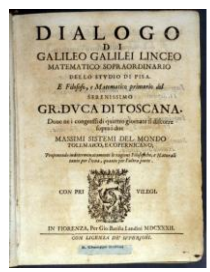
THE PARTICLE ENIGMA, HIGH SCHOOL PHYSICS, AND THE SEARCH FOR SCIENTIFIC LITERACY[1]

Abstract
There is a compelling reason why students should study physics in high school. It is not, however, for the reasons so often given. It is not, for example, to enable students to understand contemporary physics or to learn to think scientifically, nor is it because our Nation's future depends on our capability in science and engineering or because U.S. students as a whole perform poorly on international comparisons of scientific proficiency. Rather it is, I will argue, because physics is essential for achieving scientific literacy, a requisite of the general education of *all* students. In this I will be joined by Galileo's interlocutors from the *Dialogue Concerning the Two Chief World Systems*: Salviati, Simplicio, and Sagreda.

Background

The Leaning Tower
Pisa, Italy



Turning to the greatest physics educator of all time, Galileo Galilei, for advice on how to formulate my remarks at this AAPT session, he told me that if he were to be honored with the Oersted Medal (a long shot, given his age), he would use his *Dialogue Concerning the Two Chief World Systems*[2] to frame his speech.
What is good enough for Galileo is certainly good enough for me. Thus I decided to organized my remarks as a *Dialogue Concerning the Two Chief Physics Education Systems*[3] (not elegant, but better in Italian—*Dialogo sopra i due massimi sistemi del fisica educazione*).

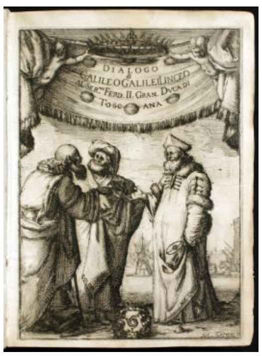
[2] Galileo Galilei, *Dialogue Concerning the Two Chief World Systems, Ptolemaic and Copernican*, second revised edition, translated by Stillman Drake. Berkeley: University of California Press, 1962.
[3] F. James Rutherford, *Dialogue Concerning the Two Chief Physics Education Systems.* Unpublished and no wonder!

Serving as their agent, Galileo then introduced me to Salviati, Simplicio, and Sagredo, at a café near the Leaning Tower, and after Chianti-enhanced negotiations—financial and logistic—they agreed to participate. My role, it was decided, was to attend the discussions, take notes, and keep quiet. When it came to it, I did the best I could, but admittedly much of the repartee escaped me. My slightly edited narrative follows.

The Setting

Berkeley, California

Proud Home of Sather Gate and Bette's Oceanview Diner



So in what follows, we listen in, as it were, on a conversation being carried on by **Sal**viati, **Sag**reda, and **Sim**plicio. Their conversation will have to do with two different views the value of high school physics and consequently of its content and accessibility. We first encounter them in a Berkeley coffee bar (free Wi-Fi) with their iPads at the ready and Google online. A word about the cast members, otherwise known in Galileo's *Dialogue* as the **Interlocutors.**

Comment [BR1]: Insert images

Simplicio (double espresso, no sugar) is a physicist from Le Conte Hall, well known as a hang out for Nobelists of the physics persuasion and as a torture chamber for pre-med students. He believes that our future depends on sustaining traditional year-long high school physics courses that faithfully reflect the science of classical and modern physics.

Salviati (latte macchiato), is a science educator said to be a drifter who wandered from schools to universities to government agencies before finally ending up with a full-time job at a scientific society. He is committed to the notion that the chief value of physics in high school has to do with the distinctive contribution it can make to scientific literacy, an outcome to which traditional physics courses, he believes, do not contribute significantly.

Sagreda (Golden Dragon oolong tea), is a transvestite Berkeley activist,[4] who was, with the editorial support of the Berkeley Daily Planet (née The Berkeley Barb), elected to the Berkeley School Board on the lively slogan "Learning Trumps Everything Else!" In these conversations, she is initially quite neutral—but will she remain so, or will she move to embrace, so to speak, Simplicio or Salviati? We will see.

It happened that several discussions had taken place casually at various times among the interlocutors, and had rather whetted than satisfied their thirst for learning. Hence very wisely they resolved to meet together on certain days during which, setting aside all other business, they might apply themselves more methodically to the contemplation of the wonders of God in the heavens and upon the high schools on Earth.[5]

THE FIRST DAY
In Which Our Threesome, ~~At~~Occupying an Outside Table at Peet's Coffee and Tea, Discuss the Value of High School Physics for *Students*

After noting how great it was to be getting together after all these centuries, and the customary but brief exchange of compliments, Salviati commences as follows: ~~*7~~

Salviati. Yesterday we resolved to meet today and discuss as clearly and in as much detail as possible the character of high school physics and the efficacy of those laws of education which up to the present have been put forth by the partisans of the traditional position on the one hand, and by the followers of the science literacy position on the other. First let each of us state his or her position on these two positions.[6] Simplicio please get us started.

Simplicio. As I see it, it is perfectly clear that a century of physics teaching in high schools has successfully contributed to the scientific and economic leadership of our country. It works, so why abandon it for some other untested approach?

Sagreda. But wait, good friend, precisely what is traditional high school physics like? What is it that you want to continue?

Sim. First and most important, rigor and fidelity to physics is key to high school physics. No watering down to attract disinterested or unprepared students. Second, note that physics holds a coveted spot in high school curricula, namely that of a senior year course. Thus it has students who have had three years of math and who are willing to

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[4] There is reason to believe that Galileo knew that Sagredo was really Sagreda, a cross-dressing Florentine. He went along with this deception because he was already in trouble enough with the Vatican and in no mood to have transgender issues on his back.

[5] *Dialogue*, p. 7 (All such entries refer to the Stillman Drake translation cited earlier.)

[6] *Dialogue*, p. 9

undertake what in most schools is regarded as intellectually the most demanding course. Everyone knows that physics is for students who are serious about learning and are expecting to go on to a major university, perhaps to pursue science or engineering. And enrollments in high school physics are steadily rising, another bit of evidence for the continuation of traditional courses.

Sal. Please, Simplicio, rigor is one thing, but exclusiveness—a coveted status, as you put it—may characterize traditional high school physics, but that's part of the problem, not a solution for it. And why do you sidestep content?

Sim. Well, I was going to get to that before being interrupted. The best way to answer your question is to look at the content of the most popular high school textbooks, Serway's *Holt Physics*[7] and Zitzewitz's *Physics Principles and Problems.*[8] They cover mechanics, states of matter, waves and light, electricity and magnetism, and modern physics, surely the essentials for a comprehension of our science! To go into further detail would take the entire morning and then some.

Sag. I think I now understand your position, Simplicio, and I will consult those text as soon as I can. Now I would like to hear from Salviati.

Sal. I cannot state my position before correcting a few of my colleague's misleading assertions. As I have already suggested, the "coveted" place of physics in the high school curriculum and its arduous reputation may well be a negative factor rather than a positive one. As of last year, only 37% of seniors had taken a physics course prior to graduation.[9] Yes, enrollments have been growing in high school physics, but as AIP surveys show, the growth is due to the increase of courses using non-traditional "conceptual" texts, most notably that of Hewitt.[10] From 1987 to 2009, the enrollment of students in courses using conceptual texts increased by 41%, while enrollment in standard courses using traditional texts did not grow at all. As an indication of the level of those two textbooks, I cannot fail to point out that they are also the most widely used in honors physics and one of them in advanced placement physics.

Let me also . . .

Sag. Enough, Salviati**,** your criticisms have been heard, but what we want to hear from you is a clear statement of *your* position.

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[7] Raymond A. Serway and Jerry S. Faughn, *Holt Physics*. Holt, Rinehart and Winston, 974 pages, 4.2 pounds

[8] Paul W. Zitzewitz, *Physics Principles and Problems*. McGraw/Glencoe, 943 pages, 4.8 pounds

[9] http://www.aip.org/statistics/

[10] Paul G. Hewitt, *Conceptual Physics*. Addison Wesley, 816 pages, 3.9 pounds

Sal. My position on the issue before us on this glorious Bay Area day is that physics is so important that it needs to be part of *every* student's general education, and, moreover, that traditional high school physics does not contribute properly to that end since it does not attract most students and because its content is not entirely appropriate. Physics should be part of a curriculum that prizes the interaction of the arts, humanities, and sciences, that fosters creativity and independent thinking, that establishes the high school year as important in their own right, yet provides a base for continuing intellectual and social growth. This calls for more than simply developing a new 12th-grade physics course.

Sag. I believe I now understand both of you, although before our conversations are over, I hope to increase my understanding, as I said, by examining the textbooks mentioned so far and the AIP data. Before long you both will have to elaborate on your views, but let's now take a ~~short~~ 15-minute ~~rest~~ break, stretch our aged legs, reorder our drinks, check email, and then move on. When we return, we will focus on why students should study physics in high school.

[In obedience to timeless tradition, the 15~~-~~-minute break ~~takes~~ took 35 minutes]

Sag. Refreshed, this is how we will now proceed: Simplicio will start the conversation by providing a reason why students need traditional physics. Salviati will respond, and I will intervene as necessary to understand both of you. And then Simplicio will introduce another reason, if he wishes, and so on until we have finished with our discussion of *physics and students*, or until it is time to head for our lunch at Chez Panisse. I don't know how I came to be the referee in this dialogue, but so be it.

Sim. Fair enough. Everyone knows—or should know—that great advances are being made in physics these days. High school graduates need a solid background in traditional physics or they will be unable to follow these exciting developments.

Sag. That sounds reasonable enough, but I'm not sure what those exciting developments might be. Please give me an example.

Sim. There are so many, but at the top of the list is particle physics; it is booming and on the verge of making one of the greatest discoveries of all times—namely finding the Higgs boson. The Large Hadron Collider is the powerful tool leading the chase. It took 15 years and $10 billion to build the 18-mile electromagnetic racetrack 300 feet underground near Geneva, Switzerland, and is operated by the European Organization for Nuclear Research (CERN). The search for the Higgs is the world's biggest and most expensive physics experiment ever. And to make it even more exciting, the Trevatron at the Fermi National Laboratory in Illinois is also on the trail of the Higgs, and it has a bit of a head start, but either a weaker collider. If that curious particle actually exists and is found, physicists say it will reveal primordial forces present in the first one-billionths of a second in the life of the universe, and it will explain how all other nuclear particles gain their mass.

But does it exist? Will it have the properties predicted for it? Can the underdog Trevatron beat out the LHC favorite? Exciting, right? As a recent article by Dennis Overbye was headlined in the *New York Times*, there are “Trillions of Reasons to Be Excited.”[11] This is the physics super bowl and students should be prepared to be in on it by having enough physics preparation.

Sal. A good example indeed. It illustrates what I call **The Particle Enigma**, namely basing general, precollege physics education on what can’t be seriously understood by most non-physicists. Leaving aside the unwavering promise of particle physicists that the ultimate secret of the universe was about to be revealed, few people other than physicists are now interested in or are likely to become interested in whether the Higgs exists or not, or if it does exists, whether or not it is found. As the headline on the second page of Overbye’s article more correctly put it, “*For Physicists*, Trillions of Reasons to be Excited” [Italics added].

Moreover, almost none of us can understand nuclear particles beyond our good old friends the protons, neutrons, and electrons. No physics course is likely to change that. Here, Sagreda, is the Wikipedia rendition of the particle zoo. Do you think the Berkeley School Board would ever decide that students ought to learn enough physics to understand what they are and what they are all about?

> The Standard Model describes the strong, weak, and electromagnetic fundamental forces, using mediating gauge bosons. The species of gauge bosons are the gluons, W^- and W^+ and Z bosons, and the photons. The model also contains 24 fundamental particles, which are the constituents of matter, namely:
>
> - Six "flavors" of quarks: up, down, bottom, top, strange, and charm;
> - Six types of leptons: electron, electron neutrino, muon, muon neutrino, tau, tau neutrino;
> - Twelve gauge bosons (force carriers): the photon of electromagnetism, the three W and Z bosons of the weak force, and the eight gluons of the strong force.

And, as Simplicio has curiously brought to our attention, it also predicts the existence of a type of boson known as the Higgs boson, which is yet to be discovered. Got all that?

[11] Wow! Let’s see, that’s a million million million, or maybe it’s it a billion billion, or a zillion? Well, whatever, it’s apparently lots of reasons for being excited by the Higgs contest—more reasons than we have for being excited about the San Francisco Giants winning the World Series.

Sag. OMG! Is there a "substandard" model? Don't answer. Have you another reason, Simplicio, hopefully a more understandable one, to offer for traditional high school physics?

Sim. Yes, several, in fact. An obvious one is that since the time of our creator, Galileo, physics has been the fundamental science, the one on which all other natural sciences are ultimately based. It follows that high school students need physics in order to really understand astronomy, geology, and chemistry—and even biology these days.

Sag. Before Salviati responds, I need to point out that in most schools, physics is the *last* course taken and therefore comes too late to help students with the other school sciences. Our Board has never been asked by the Berkeley High School science department to move physics downward in the curriculum.

Sal. For more reasons than that given by Sagreda, what I dub **The Granddaddy ~~Hubris~~ Conceit** can be dismissed out of hand~~,~~. There is not a shred of evidence that students would be able to learn the other sciences better with physics behind them. Anyway, if physicists really believed it, you might think that they would lobby hard to move physics to an earlier slot. But they don't. The Physics First movement seems to be making very little headway.

Sim. And for good reason. ~~That's~~ It's because students that young—14 or 15—are not ready for a serious physics course, and on top of that they have not yet had enough math. Taking so-called Physics First ~~is probably a good idea~~may be OK—but only if those students later take a heftier year-course as juniors or seniors. In a traditional senior-level course with algebra, geometry, and hopefully trig as prerequisites, the course can be designed to help students learn to think like physicists, which is to say scientifically.

Sal. That is a lofty goal—I call it **The Brain-Power Allure**—one claimed, as I'm sure you well know, by the other school science subjects as well. Indeed, if the claims of high school Earth Science, Biology, and Chemistry are valid, then students ought already to be pretty good scientific thinkers by the time they reach physics. Are you arguing that their claims are overblown?

Sim. No, not at all. The thing is that physics by its nature is not a descriptive science in which memory is key—classification systems, names of organisms and chemicals, etc., that predominate in the other school sciences. Physics is, by contrast, far more mathematical and hence can be applied to all situations in which scientific thinking is called for.

Sal. I would love to hear you make that statement at a meeting of chemistry or biology teachers. But no matter, for there is little to back up the usual claim of any of the school sciences that students gain scientific thinking skills that are transferable to everyday life.

With good teaching they learn how scientific thinking manifests itself in each of the sciences they study. That's valuable because in that way each can contribute to the more general goal of *understanding* the nature of the science, something very different than gaining the *skills* of science.

Sag. Now that I think about it, in our schools students take history to learn about our past, not to learn to think like historians; take literature to learn how people behave in different situations, not to learn to think like novelists; and take civics to learn how government works and what good citizenship requires, not how to think like politicians.

Sal. Right. The way people think in their post-school lives is no doubt influenced to some degree by all of their school experiences taken together, in class and out. There are, however, so many variables at play, that singling out any one from the grand mix, say physics, as paramount cannot possibly be confirmed "scientifically." When physicists are *doing* physics they are by definition engaged in scientific thinking, but it does not follow that in their everyday personal lives as citizens, consumers, and social beings they are necessarily doing so.

Sag. If I hear you right, you seem to be saying that taking physics is not important?

Sal. Quite the contrary. I want all students to learn some physics, but not because I think they will learn necessarily to think like physicists doing physics, or any other scientists plying their trade.

Sim. You know as well as I do, Salviati, that there has never been any survey of the thinking behavior of scientists compared to that of other citizens, as to their politics or any other dimension of daily life. There is no basis for your claim.

Sal. Nevertheless, Simplicio, I do not have to support my position with evidence. It is you who are making a claim for the thinking value of physics, and so it is you who needs to come up with some empirical support.

Sag. In any case, we are about out of time, so we might conclude for the day.

Sim. Just one more point first, if I may. A college education is becoming ever more important, and so getting into college is a serious consideration for high school seniors. Taking a traditional physics course increases a student's chance of being accepted into a university, especially a leading university.

Sal. If your **Bitter Medicine Leg-up** for taking physics—never mind what you will learn, this will give you a leg up for getting into a good college—has merit, then advanced placement physics is a better bet. But what does this have to say about the intellectual value of physics education?

Sag. I know you would like to respond, Simplicio, but our time is up. However, in your defense, I admit I advised my high school daughter to take physics for that very reason, but she said, "Not to worry. I've good grades, I aced the SAT, I'm a volunteer at Children's Hospital, I made the varsity basketball team, ~~and~~ my eventual goal is an MBA, and physics might ruin my gpa, so thanks but no thanks." Teenagers aside, let me sum up today's dialogue. Simplicio has argued that the value of a traditional physics course for *students* (the focus of our discussion this morning) resides in

- enabling them to follow the exciting progress taking place in physics, citing the search for the Higgs particle as an example;
- improving their ability to understand the other sciences;
- teaching them to think scientifically; and
- putting them in a strong position for acceptance into college.

Salviati challenged each of those claims in turn, asserting that

- today's physics is out of the reach of most people including those having had a traditional high school course in physics (the Particle Enigma);
- a senior year course in physics is in no position to improve student's understanding of the other school sciences (the Granddaddy ~~Hubris~~Conceit);
- there is no evidence that a physics course as ordinarily taught provides students with scientific thinking skills that transfer to ordinary life situations (the Brain-Power Allure); and
- it is unlikely that a12th grade physics course on a transcript has much influence on college admission, which anyway is not an educationally attractive reason for taking physics (the Bitter-Medicine Leg-Up).

Sag. And now, gentleman, it is time to head to Chez Panisse for lunch, where, thanks to our author, we will have on the table a chilled bottled of Mendocino County Toad Hollow uncorked 2009 chardonnay and one of Mendocino County Hutch 2008 old vine zinfandel, with Mendocino County Boont Ale available if desired.

THE SECOND DAY

In Which Our Stalwarts,
Meeting at Berkeley ~~High School~~City Hall ~~I~~Iinstead of at Peet's,
Discuss the Value of High School Physics for *Society*

Romare Bearden Mural , Berkeley City Hall[12]

[12] "Berkeley-The City and Its People" has hung behind the City Council seating in the Old City Hall since it was commissioned by the Berkeley Civic Arts Commission in 1974. It is the largest and most expansive of the hundreds of collages the African American artist

Sagreda. Welcome back. I'm sorry I couldn't join you last evening to hear the San Francisco Symphony Orchestra—when it comes to Mahler, it's hard to beat Michael Tilson Thomas—but the Berkeley School Board was in session and of course I had to be there. Anyway, by meeting here today at Berkeley High, instead of at Peet's Coffee and Tea, as we did yesterday, we should be free of the distractions of aging hippies, street musicians, and the signature solicitors for environmental, immigrant, pot, gay, capital punishment, and antiwar causes. But now let us proceed with the focus of our conversation today, which is *high school physics and society.*

Salviati. Yesterday took us into so many and such great digressions twisting away from the main thread of our principal argument that I do not know whether I shall be able to go ahead without your assistance in putting me back on the track.[13]

Sag. I am not surprised that you should find yourself in some confusion, for your mind is as much filled and encumbered with what remains to be said as with what has been said. But I am simply a listener and have in my mind only the things I have heard, so perhaps I can put your discourse back on its path by briefly outlining these for you.[14]

As I recall it, yesterday's discourse may be summarized as a preliminary examination of two opinions as to which is the more probable and reasonable: The first holds that traditional high school physics is important for students because it enables them to

composed of photographic and other paper elements throughout his career. This mural highlights Berkeley's distinctive natural beauty, architectural monuments, and diversity as a community and represents Bearden's earliest public art commission.

[13] *Galileo*, p. 123
[14] *ibid*

follow the exciting advances taking place in physics, helps them understand the other natural sciences, prepares them to think scientifically, and increases their college admission chances. The other opinion, claiming those reasons to be weak at best, considers that the attainment of science literacy is the primary purpose of high school science and traditional physics courses do not contribute sufficiently to that end.[15]

Simplicio. Whatever one thinks of the value of physics for students, the value for *society* cannot be doubted. With a solid education in physics, graduates can participate effectively in social, political, and scientific decisions. And the converse is equally true—without physics they cannot. Not even Salviati can ignore the fact that America's future depends on science education—sorry, STEM education.[16] As the recent report of The President's Council of Advisors on Science and Technology[17] put it:

> STEM education will determine whether the United States will remain a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection, and national security. It will help produce the capable and flexible workforce needed to compete in a global marketplace. It will ensure that our society continues to make fundamental discoveries and to advance our understanding of ourselves, our planet, and the universe. . . . It will provide the technical skills and quantitative literacy needed for individuals to earn livable wages and make better decisions for themselves, their families, and their communities. And it will strengthen our democracy by preparing all citizens to make informed choices in an increasingly technological world.[18]

Sag. And what, pray, is this thing called STEM?

Sim. According to PCAST, STEM education includes the subjects of mathematics, biology, chemistry, and physics, which have traditionally formed the core requirements of many state curricula at the K-12 level. In addition, the report includes other critical subjects, such as computer science, engineering, environmental science and geology, fundamental concepts with which K-12 students should be familiar.

Sal. It's what most of us call science and math education. As I see it, STEM equals, in the way of education acronyms, science + technology + engineering + mathematics—and it

15 *ibid*

16 ~~STEM equals, in the way of education acronyms, science + technology + engineering + mathematics—and it makes the engineering educators and technology educators feel better about science and math education getting all the limelight. It is entirely unnecessary and distracting.~~ For another take on this jargon, see Natalie Angier, STEM Is Not About Flowers, New York Times, 5 October 2010

~~17 Those who know their science policy acronyms call it PCAST.~~

18 Those who know their science policy acronyms call it PCAST.

makes the engineering educators and technology educators feel better about science and math education getting all the limelight. It is entirely unnecessary and distracting.

Sag. OK, ~~Simplicio~~gentlemen, no more bickering about STEM. ~~now that I have a handle on PCAST and STEM,~~ I would appreciate it, Sim, ~~like you to~~if you would give me an example or two of how high school physics responds to the PCAST claim.

Sim. Well, for instance there is the matter of nuclear power. Should we build more nuclear power plants? What should we do about the disposal of nuclear waste? Without knowledge of the nature of radiation citizens cannot contribute sensibly to deciding such matters. With it they can. Or take the case of the Trevatron at FermiLab. Should the laboratory concentrate its resources on that aging atom smasher in an effort to beat CERN to the discovery of the Higgs, or should it shut the Trevatron down and instead use its resources to support many waiting smaller experiments? Citizens need knowledge of elementary particle physics and the importance of the Higgs in order to help decide on how public funds are best deployed.

Salviati. I can't think of better examples of the **Value-Added Decoy**. You say, in effect, that learning physics for its own sake is not inducement enough, so you make other claims for its indispensible worth. As to nuclear power plants, even scientists, yes ~~-~~even physicists who understand radiation physics very well, are not of a single mind with regard to nuclear energy and nuclear waste disposal—not to mention nuclear weapons. It is not at all clear that ordinary citizens can bring much to those issues whether or not they have had high school physics.

And the same can be said for the Trevatron case. That matter will be determined by the outcome of arm-wrestling within FermiLab between the scientists who want to go full steam ahead for the Higgs, and those who want to pursue other experiments, and, the decision is further complicated by the joust between FermiLab and its funding agency, the U.S. Department of Energy. The decision is complicated even further by the fact that the U.S. participates in the funding of CERN and the Large Hadron Collider, and that many American scientists are engaged in the Higgs experiment. In all of this, high school physics can be of no influence one way or another.

Sag. At the outset of this discussion of the relationship between high school physics and society, Simplicio, you said that with a solid education in physics, graduates can participate effectively in social, political, and scientific decisions, but so far you and Salviati have focused on scientific decisions. Is it really the case that a course in traditional high school physics prepares graduates to deal better with social and political issues, which I assume includes economic ones?

Sal. A good question Sagreda. I would like to hear Simplicio explain how high school physics graduates could have made a difference with regard to the behavior of our banking wizards and foreclosure overlords. Or decisions on the placement of off-shore oil wells and wind farms, the treatment of illegal immigrants, our fiscal and human rights disputes with China, the huge number of Americans living below the poverty line, capital punishment, Iraq and Afghanistan, disarmament, “don’t ask, don’t tell,” and so on. These are the reigning social, economic, and political issues of our times, and it is hard to see what high school physics has to do with them, Simplicio.

Sim. I cannot go through those issues one by one, Salviati, for it would take too long, and then you would probably come up with more objections. Indeed, I’m surprised you didn’t mention overfishing and skyrocketing medical costs and stubborn unemployment, etc. etc. etc. Anyway, I am not claiming that it is the *content* of high school physics that citizens need to deal effectively with such matters. Rather it is the way of thinking—*habits of mind*, if you will—with which physics empowers citizens. It includes the development of analytical skills and an attitude that favors data over dogma.

Sal. To which I can only repeat what I said yesterday, namely that there is no evidence that physics courses provide students with scientific thinking skills that transfer to ordinary life situations. Courses in statistics, civics, social studies, history, and law might have a better claim than physics to social relevance.

Sag. In this regard, last evening at the Berkeley School Board meeting, F. James Rutherford, a Berkeley resident and a visiting scholar at UC Berkeley, made an interesting presentation. He claimed that one way to increase the relevance of science to society is to organize instruction *contextually* from time to time in middle and high school courses, that is occasionally to treat science content from a “real-world” perspective. He said that many such contexts exist, including engineering, environment, mathematics, inquiry, health, sports, technology, history, biography, art, and themes such as scale, systems, constancy and change, and models. His point was that people are more likely to be able to apply scientific knowledge and skills to non-science matters if they are learned in “practical” contexts rather than abstractly.

As a demonstration of how from an educational perspective science learning and environmental understanding effectively complement each other, the National Science Foundation funded a project of the Environmental Literacy Council and NSTA to create demonstration modules for middle and high school teachers, with Rutherford as the PI and author. A central requirement was that the modules must actually help the teachers teach whatever science concepts they had already planned to teach, and to do so without introducing added burden.

The example he shared with the Board members was the module Radioactive Waste intended for high school physics teachers.[19] As he wrote in the module’s Introduction:

[19] *Resources for Environmental Literacy: Radioactive Waste*. Washington, D.C.: NSTA Press, Environmental Literacy Council, *Resources* 2007.

> The purpose of this module is not to assess the merits of the various processes that produce radioactive waste, not to promote any particular disposal method. Rather, the aim is to provide a useful resource to enhance student understanding of specific scientific ideas and to promote the value of science in environmental decision making—in this context, to consider the issue of radioactive waste disposal by understanding the physics of radioactivity.

Sim. So there you are, Salviati, evidence that physics can indeed prepare students to participate effectively in public affairs.

Sal. I would hope so, for the claim of such modules is that *contextual* teaching gives us a way to make science teaching socially significant. But even if the modules succeed as intended, still fewer than 40% of seniors take physics, so the total social impact would still be limited.

Sim. Not so! What counts is leadership, not mass action.

Sag. With that claim, our conversation is now turning toward questions relating to the actual science competence of our high school graduates. We will take a short break now, during which time I will try to assemble some data on the performance of our students. When we return, we will continue with our discussion of high school physics and society.

[As yesterday, a 35-minute-long 15-minute break]

Sag. During our break, I tweeted my office to see if we had yet received a report from a committee created by Board some months ago to study the TIMSS, PISA, and NAEP science and mathematics assessments in relation to our Berkeley K-12 curriculum. It apparently turned out to be a difficult assignment because the assessments differ in intent, process, and content. In response to my tweet I was tweeted back to the effect that we still have not received a final report—although committee members have said informally that our country has nothing to be proud of in these subjects.

Sim. I should say not! It is embarrassing that we lag behind so many other nations in science. And not only embarrassing, our schools poor performance in science puts our future at great risk in a world in which science and technology drive economies and international status. As a recent *New York Times* editorial stated:

> The situation remains grim. According to a follow-up report published last month, the academies found that the United States ranks 27th out of 29 wealthy

> countries in the proportion of college students with degrees in science or engineering, while the World Economic Forum ranked this country 48th out of 133 developed and developing nations in quality of math and science instruction.[20]

And now we are confronted with the most recent PISA tests in which Shanghai finished at the top, far ahead of all other cities and countries, and in which the U.S. ended up far down in the ranks. In the face of those results, the redoubtable Chester E. Finn Jr. said, "Wow, I'm kind of stunned, I'm thinking Sputnik," and the U.S. Secretary of Education, Arne Duncan, said "We have to see this as a wake-up call."[21]

Sal. Careful, Simplicio, about jumping on the "America's schools and teachers are terrible" bandwagon. It is not clear what those assessments can tell us about the quality of high school science, let alone high school physics. As Sagreda said, there have been lots of studies and interpreting them is complicated. As the National Center for Educational Statistics in the U.S. Department of Education concludes.

> Because there are differences in the features, frameworks and items of the national and international assessments, direct comparisons among the assessments are not useful. Rather the results from different studies should be thought of as different lenses through which to view and better understand U.S. student performance. [22]

Anyway, as to high school science, TIMSS focuses mostly on the fourth and eighth grades, and PISA on fifteen-year olds. That leaves NAEP, which is not international in scope. According to the report, the last assessment of science in NAEP (2005) showed no statistically significant differences in the performance of twelfth-graders since 2000, but a slight decrease since 1996.[23]

Sim. That supports my position. We are not good enough and we are not getting better.

Sal. And also my position, which is that for many reasons it is excruciatingly difficult to improve our educational system. At best it will take decades, and longer still unless we reverse our rising percentage of students living in poverty, since such students do poorly in most subjects.[24] The national goal adopted in 1990 by state governors and President George H. W. Bush that "U.S. students will be first in the world in science and

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[20] 48th Is Not a Good Place, *New York Times*, 26 October 2010

[21] *New York Times:* Top Test Scores From Shanghai Stun Educators, December 7, 2010.

[22] NCES, Comparing TIMSS with NAEP and PISA in Mathematics and Science, http://nces.ed.gov/timss/results07.asp

[23] As of this writing, the 2010 results have not yet been released.

[24] Boe, Erling and Sujie Shin, "Is the United States Really Losing the International Horse Race in Academic Achievement?" *Phi Delta Kapan*, May 2005, 688-695

mathematics achievement" by the year 2000[25] made no sense, as we now know. We are just as unlikely to get there in 2020. On the one hand, what I think of as **The Comparison Chimera** distracts us from the social and economic reforms needed to reform education radically, but on the other hand it frees us to focus the K-12 science curriculum on seeking science literacy rather than on becoming *numero uno* on international tests.

As to Shanghai, why are we surprised? Upon his recent return from an educational research visit to China, Mark Schneider, a commissioner of the Department of Education's research arm in the George W. Bush administration noted said he considered the accuracy of these results to be unassailable, but that some factors may have influenced the outcome. "For one thing," he said, "Shanghai is a huge migration hub within China. Students are supposed to return to their home provinces to attend high school, but the Shanghai authorities could increase scores by allowing stellar students to stay in the city, he said. And Shanghai students apparently were told the test was important for China's image and thus were more motivated to do well." What motivated the 5100 American 15-year olds randomly selected from across the entire country?

Sag. Are you saying that we do not have to worry about high school physics? That high school science is not a problem? That it doesn't matter that other countries best us in science?

Sal. Not at all. I worry a lot about high school physics and think it is a problem. But it is not the international results that worry me the most—they are not pertinent as I noted earlier. In principle, NAEP is another matter, but keep in mind that physics does not figure much in the results since the testing takes place early in the senior year before the physics course is very far along. My worry is twofold: traditional high school physics does not reach enough students, and it does not contribute as it should to science literacy for all students and to the dynamic curriculum that would energize and enrich the learning of all students.

You talk about the future of society depending on high school physics courses, yet those who do lots of the country's work mostly avoid physics as now taught. Consider the course-taking pattern of students concentrating on occupations (rather than professions such as law and science). Thirteen such majors make up 37.6% of the 2005 graduating class. The first number in the following list is the percent of graduates for each of the occupational concentrations. The second number in the list is the average physics courses credits for each of the occupational concentrations. Leading the pack were

[25] National Education Goals Panel, *The National Education Goals Report: Building a Nation of Learners.* Washington, D.C.: 1991

Computer and Information Science and Engineering Technology—but still only half of those graduates took a physics course. [26]

Agriculture 4.8% of all high school students/20% of which take physics
Business finance 1.4/40
Business support and management 5.7/30
Communications and design 5.5/30
Computer and information science 3.8/50
Construction and architecture 2.1/20
Consumer services 2.1/20
Culinary arts 1.5/20
Engineering technology 2.6/50
Health science 3.4/30
Manufacturing, repair, and transportation 7.2/20
Marketing 2.4/30
Public services 1.4/30

Sim. Look, my good friend, you argue that those students, regardless of their concentration, need the kind of physics that will attract them and contribute to science literacy as part of their general education, but have yet to come clean with exactly what you take science literacy to be. Nor have you clarified why physics is essential to its attainment. You have had fun, it seems to me, plucking my feathers, so now it is time for you to take your chances.

Sal. With pleasure. As to the content of science literacy, I refer you to *Science for All Americans*, [27] the Project 2061 gem published in 1989. As far as I know, it is unique compared to any of the standards reports in any subject by laying out the final learning goals in essay format without intervening grade-level learning goals and without reference to curriculum. And it is the only one that produced offspring sharing its own DNA: *Benchmarks for Science Literacy*[28] shows how the categories of learning goals play out over the school years; *Resources for Science Literacy*[29] provides a variety of information backing up *SFAA* and *Benchmarks*; and the *Atlas of Science Literacy*[30] offers nearly 100 conceptual maps illustrating how grade-level learning goals link over time to achieve important literacy insights.

[26] National Center for Educational Statistics, *Science Achievement and Occupational Career/Technical Education Coursetaking in High School: The Class of 2005*, May 2010.
[27] American Association for the Advancement of Science (AAAS), *Science for All Americans*. New York: Oxford University Press, 1989
[28] AAAS, *Benchmarks for Science Literacy*. New York: Oxford University Press, 1993
[29] AAAS, *Resource for Science Literacy, Oxford University Press. 0000*
[30] AAAS, *Atlas of Science Literacy,* Washington, D.C.: NSTA, Vol. 1 (2001), Vol. 2 (2007)

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Since my main point is that physics should be a main player in contributing to the attainment of science literacy by all students, I have prepared a table for your consideration showing areas of science literacy to which physics as a subject should make major contributions. Other school sciences can make contributions to some of these areas, but some depend uniquely on physics. Traditional physics courses address some but not nearly all of them in a deliberate way.

CATEGORIES OF LEARNING GOALS SELECTED BY SALVIATI FROM *SCIENCE FOR ALL AMERICANS* TO WHICH HIGH SCHOOL PHYSICS CAN AND SHOULD MAKE MAJOR CONTRIBUTIONS

The Physical Setting The Universe The Earth Processes That Shape the Earth Structure Of Matter Energy Transformations Motion Forces Of Nature	**The Nature of Science** The Scientific World View Scientific Inquiry The Scientific Enterprise	**The Designed World** Materials and Manufacturing Energy Sources and Use Communication Information Processing Health Technology
The Nature of Mathematics Mathematics, Science, and Technology **The Nature of Technology** Technology and Science Design and Systems	**Historical Perspectives** Displacing the Earth from the Center Of the Universe Uniting the Heavens and Earth Relating Matter & Energy and Time & Space Extending Time Splitting the Atom Harnessing Power	**Common Themes** Systems Models Constancy And Change Scale **Habits of Mind** Values And Attitudes Communication Skills Critical-Response Skills

The table does not presuppose any particular course or textbook. There are many possibilities for recasting the high school science curriculum (and indeed the entire K-12 science curriculum) to enable all students to encounter serious physics content, becoming more science literate year by year. *Designs for Science Literacy*[31] describes a possible computer-based engineering approach to curriculum construction, and there can be others.

Sim. If you had taught physics, you would know that there is not time enough to teach solid physics and touch all of that content also.

[31] AAAS, *Designs for Science Literacy*. New York: Oxford University Press, 2001

Sal. Well, in fact I have taught high school physics, and although I did not entirely succeed in meeting those science literacy challenges, I met enough of them to persuade myself that with the collaboration of math, history, social studies, and English teachers, it would be possible to meet all of them.

And the Project Physics Course, developed at Harvard in the heyday of the Sputnik Crisis, made headway in that direction. Anyway, your rejoinder merely reinforces my point—traditional physics can't or won't concentrate significantly on the science literacy goals. You may worry about "watering down" physics, but why? I recall that Project Physics was accused of not being "real physics," but student enrolment in physics increased significantly in schools where it was introduced, the proportion of girls went up, in New York PPC students performed as well as other students on the physics Regent's exam, and it apparently did not handicap the students for being accepted to college. And, after all, most high schools these days have honors physics or advanced placement physics for those students headed toward a scientific or engineering major in college.

Sim. I notice from your table that in your eyes science education—including high school physics—is almost entirely about acquiring knowledge, little or nothing about gaining scientific inquiry skills. That is a strange, even negligent, view of physics education. The standards documents think otherwise. To wit:

> **Science**. Students will gain the abilities necessary to do scientific inquiry. This includes being able to identify questions and concepts that guide scientific investigations; design and conduct scientific investigations; use technology and mathematics to improve investigations; formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternative explanations and models; and communicate and defend a scientific argument.[32]
>
> **Technology.** Students will develop abilities for a technological world. This includes becoming able to apply the design process, use and maintain technological products and systems, and assess the impact of products and systems. [33]

Sal. Well, truth be told, I lost my feathers on that account long ago. But even as a featherless fowl, I think I'm right. Look at those skills through citizen eyes. Conduct scientific investigations? Why should a person not in any scientific or engineering

[32] National Academy of Sciences, *National Science Education Standards*. Washington, DC: National Academy Press, 1996
[33] International Technology Education Association, *Standards for Technological Literacy*. Reston, VA: ITEA, 2000

occupation ever have occasion or need to do so? Actually, those are skills that graduate science students and post-docs are busy developing. What is sufficient for most of us is reasonable knowledge of what scientific inquiry is like.

Our author told me about an occasion concerning the 150 teachers who were working together for four years on what in time was to become *Benchmark for Science Literacy*. They were at the University of Washington for the s~~S~~ummer and the first invited speaker was a biochemistry professor from that university. He described a particular experiment that he and his associates (other professors, post-docs, and doctoral students) had worked on for some time only to have the experimental and control groups give the same results.

A high school science teacher asked if such failures didn't discourage him, to which he replied that he regarded it not as failure but as the way things work in science. He said that his team then had its most productive year, ultimately finding out that their technique was not the problem, as they had thought, but rather their faulty conceptual understanding of the science involved. Later that year, that scientist, Thomas Cech, was awarded the Nobel Prize in chemistry.

Sag. That's a nice story, Salviati. If I understand you, the point of the story is that scientific research today is a very sophisticated business not likely to be seriously undertaken or critiqued by even well-educated non-scientists.

Sal. Exactly. Just look in the science journals. The research papers are arcane, usually have many authors, sometimes dozens, often from different countries, have gone through a rigorous review process by peers (during which submissions by talented scientists are frequently rejected), then often to be followed up by letters to the editor pointing to flaws in the research. These days, scientists in one discipline have trouble reading the research papers of those in other disciplines, so expecting high school graduates to "design and conduct scientific investigations" is unreasonable. Fortunately, professional science writers and some scientists are able to "translate" scientific findings for the general public.

Sim. I can't believe you are arguing that high school physics students should not carry out experiments.

Sal. I'm not. Good lab sessions can help students understand the concepts being taught, but not scientific skills, given the nature of science investigations these days. Moreover, much of what goes on in school labs is the antithesis of real scientific investigations. As long ago as 1964, an article pointed out that if at the outset of an "experiment" students know what the problem is, have been given the tools to use, have 50 minutes to conduct the "experiment," and know there is a correct answer, it is not science, however useful it might otherwise be.[34] And look at the complexity of valid experiments by excellent scientists in which the effects seem to shrink is successive studies.[35]

I would like to add that if a goal of physics education is awareness of -how physics influenced our understanding of the natural world, history is essential. Not just nice but necessary. The reasons ~~why that is so~~ have been clearly put forth in *Science for All Americans* and *Benchmarks.*

> There are two principal reasons for including some knowledge of history among the recommendations. One reason is that generalizations about how the scientific enterprise operates would be empty without concrete examples. Consider, for example, the proposition that new ideas are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many different investigators. Without historical examples, these generalizations would be no more than slogans, however well they might be remembered. For this purpose, any number of episodes might have been selected.
>
> A second reason is that some episodes in the history of the scientific endeavor are of surpassing significance to our cultural heritage. Such episodes certainly include Galileo's role in changing our perception of our place in the universe; Newton's demonstration that the same laws apply to motion in the heavens and on earth; Darwin's long observations of the variety and relatedness of life forms that led to his postulating a mechanism for how they came about; Lyell's careful documentation of the unbelievable age of the earth; and Pasteur's identification of infectious disease with tiny organisms that could be seen only with a microscope. These stories stand among the milestones of the development of all thought in Western civilization.

It is too bad that the National Science Education Standards treats such history as essentially optional.[36]

Sag. I seem to have intermixed our two questions on high school physics and society. One has to do with whether high school physics is necessary for preparing graduates to be able to deal effectively with the issues facing a world driven by science and technology; the other asks if high school physics is important for improving the standing of our schools in international comparisons.

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34 F. J. Rutherford, "The Role of Inquiry in Science Teaching," *Journal of Research in Science Teaching*, 1964, 80-84.
35 Jonah Lehrer, "The Truth Wears Off," *The New Yorker*, December 13, 2010, 52-57.
36 NSES, *Ibid*, p. 204.

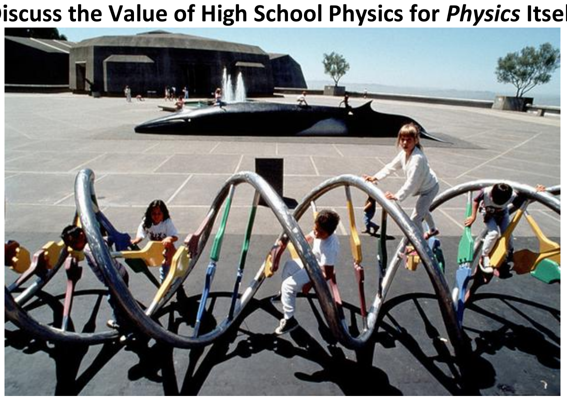
Sim. I have made my position clear on both matters, I believe. A good physics course is indeed necessary for yielding savvy citizens, and it is essential for increasing our position in the top rungs in international comparisons, not simply the overall position.

Sal. And I have responded that improving international test scores in science is not a proper goal for teaching physics in high schools. We are perfectly able to set our own learning goals and estimate our progress toward them. And as to social impact, if physics is to have any discernable influence, it will have to be taken up in class and will have to settle with knowledge rather than research skills. Actually high school classes featuring economics, law, and statistics and probability might be more relevant. And modest claims are in order. Keep in mind that Japan beats us by a wide margin in science and mathematics every time, yet for more than a decade it has been in the economic and social doldrums; and even when our scores were relatively low, our economy prospered. And its recent nosedive had to do with banking, not physics.

Sag. With that said, it's time for lunch. It's off we go to Sal's Deli— Salviati, I'll bet, for the to-die-for smoked trout special, Simplicio for the incredible Pastrami Ruski, and me for its soothing Matzo Ball soup.

DAY THREE

In Which Our Characters,
Meeting at the Lawrence Hall of Science,
Discuss the Value of High School Physics for *Physics* Itself



Salviati. Well, by meeting here high up on the hill, thanks to the Hall's gracious director, Dr. Elizabeth Stage, perhaps we can elevate our discussion a bit.

Sag. That's a bad joke, so we will ignore your comedic impulses and proceed with the third day of our dialogues. I have been impatiently awaiting your arrival, Salviati, that I might hear your novel views about high school physics and the future of physics itself. That has made the hours seem very long to me last night and this morning, though I have not passed them idly. On the contrary, I have lain awake most of the night running over in my mind yesterday's arguments and considering the reasons adopted by each side in favor of those two opposing positions—the earlier one of traditional high school physics, and this later one of scientific literacy. Among the partisans of both, especially in modern times, I seem to discern some who introduce very childish, not to say ridiculous, reasons in maintaining the opinion which appears to them to be true.[37]

Sal. The same has struck me even more forcibly than you. I have heard such things put forth as I should blush to repeat—not so much to avoid discrediting their authors (whose names could always be withheld) as to refrain from detracting so greatly from the honor of the human race.[38]

Sag. No good can come of dealing with such people, ~~. . .~~therefore let us continue with our good Simplicio, who has long been known to me as a man of great ingenuity and entirely without malice.[39]

Sim. Please excuse me for being a bit tardy, but I had to stop on the way at my neighborhood marijuana clinic to replenish my supply and the place was crowded with out-of-state buyers. But turning to today's issue, my first point today is that the nation is undeniably and dangerously at risk as one report after another has proclaimed. You recall, for instance, *A Nation At Risk.* It said that we were in deep trouble—and said it with flair.

> Our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world. . . . educational foundations of our society are presently being eroded by a rising tide of ~~me~~m~~di~~ediocrity that threatens our very future as a Nation and a people. What was unimaginable a generation ago has begun to occur—others are matching and surpassing our educational attainments. If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war.[40]

We knew then and know now that our decreasing scientific capability can be traced to fewer high school graduates electing to become scientists and engineers. ~~-~~In particular, we have to be worried about the decline in the physics pipeline, for physics remains at the center of innovation and progress.

[37] Galileo, p. 321
[38] Galileo, p. 322
[39] *ibid*
[40] *A Nation At Risk: The Imperative for Educational Reform*, which billed itself as A Report to the Nation and the Secretary of Education of the United States Department of Education by The National Commission on Excellence in Education. April, 1983.

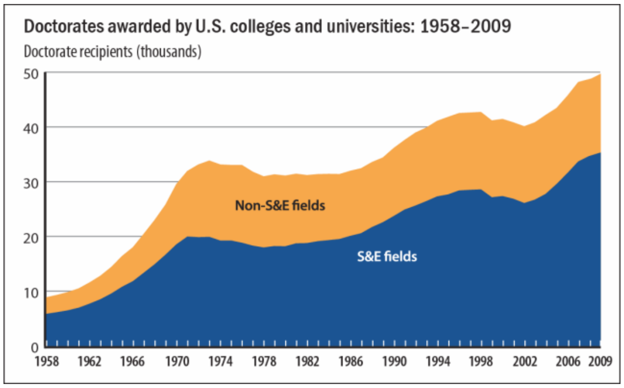
Sal. Your uncritical acceptance of such reports presupposes that 1) we actually have a shortage of physicists, and 2) that the high schools are to blame for the shortfall. Let's examine each of these premises in what I think of as your **Species Survival Mandate**.

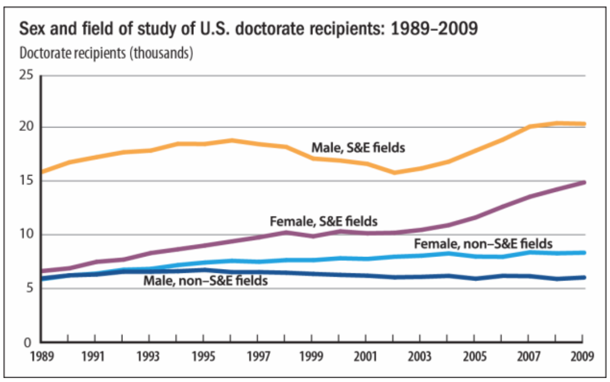
According to the calculations of the scientific community, it would seem as though we are always faced with a shortage of scientists and engineers. In 1989, for instance, the NSF published *The State of Academic Science and Engineering*.[41] It predicted a cumulative shortfall of 675,000 S & E bachelors degrees by 2010. Analysts calculated *annual* shortfalls 9,600 PhDs between 1995 and 2010, and perhaps as many as 14,000 short in2010.[42]

So here's what happened, according to NSF.

> U.S. academic institutions awarded 48,802 research doctorate degrees in 2008, the sixth consecutive annual increase in U.S. doctoral awards and the highest number ever reported by the Survey of Earned Doctorates (SED). . . . Doctorates awarded in science and engineering (S&E) fields of study accounted for the overall growth in 2008. As for physics doctorates, 1,378 were granted in 1998, and 1,586 in 2008, with an increase in the number awarded every year between 2003 and 2008.[43]
>
> As for 2009, the NSF reported more gains, as these graphs show:[44]

[41] National Science Foundation, Directorate for Scientific, Technological, and International Affairs, Division of Policy Research and Analysis, *The State of Academic Science and Engineering*, NSF 1989.
[42] John C. Vaughn and Robert C. Rosenweig, "Heading Off a Ph.D. Shortage, "*Issues in Science and Technology,* winter 1990-91*.*
[43] National Science Foundation, Table 1. Doctorates awarded, by major field of study, 1998-2008, NSF 10-308, November 2009.
[44] National Science Foundation, Doctorates awarded, by major field of study, 1998-2009, NSF 10-308, November 2010.





Far from the predicted decrease in production, there have been *increases* in both S&E doctorates overall and in physics doctorates. Note that as women increasingly acquire doctoral degrees, they are almost entirely in S & E fields.

Sim. But surely you realize that a "shortfall" is not the same as a "shortage" or a "scarcity."[45] What counts is the difference between supply and demand. However you cut it, we do not have enough scientists and engineers and we are not developing enough new ones. Some 1,500 or 1,600 new physicists a year will not keep us competitive in the world of science and technology.

Sal. Well, demand is notoriously difficult to quantify, but there are indirect indicators. For one, in academia the number of tenured positions is decreasing, and so the increasing flow of Ph.D.s is resulting in an increase in the number of "post-docs," *i.e.*, scientists who cannot get the academic job they thought they were headed for. For

[45] For more on this semantic merry-go-round, see Daniel S. Greenberg, *Science, Money, and Politics*, University of Chicago Press, 2001, p. 121.

another, the amount of grant money for research still does not come close to supporting all of the competent scientists being generated. If anything, we have a surplus of -research scientists in relation to available research funding.

Sag. I hear that we are dependent on foreign scientists and engineers in this country. Is that the reason for our surplus, if we have one? Or if we have no surplus, is it evidence that we ourselves are not producing enough scientists and engineers? This is all very confusing?

Sim. The latter, of course—we are losing our premier position because too many of our high school graduates choose careers in law and business rather than science and engineering. This is generally understood, Sagreda. Start filing the physics career pipeline in high school and we will be able to take back the jobs and secure our science and technology independence and leadership.

Sal. It is not correct to claim that our R & D future is at risk because we employ a large number of scientists and engineers from other countries—nor, for that matter, because we provide the doctoral training of so many foreigners. We are the beneficiaries of what is a surely a win-win situation. We train foreign students here, and if they remain in the US, we benefit from their scientific and engineering expertise; if they return to their own country, we benefit because of their ties to our scientific establishment. One need only to look at the authorship of research papers published in scientific journals to see evidence of the interconnected web of scientists from around the world. Science has become an international enterprise, and surely that is good for science and good for the world.

But if you want to make the case we need more students to pursue doctorates in physics, and that high school physics is the ultimate source of the "pipeline," you will have to admit that traditional physics is not doing the job. And you will have to confront the fact that about half of undergraduate science majors change out of science. That cannot be blamed on the high schools.

Sag. For some years, the Berkeley Board of Education has been trying to determine what the relationship is between the courses our students take in high school and what they major in as undergraduates. Nothing systematic has shown up. To top it off, the undergraduates frequently change majors after the first year or two. The subject they liked in high school turned out, once they got into it at the college level, to be not so compelling after all, or they encountered a subject—paleontology? philosophy? neuropsychology?—previously unknown to them that now captures their interest. So now we concentrate, in spite of the awful testing pressures on us, in trying to provide every child with a solid general education. We want educated graduates, whatever follows.

Sal. A good decision. And, I repeat myself, but an essential part of that general education of every child is science literacy, an essential part of that of which is physics.

Sag. Time for a break, during which Elizabeth Stage has offered to personally take us on a tour of the Hall, so we can see some of what is underway these days and meet some of its talented staff. It is easy to forget that schools are not the only place where learning takes place. The print and electronic media have a role to play, of course, but it's limited and not always trustworthy; the nation's science museums (an obsolete term for what they do), however, are responsible for a lot of good science learning outside the schools and for helping the teachers and schools to enrich their science teaching.[46]

[Dialogue Briefly Suspended]

Sim. During the break, I ducked out and headed down the hill a bit to visit with some of my colleagues at the Lawrence Berkeley National Laboratory. What a place! From the 1950s through the present, it has maintained its status as a major international center for physics research, and has also diversified its research program into almost every realm of scientific investigation. It exemplifies the continuing centrality of physics in basic and applied science. And it is a reminder that our high school graduates should understand the urgent need for the continuing support for physics research.

Sal. What's the budget this year at the Berkeley Lab, Simplicio?

Sim. Around $750 million. Why do you ask?

Sal. Well, that investment plus that supporting the SLAC National Accelerator Laboratory at Stanford, which has been going since 1962, and the nearby Livermore National Laboratory, going since 1952 -and now operating with a budget of $1.5 billion, and adding in the many research grants that Cal, Stanford, and UC Davis get every year, we're talking about something more than $3 billion spent for physics or physics related research in the Bay Area alone every year—not counting the research investments of HP and other Silicon Valley denizens. Isn't it interesting that for more that half a century, the Bay Area has been in the research biz big time even though the citizens have never had a chance to vote on it one way or another? Nor have they shown any need to do so. That can be seen as virtual support of physics by the public.

Sag. Dazzling! Year after year the school districts in the Bay Area and throughout the country struggle for funding—right now facing the third year of cutbacks—and indeed citizens do get to vote on school taxing levels.

[46] The Exploritorium, created by the physicist and Oersted Medalist Frank Oppenheimer, has had a world-wide impact on science education.

Sim. You have to understand that modern scientific research is by its nature expensive, long-term, and provides thousands of jobs for physicists and other scientists. It is not something that can be cut back on. It is simply too important!

Sag. Education is also expensive and long-term and too important to cut back on. It gets cut back on anyway. This even though the spending on scientific research in the Bay Area is vastly greater than the spending on scientific education in the schools.

Sal. My point, anyway, in raising the money question is not that too much or too little is spent on physics research—I don't know what the right balance is—but that it is not up to the schools to persuade students of the need to support it. Its job is learning for its own sake, not for the sake of physics. I hope that I have sundered the notion that the high schools should be responsible for sustaining the physics pipeline and for building public support for physics research—what I think of as **Physics Forevermore and More.**

With or without good science education in the schools, physics research continues to receive considerable financial support—but never of course as much as the physicists say they need. Physicists argue among themselves about the usefulness of the $1.5 billion Alpha Magnetic Spectrometer to be situated on the space station. Its advocates say "that it could confirm that mysterious signals recorded by other satellites and balloons in recent years are emanations from dark matter, revealing evidence of particles and forces have only been theoretical dreams until now."[47] Sound familiar?

Or return to our friend the LHC and the Higgs boson.

> Physicists also admit that, regardless of the intellectual foment it would cause, finding nothing would create problems, at least with the governments that paid for the LHC. . . . However, finding only the Higgs may make life nearly as difficult for physicists trying to persuade governments to build the next great particle smasher, the proposed International Linear Collider (ILC). Costing between $10 billion and $15 billion, the ILC would, [by] colliding indivisible electrons and positrons., generate cleaner collisions that should reveal details of new particles that will be obscured by the messy proton-on-proton collision at LHC.[48]

Particle physics forevermore indeed.

Sag. Wait awhile, Salviati, for in this argument I find so many doubts assailing me on all sides that I think it is time for us to conclude our dialogue. More conversation would only add to my uncertainties.[49]

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[47] *New York Times*, November 17, 2010
[48] *Science*, 23 March 2007
[49] Galileo, p. 16

Sal. I shall willingly pause, for I run the same risk too, and am on the verge of getting shipwrecked. At present I sail between rocks and boisterous waves that are making me lose my bearings, as they say.[50]

Sim. Had I not formed from previous arguments such a high opinion of Salviati's soundness of learning and Sagreda's sharpness of wit, with their kind permission I should wish to leave without hearing more, as it would appear to me an impossible feat to contradict such palpable experiences. And without hearing any more, I should like to cling to my old opinion; for it seems to me that if, indeed, it is false, it may be excused on the grounds of its being supported by so many arguments of great probability. If these are fallacies, what true demonstrations were ever more elegant?[51]

Sal. Now, since it is time to put an end to our discourses, it remains for me to beg of you that if later, in going over the things that I have brought out, you should meet with any difficulty or any question not completely solved, you will excuse my deficiency because of the novelty of the [science literacy] concept and the limitations of my abilities; then because of the magnitude of the subject; and finally because I do not claim and have not claimed from others that assent that I myself do not give to this invention, which may easily turn out to be a most foolish hallucination and a majestic paradox.[52]

Sag. As you know, we had planned, as in Galileo's *Dialogue Concerning the Two Chief World Systems*, to meet for a fourth day of conversation. As it has turned out, however, we seem to have run out of more to say without confounding our confusions. It is appropriate, therefore, to bring our *Dialogue Concerning the Two Chief Physics Education Systems* to an end. Tomorrow we will meet at the UC Faculty Club for lunch, thanks to Simplicio, where, along with other guests, we will listen not to ourselves again but to our author, who, as luck would have it, has just been honored with the Oersted Medal Award.

Meanwhile, according to our custom, let us go and enjoy an hour of refreshment on the Bay in the gondola that awaits us.[53]

DAY FOUR

During Which Simplicio, Salviati, and Sagreda, and Other Guests Meet for Lunch at the University of California Faculty Club, To Listen to The 2010 Oersted Medal Recipient

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50 *ibid.*
51 Galileo, p. 154
52 Galileo, p. 537
53 Galileo, p. 539

Field Questions Regarding His Position on High School Physics and Science Literacy

Simplicio. It is my pleasure to introduce our author, F. James Rutherford. He is to be honored with the Oersted Medal of the American Association of Physics Teachers. In responding to that, he made possible the *Dialogue Concerning the Two Chief Physics Education Systems* that engaged Sagreda, Salviati, and myself in torrid discourse for three days. He will make only a few opening remarks, then open the floor to questions from you.

Oersted Medal Award Recipient (OMAR). Thank you, Simplicio, for that gracious, if rather brief, introduction. I was privileged to sit in on the dialogue, silently taking the notes for the three days. Anyone interested in seeing them—and I assure you that they make lively reading—can find them on my website SE>encore, the address of which is www.scienceeducationencore.org But now I can have my own say. In short it is this:

> Schools may well take on responsibilities in response to the special needs of some students, the community, or the nation, but providing all students with a sound general education is their imperative.
>
> General education is comprised of the knowledge, skills, and values students acquire from the arts, humanities, natural sciences, mathematics, social studies, technology, and physical education. It is learning for its own sake and for learning how to learn. It can serve as a platform of more advanced studies in school and out.

Question from Meg Whitman. First let me thank Simplicio for inviting me to this lovely luncheon and for the privilege of paying for it. If I were governor**,** I would want to know more about *useful* education. Business and industry need well-qualified workers, academia needs freshmen ready take on serious science and engineering courses.

OMAR. True, general education, as I construe it, is not vocational education, which for the most part comes after graduation from high school as on-the-job training or in colleges and universities. But it is the best bet we have for producing graduates who are ready to lead interesting and useful lives. I am reminded of a statement found in *A Nation At Risk*—yes, the famous (infamous?) "rising tide of mediocrity" report—expressing its guiding philosophy:

> *All, regardless of race or class or economic status, are entitled to a fair chance and to the tools for developing their individual powers of mind and spirit to the utmost. This promise means that all children by virtue of their own efforts, competently guided, can hope to attain the mature and informed judgment*

> *needed to secure gainful employment, and to manage their own lives, thereby serving not only their own interests but also the progress of society itself.*[54]

That's what a thoughtfully designed general education can achieve—but here's my point—not by deliberately training students for "gainful employment" or on how to "manage their own lives." So many family, social, cultural, economic, peer group, health, and other factors—including chance—influence how people live their lives that the influence of K-12 education cannot be targeted with precision. But that does not mean it is unimportant. It means that we bet on an education that features understanding how the world is and was as seen through the eyes of the different fields of study—knowledge for its own sake but also as knowledge as a foundation for more learning throughout life, some of which may very well influence their occupational and personal lives, but we don't know which ahead of time.

Question from S. James Gates, Jr.[55] That's all very well and good, but science does not seem to be much in view. Were does it fit in your "general education" scenario?

Simplicio. I want to interrupt to thank professor Gates for leaving Washington on short notice to join us today. As a member of the President's Council of Advisors on Science and Technology, and Co-Chair of the PCAST Working Group that prepared the report *Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future,* your concerns about STEM education are our concerns about STEM education.

OMAR. It is true that I have not yet highlighted the role of science in general education. So let me turn to that. But wait. I cannot shun, parenthetically, noting that my concern is not STEM education but science education. STEM is a confusing acronym on its way to becoming education jargon. I will expand on that in an article I am wring in response to the PCAST report and it will be posted on my website SE>encore.[56]

The role of science education in general education is to focus on science literacy. So just what is science literacy? But first, what is it **not**?

> It is *not* having acquired a mish-mash of scientific facts, laws, and theories, since science literacy requires coherence, a view that sees science as a dynamic human enterprise.
>
> It is *not* having become a "little scientist," with pre-professional knowledge and skills and the ability to conduct meaningful scientific investigations, since that is

[54] *A Nation at Risk,* April, 1983, p. 1
[55] John S. Toll Professor of Physics Director, Center for String and Particle Theory University of Maryland, College Park
[56] www.scienceeducationencore.org

not a reasonable goal and depends on a great deal more education and training. However, *understanding* how scientific research is carried out is a realistic and important goal.

It is *not* having completed some number of traditional science and math courses. There is little evidence of interconnectedness among science courses, or between science and math courses—each proceeds on it own. Moreover, the number of science courses required allows students to skip certain courses, physics being the stellar example.

So then, what **is** science literacy? Drawing on *Science for All Americans*, my short answer is that:

It *is* being aware that over the course of human history, people have developed many interconnected and validated ideas about the physical, biological, psychological, and social worlds. Those ideas have enabled successive generations to achieve an increasingly comprehensive and reliable understanding of the human species and its environment. The means used to develop these ideas are particular ways of observing, thinking, experimenting, and validating. These ways represent a fundamental aspect of the nature of science and reflect how science tends to differ from other modes of knowing.

It *is* being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes.

It *is* seeing the relevance of science in various contexts such as engineering, environment, energy, health, history, and themes such as systems and scale.

A short answer is necessarily a general answer. Adding detail now is not feasible, but my view has not change much from that in *Science for All Americans* and amplified in *Benchmarks for Science Literacy* and *Atlas of Science Literacy.*

Question from John Roeder. Let me remind you, Jim, that this luncheon meeting—and your award—is supposed to be about physics education, not education in general. So my question is, where does physics fit in your scheme of things?

OMAR. Good question**.** I'm sure that everyone here knows of Dr. John Roeder as an outstanding high school physics teacher and as a national leader in energy education, but some of you may not be aware that he is the long-time Editor-in-Chief of the

Teachers Clearinghouse for Science and Society Education Newsletter.[57] I urge you to check it out on the Clearinghouse website.

At the outset, Salviati made the point, with which I agree, that physics is an essential part of science literacy, which, in turn, is a necessary part of every child's general education. Physics, yes, but surely not all of the physics taught in a typical physics course, and just as surely, some aspects of physics usually not taken up. So if we assert that the reason for students to study physics in high school is because physics is indispensable to general education, we must then specify what physics that is and why it is so essential for everyone's education.

The table presented by Salviati on the Second Day of the Dialogue presents the listing of topics that physics can and should contribute to. The next level of detail is too much to present here, but one can see what that could be by referring to each of them in *Benchmarks*. Note that most of those topics are not *themselves*, physics content, but rather content that physics can help students ~~learn~~understand.

Question from Galileo Galilei. When we talked—and you explained to me why I could not be a candidate for the Oersted Medal Award—I emphasized that the idea of the *Dialogue* was to present an even-handed discussion comparing the strengths and weaknesses of the traditional view of the universe, the Ptolemaic one, and a theoretical new one, the Copernican. Maybe I missed it—celestial Wi-Fi is often cranky—but it seems to me that you set up Salviati as your mouthpiece, giving him strong arguments for putting down the traditional high school physics course defended weakly by Simplicio and for supporting some new kind of high school physics course. Unfair, especially for a man of science.

OMAR. I'm not sure what your questions is, dear Sir, but with all due respect, your charge of one-sidedness is surprising, since as is well known, and as the Vatican knew in your day, and as your house arrest attests, Salviati was your mouthpiece and ~~the~~ your *Dialogue* is anything but balanced.

Galileo. But you don't have to deal with the Vatican.

OMAR. True, but then you weren't up against the AIP, APS, and AAPT! Anyway, my concern with your comment is that it reveals what may be a misconception by others a well. So let me be clear:

[57] The Teachers Clearininghouse for Science and Society Education, Inc was founded at the New Lincoln School on 11 March 1982 by Irma S. Jarcho, John L. Roeder, and Nancy S. Van Vranken. Its purpose is to channel information on science and society education as well as data on available materials and other resources.

> I am not recommending that traditional high school physics courses be either discontinued or continued. What I am saying is that they do not contribute sufficiently to the fundamental goal of science literacy for all students as part of their general education.
>
> I am not promoting any other high school physics course in particular. What I am claiming is that the *curriculum* as currently manifested in most high schools is not doing the science literacy job well enough. It is therefore, the curriculum that needs to be redesigned including the place of physics in it.

How this might be accomplished in the next 20 years or so is described in *Designs for Science Literacy*, which I wrote with the late Andrew Ahlgren. As *Designs* asserts, it is not only physics and other high school sciences that need recasting, but also high school mathematics, history, social studies, and literature to include appropriate science. And it is not just content alone that needs attention, for curriculum coherence matters and contexts matter and teaching approaches matter and learning materials matter. Materials such as the Project Physics seven volumes of readings, the PSSC paperback series, and the science-related trade books listed in *Resources for Science Literacy* need to find a place in the high school curriculum.

Question Twitted from the U. S. Secretary of Education, the Honorable Arne Duncan. sorry, jim, cant b there, cuz on way 2 WH 2 brief prez on rce 2 tp. hope 2 gt mor $$. glad rahm won't be there. a pain. my ? is whr duz yr phycs pln fit in2 rce 2 tp? cheers, arn.

OMAR. Truth to tell, Arne, nowhere. I do not believe we are in or ought to be in "a race to the top." To outscore which countries? Japan and Singapore and Shanghai and Norway on somebody's test? Tops in what? Reading and math? Isn't good enough good enough? And racing to the top in science and history and art and civics and health? If anything, a balanced general education is what we ought to be as good as or better than any other country, but that is being undermined by a race to the top base almost entirely on the "objective" test mania.

In this country we are fully capable of setting our K-12 learning goals and organizing ourselves to achieve them. If we really want to, that is. If we continue to believe that our public schools will shape our future as they shaped our past. If we stop the current fashion of denigrating our schools and teachers, but reach out to help them to improve themselves and the system. Emphasizing the closing schools, belittling the commitment and skills of teachers, subsidizing the creation of more and more -charter schools, and turning to the world of business for guidance and for school administrators is not the way to engage the teachers and other educators as eager and creative participants in reform.

Sorry, Mr. Secretary, for this outburst, but I am appalled at the way schools and teachers are being portrayed. They are not responsible for Vietnam or Iraq, for the recessions we have had since the end of WWII, for the large influx of immigrants from every corner of the world, for the rising level of poverty among children, for state and federal budget deficits—but they are affected by those and many other situations for which they have no responsibility.

Nor do the outsiders declarations of what is wrong and what needs to be done to fix things actually help much, if at all. The recent PCAST report, *Prepare and Inspire*, for instance, involved more than 70 individuals, of which most were distinguished scientists and only three were school teachers (of which grade levels and which sciences we are not informed). That is not the way to recruit teachers to a reform plan. Even its title gives pause. *Inspire*? Just who is it that will inspire teachers? University scientists?

Question from Dante. I hear that on SE>encore you have somehow equated science education reform to passage through my Purgatorio—and without my permission, I am sorry to learn. What's ~~is~~ this all about? I hope you are not saying that taking high school physics is like being in purgatory!

OMAR. I characterize reforming school science as "Purgatorial" in the belief that achieving significant educational reform is bound to be more painful and lengthy and difficult than we would like. History tells us that there is no simple, painless, quick fix available. Still, science education reform is not doomed to the everlasting hopelessness of the **Inferno**: we can hope for reform, if we are willing to make the necessary changes, however long it may take, however painful, to root out our "evil tendencies," but we cannot hope for **Paradise**, which is to say for a perfect system of education. So Consider:

- In the *Divine Comedy*, Purgatorio is situated between the Inferno and Paradiso; here in our world, science education is situated between abject failure and dreamy perfection.
- The souls in purgatory are confronted by our moral failures (the seven deadly sins); we science educators by our many professional failures.

- Salvation is possible for the souls in Purgatorio, but only if they recognize their sins and work long and hard to remove them; success is possible for science education reformers, but only if they identify their failures and work long and hard to reverse them.

As to our seven deadly reform sins, my nominations are these:

Crisis addiction
Reform impatience
Panacea paralysis
Curriculum rigidity
Testing travesties
Technological timidity
Outmoded professionalism

I cannot now expand on all of those, but I will be writing on each of them and posting them on SE>encore under "Editorials."

Question from Barbara Rutherford. For a person who spent 60 years in pursuit of science education reform, enjoying ups and weathering downs, your last remarks, while perhaps on target, strike a negative tone. Can't you close with something more positive?

OMAR. Well, yes, dear, I can and I will. With two spirit-boosters, in fact. They are apt to have little impact on high school physics reform, but they are, I think, of lasting interest.

ONE. The science literacy oriented Project Physics Course created at Harvard in the 1960s by Gerald Holton, myself, Fletcher Watson, Andrew Ahlgren and many other physics teachers, physicists, science educators, science historians, film makers, test makers, equipment designers, field evaluators, and doctoral students essentially disappeared in the 1980s. Now, however, it is again available. The texts, teacher resource book, student guides, transparency volumes, readers, programmed instruction booklets, test booklets, and supplemental topic volumes are all now all available on Internet Archive as the Project Physics Collection.

Its Internet address is www.archive.org/details/projectphysicscollection. And the Project Physics film loops and *The World of Enrico Fermi*/*People and Particles* DVD are available from AAPT. This resurrection is, I hope, good news for young physics teachers and physics education historians.

TWO. Also on the upside, I can announce the website Science Education Encore, or SE>encore for short. The site has two main purposes. One is to share some of the ideas and resources that I have come to believe—after more than a half-century of experience—are of lasting significance, or provocative, or at least entertaining. The other is to serve as an arena for exploring some of those ideas with others. SE>encore includes such pages as Second Thoughts, The Purgatory Fix, Galileo and Friends, The Federal Role, Classics, Cover Art, and The DNA Follies. I hope that physics educators will join me there.

But now, Simplicio, Salviati, Sagreda and good friends and colleagues, I must leave to catch a plane for Jacksonville. Thank you AAPT for this great honor, for there is no more satisfying way for a former physics teacher to top off his career than by receiving the Oersted Medal. Thank you, AAPT.

And Galileo—please forgive me.

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