Physics for future Presidents

**Supreme Court Justices, Congressmen, CEOs,
Diplomats, Journalists, and other World Leaders**

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Preface

Physics is the liberal arts of high tech

Physics for future Presidents? Yes, that is a serious title. Energy, global warming, terrorism and counter-terrorism, health, internet, satellites, remote sensing, ICBMs and ABMs, DVDs and HDTVs -- economic and political issues increasingly have a strong high tech content. Misjudge the science, make a wrong decision. Yet many of our leaders never studied physics, and do not understand science and technology. Even my school, the University of California at Berkeley, doesn't require physics. *Physics for future President*s (or *PffP*) is designed to address that problem. Physics is the liberal arts of high technology. Understand physics, and never again be intimidated by technological advances. PffP is designed to attract students, and teach them the physics they need to know to be an effective world leader.

Is science too hard for world leaders to learn? No, it is just badly taught. Think of an analogous example: Charlemagne was only half literate. He could read but not write. Writing was a skill considered too tough even for world leaders, just as physics is today. And yet now most of the world is literate. Many children learn to read before kindergarten. Literacy in China is 84% (according to the OECD). We can, and must achieve the same level with scientific literacy, especially for our leaders.

This course is based on several decades of experience I've had presenting tough scientific issues to top leaders in government and business. My conclusion is that these people are smarter than most physics professors. They readily understand complex issues, even though they don't relax by doing integrals. (I know a physics professor who does.) PffP is not Physics for Poets, Physics for Jocks, or for Physics for Dummies. It is the physics you need to know be an effective world leader.

Can physics be taught without math? Of course! Math is a tool for computation, but it is not the essence of physics. We often cajole our advanced students, "Think physics, not math!" You can understand and even compose music without studying music theory, and you can understand light without knowing Maxwell's equations. The goal of this course is not to create mini-physicists. It is to give future world leaders the knowledge and understanding that they need to make decisions. If they need a computation, they can always hire a physicist. But the knowledge of physics will help them judge, on their own, if the physicist is right. Let me illustrate what can be taught by telling a short story that I share with my students in the first lecture. It tells them what I want from them.

An ideal student

> Liz, a former student of my class, came to my office hour, eager to share a wonderful experience she had had a few days earlier. Her family had invited a physicist over for dinner, someone who worked at the Lawrence Livermore National Laboratory. He regaled them through the dinner with his stories of controlled thermonuclear fusion, and its great future for the power needs of our country. According to Liz, the family sat in awe of this great man describing his great work. Liz knew more about fusion than did her parents, because we had covered it in our class.
>
> There was a period of quiet admiration at the end. Finally Liz spoke up. "Solar power has a future too," she said.
>
> "Ha!" the physicist laughed. (He didn't mean to be patronizing, but this is a typical tone physicists affect.) "If you want enough power just for California," he continued, "you'd have to plaster the whole state with solar cells!"
>
> Liz answered right back. "No, you're wrong," she said. "There is a gigawatt in a square kilometer of sunlight, and that's about the same as a nuclear power plant."
>
> Stunned silence from the physicist. Liz said he frowned. Finally he said, "Hmm. Your numbers don't sound wrong. Of course, present solar cells are only 15% efficient… but that's not a huge factor. Hmm. I'll have to check my numbers."

YES!! That's what I want my students to be able to do. Not integrals, not roller-coaster calculations, not pontifications on the scientific method or the deep meaning of conservation of angular momentum. She was able to shut up an arrogant physicist who hadn't done his homework! Liz hadn't just memorized facts. She knew enough about the subject of energy that she could confidently present her case under duress when confronted by a supposed expert. Her performance is even more impressive when you recognize that solar power is only a tiny part of this course. She remembered the important numbers because she had found them fascinating and important. She hadn't just memorized them, but had thought about them and discussed them with her classmates. They had become part of her, a part she could bring out and use when she needed them, even a year later.

Physics for the future leader

PffP is not watered-down physics. It is advanced physics. It covers the most interesting and most important topics. Students recognize the value of what they are learning, and are naturally motivated to do well. In every chapter they find material they want to share with their friends, roommates, and parents. Rather than keep the students beneath the math glass ceiling, I take them way above it. "You don't have the time or the inclination to learn the math," I tell them. "So we'll skip over that part, and get to the important stuff right away." I then teach them things that ordinary physics students don't learn until *after* they earn their Ph.D.

The typical physics major, even the typical Ph.D., does *not* know the material in this book. He (and increasingly she) knows little to nothing about nukes, optics, fluids, batteries, lasers, IR and UV, x-rays and gamma rays, MRI, CAT, and PET scans. Ask a physics major how a nuclear bomb works and you'll hear what the student learned in high school. For that reason, at Berkeley we have now opened this course for physics majors to take. It is not baby physics. It is advanced physics.

I must confess that I made one major concession to my Berkeley students. They really do want to learn about relativity and cosmology, subjects superfluous for world leadership, but fascinating to thinking people. So I added two chapters at the end. They cover subjects that every educated person should know, but they won't help the President make key decisions.

The response to this new approach has been fantastic. Enrollment grew mostly by word-of-mouth from 34 students (Spring 2001) to over 500 (Fall 2006). The class now fills up the largest physics-ready lecture hall at Berkeley. Many of my students previously hated physics, and swore (after their high school class) never to take it again. But they are drawn, like moths to a flame, to a subject they find fascinating and important. My job is to make sure their craving is fulfilled, and that they won't be burned again. These students come to college to learn, and they are happiest when they sense their knowledge and abilities growing.

Students don't take the course because it is easy; it isn't. It covers an enormous amount of material. But every chapter is full of information that is evidently important. That's why students sign up. They don't want to be entertained. They want a good course, well taught, that fills them with important information and the ability to use it well. They are proud to take this course, but more importantly, they are very proud that they enjoy it.

For the instructor: pedagogy

PffP is fun to teach and fun to take, but it is unlike other courses in qualitative physics. I have used several ideas that are unusual. Instructors for this course may find it helpful to understand these.

Immersion

I teach by total immersion. Physics majors take one to four years to get a sense of what energy means. They don't learn it from the definition. So in PffP I start using the term, with many, many examples. Students feel as if they are walking into a foreign language class in which the teacher starts speaking Spanish immediately. After a semester of using the word "energy" every class, the student is beginning to understand what physicists mean by the term.

Motivate and Intrigue

Many students in this class are afraid of physics, sometimes because of a bad experience in high school. So the first step is to get them so interested that they forget their fear. Chapters usually begin with a story, anecdote, or puzzling facts. The purpose is to make the student wonder, "how can that be?" Some of important and intriguing applications are mentioned at the beginning rather than being appended at the end.

The order of topics, and the structure of the chapters is not traditional. There is no need to put "modern physics" last, following historical order. The students are eager to learn new exciting things, and in total immersion, there is no need to wait. I introduce atomic and nuclear physics early. My goal is to motivate the student by putting the most fascinating topics first. Energy is in chapter 1, explosions in 2, spy satellites in 3, radioactivity in 4, nukes in 5. The students get hooked early. By the time we get to waves, light, and integrated circuits, the student is warmed up, and ready to find those exciting too.

Images and Figures

I can't overemphasize the importance of motivation. The images and figures are chosen to be intriguing. When the student thumbs through the book, the images should stir the curiosity. "What is that?" "That's amazing!" "I'd love to understand that." Not all the images and figures meet this standard, but I tried to make as many as possible that would stir the interest of the student.

Physics as a Second Language

I don't tell them that journalists and politicians confuse energy and power. These words existed before physics gave them precise definitions. I ask my students to learn physics as a second language, and to be able to use physics terms in their specialized physics sense when talking to other physics-literate people. This avoids passing on the arrogance that physicists often affect.

Multiple Levels

Classes can be large and have a wide variety of interests and abilities. There are English majors, music majors, math majors and physics majors. Some want more math. To handle this, in lecture I often go into advanced calculations, after stating that it is not required. So, for example, announce that the next five minutes of lecture are not required; students are allowed to sleep. Then I show (for example) how the relativistic energy equation reduces to Newtonian kinetic energy, satisfying the correspondence principle. Remarkably, the students who "hate" math continue paying attention. It is fun, as long as they aren't required to reproduce it. I do the same in the text by explicitly stating when something is optional.

Don't cover everything in lecture

In liberal arts classes, the lectures make no attempt to cover all the material. Students for PffP are accustomed to learning things on their own. I spend the lectures on the most subtle material, or the most interesting (and therefore motivational), but I tell the students that they are required to learn on their own everything in the text that is not marked as optional.

Homework

To make this course attractive, I surveyed my students to find out what kind of homework they got in the non-physics courses they liked. The answer was simple: reading and writing. To address the former, I tried to write a textbook that was fun to read. I wanted the students to read the chapter through, without distraction by standard physics pedagogy (e.g. "check your understanding"). Then, to study, they should read it again.

Many of my students are freshmen, and to make sure that they did the reading on time I gave frequent short multiple-choice quizzes. These were meant to be easy for anyone who had read (but not yet studied) the chapter, but hard to guess if the student hadn't. These questions appear at the ends of the chapters.

I was surprised to discover that prior to taking PffP, most of my students did not normally read newspaper articles about science and technology. To break this bad habit, many of the homework assignments consist of the following: find a newspaper article that has physics or technology content, and write two paragraphs summarizing it. You can earn a high score even if you don't understand the article, if you state what it was that you didn't understand. (Of course, I have a secret goal. Once students clearly identify what they don't understand, they are 90% of the way towards understanding it.) In semester-end comments from students, a common comment was: "I didn't know articles like that were for me!"

I tell students that most homework will get a grade of 2 – meaning nice job, and we didn't have time to grade in any more detail. However, if they have a spelling or grammar error, they get a grade of 1. If the paragraphs they write are so well done that the teaching assistant notices and enjoys reading it, they might earn a rare 3.

For the first homework, a very large fraction of the class is sloppy and earns a 1. Within a few weeks, the writing improves dramatically. Some seniors have told me that this was more writing than they did for any other course, and even though the grading was not detailed, this regular practice improved their writing.

Exams

My exams consist 50% of essays and 50% of multiple-choice questions. My goal is to make students knowledgeable and articulate on the physics and technological aspects of important issues. I give examples of suggested essay questions at the end of every chapter. If you don't have the resources to grade essays, then you can give exams consisting solely of multiple choice questions. I give examples of these too, taken from my own exams. The average student at Berkeley gets 75% of these correct, to earn a B in the course.

Numbers

It is important for the student to be able to understand the use of large and small numbers. But I don't require them to do this themselves. We review scientific notation in the first discussion sections. I don't ask students to manipulate such numbers, but only to be able to follow it when I do. The highest priority is not to teach computation. I want them to know what is important, what is negligible, and how physics illuminates complex phenomena. I want them to be able to tell when something they are hearing is probably wrong.

Policy and Politics

I emphasize physics and try hard to eliminate policy and politics. I try to cover the technical aspects that one must understand in order to make wise decisions, and I try to avoid most of the non-technical aspects of the issues. One of my proudest teaching moments occurred in 2006 when a student asked permission for a personal question. He wanted to know my "politics". I was proud that in a class that discusses energy, nukes, technology of war, global warming, and high tech, he couldn't figure out whom I had voted for. (And I didn't tell him.) It is important to show that physics questions do not have a political spin. We can all agree on the physics. When tricky issues are raised (such as the plutonium economy) I try to give the strongest arguments on all sides. Then it is up to the students to think about the subject and decide their own positions.

The students try but can't put me in a category of, for example, pro-nuke or anti-nuke. I don't care what their opinion is. I teach them the plusses and minuses of nuclear power, and let them choose themselves.

Lectures online

My lectures are available for free online at UC, on video.google.com, and they are podcast at www.apple.com/podcasting. Links can also be found on my web page, www.muller.lbl.gov. In one lecture, I asked anyone who was watching or listening outside of Berkeley to email me. The response astounded me. As of this writing (2006), I have received email from 42 countries, including Malaysia, Mali, Tibet, Turkey, Kenya, Saudi Arabia and Iraq.

Respect

Respect of the student is essential. I treat each student tin my class with my expectation that he or she will someday be President, if not of the United States, then at least of a major company. Educating the future leaders is not just fun, it is a duty. I avoid cartoons and other images that suggest the student is "just a kid". Pictures and writing should approximate the kind that adults like, perhaps what they expect to see in a magazine such as The Economist. This really is physics for future presidents.

What I don't teach

I don't teach problem solving. I don't think that is possible to do in one semester. If these students ever need to calculate the velocity of a roller-coaster, they'll hire a physicist.

I don't explicitly teach the scientific method. There are two reasons for this. The first is that students find it patronizing and boring. The second (if a second one is needed) is that I don't consider the usual scientific method, as taught, to be correct. Few advances are made by testing hypotheses. Most discoveries are made by people who have learned the right level of self-skepticism, and are careful enough that when something unusual happens, something that they can't explain by other means, they pay attention.

I believe in the dictum of the novelist: show, don't tell. After a semester of seeing real science, covering the most important and urgent topics, students get a real sense of what science knows and doesn't. For more, see the next topic, "question periods".

Question periods

I always take the first ten minutes to answer questions on any topic. It can be something advanced, such as "what do you think of string theory", something technical, "am I anonymous on the internet?", or just an urban legend, "do cell phones ignite gasoline at filling stations?" My willingness to show when I don't know the answer, but the educated guesses that I make based on physics, demonstrate the honest that is at the core of the scientific method. For some students, this is the part of the course they enjoy the most. The material is always interesting, topical, and they can listen without the stress of thinking that they will be tested.

Commencement

The text does not try to be complete, that is, it does not try to cover every important aspect of the issues it discusses. It is impossible and unreasonable to try to do that. There is too much. This course is not meant to be a complete survey, and this book is not meant to be used as a complete reference text. Rather, the PffP approach is meant to be a commencement for the student into a life full of understanding and appreciation of science. In some sense, it doesn't matter what the student learns, as long as he learns a lot. If this course serves as an introduction to physics, and as a demonstration that advanced material is not beyond the reach, then the student will learn far more in the years following this course then he could possible learn in one semester.

Memorizing

Unlike physics students, liberal arts students don't mind learning numbers and facts. They are empowered when they know things, such as what really happened at Chernobyl, how many people died of cancer at Hiroshima, what can spy satellites really do (and not do), what is Moore's Law (most students never heard of it), what is the difference between MRI, CAT and PET scans. I tell them that whatever their point of view is, knowledge will help them. They will be able to win arguments with their friends and parents. They seem to be particularly happy with the latter. Of course, it is also conceivable that as they learn the facts, some of them will change their minds on some technological issues.

Fun

Learning is one of the greatest joys in life. Give a child a choice: the chance to learn how to ride a bike, or to have unlimited icecream for an hour. Most children will pick the former. It is a great feeling to learn. Perhaps the only greater joy is when you use that learning to contribute something to others.

Yet most students have that joy of learning beaten out of them, maybe by bad teachers. Yes, learning is hard, just like playing baseball is hard, or playing a video game is hard. The trick is not minding that it is hard. Rediscover the joy of learning. When that happens, the student will learn with much less effort. The student will be able to devote half the time to studying, but will learn twice as much.

The material in this course is fascinating. The student should find it riveting. If that doesn't happen, then it's because the student has lost sight of the joy of learning. Tell the student that the trick to learning the huge amount of material present here is to find it interesting. That should be easy, because it is. When the student recognizes that fact, then the automatic learning mechanism turns on. How can you forget things that are interesting, fascinating, intriguing, and important? Encourage the students to discuss this material with their friends. Have them present interesting facts to physics majors, and chose the facts that the physics major probably doesn't know. Tell the students to discuss nuclear power, radioactivity, energy, lasers, computers, UFOs, earthquakes, everything in this course, with their parents and friends. Anything they discuss with others in this manner (not to study, but to inform others) will be material that they will never forget.

ABOUT THE AUTHOR

Richard Muller is a Professor of Physics at the University of California, Berkeley, and a Faculty Senior Scientist at the Lawrence Berkeley Laboratory. He is known for his broad range of achievements, in fields ranging from particle physics to geophysics, applied physics, and astrophysics. His skill at explaining science to non-scientists was honed over decades of advising top business and government leaders. For 34 years he was a Jason consultant to the U.S. government on national security.

He grew up in the South Bronx, and walked north to see New York Yankee games. Neither of his parents finished high school. He attended PS 65, went to the Bronx High School of Science, and then Columbia College. At Columbia he loved the "core curriculum" in which all students, both liberal arts and science majors, take the same classes. He is proud of the fact that his diploma doesn't even mention his major (which was physics). Education shouldn't be too specialized.

Muller went to graduate school at Berkeley, where he studied under (soon to be) Nobel Laureate Luis Alvarez. After he earned his Ph.D. (in particle physics) he instigated a series of innovative physics projects, including a study of the cosmic microwave radiation (about which he wrote a Scientific American Article in 1978), a new way to measure radioisotopes (called "Accelerator Mass Spectrometry"), and a project to discover supernovae (exploding stars) for use in cosmology. He coined the name "Nemesis" for a star that he and his colleagues suggested is orbiting the sun at great distance. He has published major papers on the analysis of lunar soil, adaptive optics, paleoclimate, reversals of the Earth's magnetic field, and analysis of cycles in the fossil record. He recently wrote an article called "Meteorites and the Shield of Achilles."

Muller was appointed to the faculty at Berkeley in 1980. For many years, he taught the courses designed for physics majors. In 2001, he was asked to teach the course for liberal arts students, then dubbed *Physics for Poets*. He completely revised the course, and wrote the present book to accompany it.

He is the author of several other books: Nemesis (about dinosaur extinctions, 1988), The Three Big Bangs (with Phil Dauber, 1996), Ice Ages and Astronomical Causes (with Gordon MacDonald, a technical introduction to paleoclimate study, 2000), and *The Sins of Jesus* (1999, a novel in which Jesus is depicted as a prophet, with no supernatural powers). For three years he wrote a monthly column for MIT's Technology Review, "Technology for Presidents", based on his course PffP at Berkeley. His articles illuminate world affairs by bringing in relevant physics. They are available on his website (address below).

His work has been honored by many awards, including the Alan T. Waterman Award of the National Science Foundation, the Texas Instruments Founders Prize, and a MacArthur Foundation Prize Fellowship. He was listed by Newsweek Magazine in 1989 as one of the top 25 innovators in the United States. He is a fellow of the American Physical Society, the American Association for the Advancement of Science, and the California Academy of Arts and Sciences. Muller won a Distinguished Teacher Award at Berkeley in 1999.

The photo was taken by his wife Rosemary, in Place Jamaa el Fna in Marrakech, Morocco. Yes, it is a real cobra. For more information and photos, visit his web site www.muller.lbl.gov