science required in so many college majors? We cannot expect others to answer these questions for us.

8. Summary

We who are in mathematics and science are linked very much in the public eye. This linkage is both natural and historical, natural because, as so many have said, the laws of the universe are awesomely mathematical, and historical because at one time these were virtually the only sciences and the only mathematics. There is also a practical link, namely that in order to be a scientist, one has to know quite a bit of mathematics. And in order to be an engineer, one has to know both. I do not question the importance of mathematics for scientists.

But there are downsides to that link. If a person is poor in mathematics – and that today still often means being poor in computational mathematics – that person is often discouraged from doing anything in science. Science is too important to be so constrained.

If a person is good at one of our subjects, it is a surprise for people to learn that they are may not be particularly interested in the other. But there are fine mathematicians who are not involved with science, because there is much of mathematics that is not scientific; and there are fine scientists who are not particularly good at mathematics, and who need very little of it, because there is much of science that is not mathematical.

Yet the link is so strong that the public has a notion that there are "math-science" types, and C.P. Snow's quote is evidence that even the educated public has this view. As long as that stereotyping exists, we will not have the public support we need for our disciplines. We need to educate our students of our connections with each other, but we also need very much to educate our students of the importance of our disciplines for their everyday life, for their roles as consumers, citizens, and wage earners.

One would think that the connections would be easiest to make at the lower elementary school level, where the same teacher has the responsibility for teaching science, social studies, mathematics, and language arts. But in point of fact, the least science is done at that level. Part of the reason for this situation has to be that the teachers who are empowered with the task of teaching science are not only unprepared, but often possess unfavorable attitudes towards science. The same is true for mathematics, but not to as great an extent.

I believe that we will not get significant improvement in the mathematics or science taught in our elementary schools until we have people teaching these subjects who care about them, who view themselves as having a responsibility to keep up with these subjects, and – most important – who have the time to come to meetings or read articles such as this one. This can only be done by most teachers if they specialize. You know the line – if we can have music teachers, PE teachers, art teachers, why not math teachers and science teachers? And I believe that, with specialist teachers at the elementary school level we would have a chance for the coordination that would enrich all of our courses, and also enrich language arts and social studies.

The problems at the elementary school level in science lead to fundamental problems at the high school level. Because virtually no science knowledge is assumed, there is too much to teach at the high school level. The courses are unwieldy.

But there is another problem that must be solved before science will improve at the high school level. There must be a greater number of connections made between the courses, and students should not have to wait until 11th grade to study significant amounts of chemistry or physics. Science is too important to our lives to have so few students encounter some of its most important concepts.

And so, if it is possible to summarize these points in just a few lines, what it is that we need to promulgate:

Science is needed by everyone, not just mathematicians.

Mathematics is needed for everything, not just science.

For these reasons, we need to stress the connections between science and the everyday world of our students; we need to stress connections between mathematics and the everyday world of our students.

But also for these reasons, the subjects should not be taught together as one integrated whole.

However, we need more connections within all of our subjects, and we need to break down the barriers that keep important concepts from our students because they are linked with courses that come later. ■

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An earlier version of this paper was presented at the annual meeting of the School Science and Mathematics Association in conjunction with the annual meeting of the Michigan Council of Teachers of Mathematics.