Ubiquity Symposium

Workings of Science

Can Mankind Survive Scientific Illiteracy?

by Phil Yaffe

Editor's Introduction

This symposium contribution is a reworking of a [blog](#) published by Ubiquity in July 2016. It laments the pitiful lack of scientific literacy among great portions of the population not directly engaged in recognized scientific disciplines. In the wake of the now two-year COVID-19 pandemic, the poignancy of the title of this blog is reinforced. At the beginning of December 2021, the number of deaths worldwide from COVID-19 stood at more than 5 million; and the virus continues to rage. How many of these deaths should be attributed to mistaken opposition to basic safety protocols and vaccination stemming from fundamental scientific illiteracy cannot be measured. But if it could, whatever the number the figure might be, it certainly wouldn't be insignificant.

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The United Kingdom was recently rocked by a furious controversy about the teaching of mathematics. Parents were enraged by a problem set in a national exam to assess the mathematical skills of 6–7 year-old children [1]. Their complaint was that the problem was just too hard for any child of this age to solve.

To me, this wasn't the shocking part of the controversy. The real shock was that many of the parents complained that even they had difficulty solving the following problem.

"There were some people on a train. 19 people get off the train at the first stop. 17 people get on the train. Now there are 63 people on the train. How many people were on the train to begin with?"

I imagine nobody reading this blog took more than a second or two to come up with the correct answer; there were originally 65 people on the train.

I am not a pedagogue and have no particular knowledge of how childhood mathematical skills develop. But the fact that adults found the problem baffling should be a wake-up call to all of us.

The sad fact is, many adults seem to be largely illiterate about mathematics in particular, but also science in general. This is true not only in the U.K., but also in the U.S., and probably countless other countries as well. At the same time, we live in a world where these self-same people are constantly being called upon to consider and vote on issues related to science.

To cite just a few examples:

- Should we be so concerned about global warming as to spend billions and billions of dollars to fight it?
- Should we ban nuclear energy as being too dangerous and too untrustworthy

- Are genetically modified foods so potentially damaging that they should be prohibited even if they may be the best hope for feeding the world's burgeoning populations?
- Should homeopathy and other alternative medical treatments be recognized as legitimate, and paid for by government and private insurance plans?

How did we get into this mess? More importantly, how do we get out of it? Again, I am not a pedagogue, but I do have some ideas on the subject that have been tested through admittedly limited personal experience.

I think the principal reason for this lamentable state of affairs is that science (including math) is not taught as science at all. What students are exposed to is lessons on how to do science as a mechanical procedure, but not what science actually is. The better students will master how to solve exam problems while they are in school, and subsequently forget what they supposedly learned rather quickly after leaving school because it is no longer required.

It is my contention that if they had been taught the true nature of science while in school, those adults who were baffled by the problem set for their seven-year-old children might have been momentarily stymied but nevertheless would have correctly worked it out. The fact that it was presented as a math problem might have been the true stumbling block. If it had been presented as something else, they might not have had any difficulty at all.

"Daddy, I have a riddle for you. There were some people on a train. 19 people get off the train at the first stop. 17 people get on the train. Now there are 63 people on the train. How many people were on the train to begin with?"

"Well, honey, that's really quite easy. All you have to do is . . ."

To my mind, by simplest definition science is principally about 1. first determining what we know about a situation, and 2. then applying appropriate strategies and techniques to do something useful with what we know. This would include solving practical problems, but also using what we know to determine what we don't know in order to find out even more. I have become committed to this two-faceted description of the true nature of science due to personal experience. Let me share a few examples.

Debating Mathematics

Early in my career I was a high school mathematics teacher. My first assignment was a summer remedial class for students who had failed math during the regular school year. I was to replace a teacher who was leaving for personal reasons. I watched him for a couple of days as an acolyte before he was due to leave.

One of his standard procedures was to review the previous day's homework assignment by going down the first row, asking each student in turn what answer he or she had. If the answer was correct, he congratulated the student and then moved on down the row. If it was wrong, he gave the correct answer and then moved on down the row.

The first day I took over, I started doing the same thing. "Jane, what is the answer to problem 1?" "George, what is the answer to problem 2," "Melissa, what is the answer to problem 3?" However, almost maliciously, I asked, "Harry, what is the answer to problem 4?" Harry was stunned. "But Sir, I am sixth in the row. This isn't my problem." I replied, "I think it is. So please, what is the answer?" He stumbled and stuttered, and then gave the correct answer.

As you might imagine, I suddenly had everyone's attention. I then continued jumping around the room asking for answers from anyone I capriciously chose. This was quite a shock for those who had been nodding off and now had to sit up eyes wide open.

But obviously this wasn't enough. I was facing a whole class of students who had failed math largely because they didn't like it. Some positively hated it. They especially hated word problems. Being more complicated than simple calculations, word problems presented greater opportunities for them to make mistakes and therefore to embarrass themselves.

With this in mind, a couple of days later I tried something new. By now they were ready for the fact that I would pick students to answer at random; they had no place to hide. I asked Cynthia for the answer to problem 4. Her answer was wrong. However, instead of saying that it was wrong and then giving the correct answer, I moved right along. "Melvin, what is the answer to problem 5?"

I slowly looked around the room and saw some quizzical looks on some of the students' faces. "Arthur, you seem puzzled. Is there something wrong?" Sheepishly, he said, "Sir, you said the

correct answer to problem 4 was 26. I have 33 and I don't see my error." "Well, maybe we can help you find it. Why don't you come up to the blackboard and show us how you did it."

Reluctantly Arthur rose from his seat, went to the board, and showed his solution to the problem. Everyone of course was expecting me to point out the error, but I didn't. Instead, I asked Cynthia to come to the board and show her solution. Now everyone was expecting me to explain why Cynthia was right and Melvin was wrong. But I didn't. I put it to a vote. "If you think Cynthia's solution is correct, please raise your hand." About a third did so. "If you think Melvin's solution is correct, please raise your hand." About two-thirds did so.

Once again, they were all expecting to me say which answer was correct and explain why. Once again, I demurred. "Hmm, the vote seems to have gone in Melvin's favor. Melvin, do you still believe you have the correct answer? "Yes, Sir." "Then please come up to the blackboard and show us where you think Cynthia went wrong."

Who was right and who was wrong was really irrelevant because something wonderful had happened. For the first time in their lives, these remedial students who either disliked or even hated math had discovered they knew enough about the subject to discuss and debate it.

This was a revelation. After a few days, they began looking forward to such discussions and debates, even to the point that some of them would stay after the bell rang for recess. They had truly discovered mathematics—and it was fun.

Then I did something really radical. On an exam, I set a problem that had no reasonable solution. It was one of those classic algebra problems defining a relationship between the age of John and his father, then asking how old each person is. The starting data I gave led to the conclusion that John was 24 and his father is 13.

Part of the class gave this impossible answer because that was where their calculation led them. The other part of the class violated every rule of mathematics they had ever learned in order to produce an answer that made sense in the real world.

Which group of students deserved praise for their approach? To my mind, it was those who violated their body of mathematical knowledge to give an answer that made sense. Why? Because they had actually looked at the problem and realized that whatever the calculation showed, it simply couldn't be correct. What they hadn't realized was there was a third option,

i.e., saying that something seems to be wrong with the starting data and therefore the problem couldn't be solved.

After the exam, I explained that life seldom gives math problems in neat little packages such as those found in school. Sometimes the input is faulty. Part of understanding mathematics is recognizing when this happens. I told them that they could expect similar such "impossible problems" on homework and future exams. If they came up with an impossible answer, their job would be to say that the problem was impossible. But by itself this wouldn't be enough. They would also have to try to explain why it was impossible.

When I announced this, I nearly had a rebellion on my hands. "But Sir, this is unfair! You can't do that." But I did. After the first couple of times, they not only stopped protesting that setting impossible problems was unfair. They actually began enjoying the challenge.

Questioning Physics

I subsequently had a similar gratifying experience as a Peace Corps volunteer math and physics teacher in Tanzania. I was posted to one of the few high schools then operating in the county. Only about 15 percent of children of high-school age were actually in school, because they just weren't any schools for them to attend. Because of stiff entrance exams, this meant those who were actually there were the best and the brightest.

I took over a second and fourth year physics class. Until then, they had been taught according to what was known as the British "O-Level" curriculum. My second-year class had just completed a section on heat and temperature. I saw their scores on the exam the previous teacher had given them and they looked very good. However, I was suspicious. So as an experiment I set them the following question:

"You have two thermometers, one Celsius and one Fahrenheit. You put them on your desk and you go out of the room for two hours. When you return, the Celsius thermometer is showing 20° and the Fahrenheit thermometer is showing 68°. In which of the two thermometers is the column of mercury higher?"

Despite their excellent exam scores, almost every one of them said the mercury was higher in the Fahrenheit thermometer, because 68 is a bigger number than 20. However; if I had asked them to convert 20° Celsius into Fahrenheit, I have no doubt they all would have plugged in the

formula $F = 9/5 C + 32$ and got the right answer. The problem was, they wouldn't have had any idea what it meant.

I should put this into context. At that time, nearly all high schools in Tanzania were boarding schools. Many of these students were from rural villages and probably had never even seen a thermometer until they left home. In their culture, worrying about temperature just wasn't part of their daily lives. And worrying about different ways of expressing temperature even less so.

This was an extreme case of what can happen when students are taught to do science rather than to understand it. Basically, physics had been presented to them as abstruse laws discovered by a handful of exceptionally intelligent scientists who had the good grace to recast them into arcane equations that could be manipulated by common mortals.

Having seen how they reacted to the thought question about the two thermometers, I tried to build most of my lessons around similar sorts of thought questions. At first the students were reluctant because they knew they would never see such questions on the national exam that would actually determine whether or not they got their high-school diploma (at that time as important as a university diploma today).

However, after getting used to it, they began to really enjoy such thought questions and felt their keener understanding of physics would be a help rather than a hindrance in the national exam.

At least that was the case for my second-year physics class; my fourth-year class reacted quite differently. Even though they seemed to recognize the benefits of truly understanding physics rather than simply doing it, they also clearly recognized their final exam for a high-school diploma was less than six months away, which would determine the course of the rest of their lives. What they really wanted to do was cram for this vital exam. I could hardly blame them.

I therefore reluctantly returned to emphasizing doing physics with my fourth-year class while continuing to emphasize understanding physics with my second-year class. The upshot was, after three months or so my second-year class could analyze and work out problems my fourth-year class couldn't even understand.

As a final example, here is something I tried with both my math class in the U.S. and my physics class in Tanzania: I introduced the idea of estimation. Something I could not recall having ever been taught in high school.

I explained that for many calculations (which follows from first understanding what you are seeking to achieve with the calculation), you can pretty well guess what the correct answer will be. For example, multiply 33×42 . Think $30 \times 40 = 1200$. So the answer has to be somewhere around this figure. When you actually do the calculation, if the answer you get is something like 522 or 1583, you have almost certainly made a mistake and should do the calculation again. Of course, if you get an answer very close to 1200, you cannot be certain it is correct; but chances are it is. If you have any doubt, do the calculation again.

The students could hardly believe their ears. “Wow! It’s really possible to know if I have made a mistake even before the teacher tells me!”

I had to remind them that an answer close to the estimate is no guarantee it is correct, but an answer far away from it is a virtual guarantee that it is wrong. Although estimation was not a magic wand, to them this is how it seemed. And the improvement on homework assignments and exams was remarkable.

The moral is: Learning science (and math) is fundamentally a matter of posing and answering questions (why am I doing this and what will the correct answer tell me?), not just listening, absorbing, and calculating. In other words, you must first engage in the practice of science before you can truly understand it.

However, learning science is more than that, because it also includes becoming involved with it. My students really began to learn science in the real sense of the term only when they found they could engage with it, discuss it and debate it even if they didn’t know the answers and explore where it might help or not. In other words, to go as adventurers and explorers who discover the rules and their probabilities rather than as automata who merely remember and apply certain rules. The explorer necessarily acknowledges uncertainty and tries to find its simple core; the doer is certain the rules will invariably lead to where one has already decided he or she wants to go.

Going Against the Grain

If this distinction between understanding science and doing the rules of science like an automaton seems self-evident, it isn’t.

I still meet people who believe (neglecting air resistance) that a heavy object will fall to the ground faster than a lighter one. However, if I gave them the equation for calculating the final velocity of a dropped object ($v = gt$), they might be able to calculate the correct answer. But like my Tanzanian students with the two thermometers, they would have no idea what that answer really means. In particular, they wouldn't recognize that because there is no variable for mass in the equation, it totally contradicts their belief that heavy objects fall faster than lighter ones. They would actually have to do the experiment (which in my experience hardly anyone seems to have ever done) in order to be convinced—and amazed! With any luck, they might then ask how is it that a feather falls much more slowly than a stone. Which would be wonderful because their scientific curiosity will have been productively engaged.

Distressingly, I know people who unabashedly proclaim that understanding science is antithetical to having "a sensitive soul." To them, the arts (dance, literature, music, painting, poetry, etc.) are so qualitatively different from science that understanding the one precludes understanding the other. And of course it isn't true.

When I was a mathematics student at UCLA (University of California at Los Angeles), I recall the chairman of the physics department addressing a group of liberal arts (non-science) students. He said something to the effect, "My purpose here today is to help you understand why I get the same feeling of beauty, wonder, and awe from Newton's laws of motion as you do from a Beethoven sonata. Incidentally, I also love Beethoven sonatas, perhaps with as much passion as you do. The question is: Why do I love both and you love only one?"

It is not my purpose here to offer any kind of detailed plan for making science more accessible and less off-putting to the masses. The experiences I have recounted (and some I haven't) go back more than a half-century, so perhaps such modifications have already been put into place, or are being put into place. If so, it is probably against the opposition of certain reluctant parents.

Recently I met a man who was raging against how his son was being taught math. "George is 13 and he is just beginning to do kinds of problems I was already doing at the age of 11. What has happened to teaching standards?" "Can you still do these problems today?" I asked. "Well, no. But I could already do them at the age of 11 and George still can't at the age of 13." "If you can no longer do them now that you are 33, what have you gained? Wouldn't it be better if your son could still do them 20 or 30 years after leaving school, just like the problem put to the seven-year-olds whose parents couldn't find the answer?"

Either he didn't understand my point or just didn't want to. In any event, we changed the subject because I could see there was no sense in pursuing this one any further. Like my fourth-year physics students in Tanzania, people seem to believe the way they learned (or didn't learn) science in school was somehow preordained and therefore couldn't—and shouldn't—be modified.

I believe what they are really saying *sub rosa* is, “If the way science is taught to my children is radically changed, I won’t be able to help them. I didn’t do well in science when I was in school, but I still remember some of it. However, if it becomes totally different, I will be totally lost.”

This is a fully justified concern. Children are unlikely to rebel against a different approach to teaching science because they have nothing against which to compare it. The parents do, so this is where we should start. Parents must first be convinced that transitioning from mechanically doing science to understanding it will be of significant benefit to their offspring, i.e., they are more likely to remember and use what they learn 20 or 30 years later. They must also be convinced they can relearn science right along with their children (special provision must be made for this). And that it might actually be fun.

Postscript

Notes added in 2021 in response to questions and comments about the 2016 blog:

- First, there is insufficient space here to offer a detailed program for teaching science so that people will fully understand and appreciate its true nature. I believe that those who would design such a program would benefit from incorporating elements of the fundamental [character traits of science](#).
- Second, recognizing the unfortunate (and sometimes dire) consequences of scientific illiteracy and trying to do something about it of course is nothing new. One of the first to issue this warning was C.P. Snow in his celebrated book *The Two Cultures and the Scientific Revolution* (Cambridge University Press, 1959). His thesis was that science and the humanities, which represented “the intellectual life of the whole of western society” had become split into “two cultures” and that this division was a major handicap to both in solving the world's problems.

- Third, more recently Isaac Asimov published an influential essay titled "[A Cult of Ignorance](#)" (1980). His thesis was: "There is a cult of ignorance in the United States, and there always has been. The strain of anti-intellectualism has been a constant thread winding its way through our political and cultural life, nurtured by the false notion that democracy means that 'my ignorance is just as good as your knowledge.' I believe that every human being with a physically normal brain can learn a great deal and be surprisingly intellectual. I believe that what we badly need is social approval of learning and social rewards for learning."
- Fourth, Peter Denning, then at George Mason University and currently *Ubiquity Magazine's* editor in chief, published a book chapter titled "[Quantitative Practices](#)" (1997) [2]. His take on the problem was (and still is): "It is not literacy but practices that create actions and constitute expertise. Literacy deals with descriptions, practices with data, design, uncertainty, trade-offs. Although schools stress literacy, many important practices defy description."

References

- [1] Jackson, J. [Algebra for 7-year-olds? Standardized test question puzzles outraged parents.](#) *TODAY*. May 11, 2016.
- [2] Denning, P. J. Quantitative practices. In *Why Numbers Count*, edited by Lynn Arthur Steen. College Board Press, 1997, 106–117.

About the Author

Philip Yaffe was born in Boston, Massachusetts, in 1942 and grew up in Los Angeles, where he graduated from the University of California with a degree in mathematics and physics. In his senior year, he was also editor-in-chief of the *Daily Bruin*, UCLA's daily student newspaper. He has more than 40 years of experience in journalism and international marketing communication. At various points in his career, he has been a teacher of journalism, a

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