

Physics Education Research: Or it's so hard to find good help these days¹

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Bob Ehrlich² would like physics education research (PER) to produce more physics majors, and Karen Cummings³ warns PER not to stray far from problem solving. But whose problems do we teach students to solve?

In a disturbing article for the *Bulletin of the Atomic Scientists*, Bengt Carlson explained how Stanislaw Ulam had invented the technique of supercompression and had described it to Edward Teller. In his article, Carlson upbraids Teller for not acknowledging Ulam's genius:

An astonishing breakthrough was at hand, but where were the signs of [Teller's] elation?⁴

For Ulam had figured out how to trigger a fusion reaction, or how to build a hydrogen bomb.

The priority contest of the insane has lasted over 50 years. Teller wanted the credit. Ulam's partisans, such as Carlson, want Ulam to have the credit. None say 'This instrument of death was not my doing' or even 'I regret my part in its creation.' Rather, Hans Bethe said 'The ideas we had about triggering the H-bomb were all wrong but the intellectual experience was unforgettable'.⁵

Teller was educated in one of the finest environments for a young mathematician, the Hungarian education system, where he learnt deep conceptual understanding. Ulam, Teller, and Bethe were legendary problem solvers. Their child, the hydrogen bomb, epitomizes the connection between physics and power. Their eagerness to struggle with the interesting problems in building it reflects the disembodied thinking that physics teaches.

Please, I want no more problem solvers!

What I want

I want a world based on mutual aid⁶ rather than on power, greed, and the violence to satisfy greed. I want my teaching to encourage such a world. Physics, however, has grown up as a child of war and to serve power. By not recognizing this intimate connection, we supply students who will unwittingly or unwillingly make the world more miserable.

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 2. 'Does It Matter If Physics Educators Have Well-defined Goals?', AAPT Conference, Winter 2004, <http://www.aapt.org/scheduler/128th/results.cfm?Cat=Code&Session=CL01>
 3. 'PER's Bread and Butter', AAPT Conference, Winter 2004, <http://www.aapt.org/scheduler/128th/results.cfm?Cat=Code&Session=CL02>
 4. 'How Ulam set the stage', *Bulletin of the Atomic Scientists*, July/August 2003.
 5. Brian Easlea, *Fathering the Unthinkable: Masculinity, Scientists and the Nuclear Arms Race* (London: Pluto Press, 1983), p. 125.
 6. Kropotkin, *Mutual Aid: A Factor in Evolution* (1902). Online at (http://dwardmac.pitzer.edu/Anarchist_Archives/).

Pure physics and violence

The connection, so clear in building a hydrogen bomb, is also strong in pure physics. Many physicists were upset when Congress canceled the Superconducting Supercollider. American society, many of us felt, had abandoned man's ancient quest to comprehend the universe.

Through the US Freedom of Information Act, the physicist Charles Schwartz obtained the horse's own words, a War Department⁷ evaluation of the Superconducting Supercollider (SSC) just before Reagan approved its funding:

The SSC project will have many spinoffs for the DoD, especially in technologies required by the Strategic Defense Initiative, including particle beams, information processing, computer control, pulse power sources, and high energy accelerators.

The nuclear weapons community will benefit from the fundamental research on the building blocks of atomic matter. The SSC will provide a valuable resource of scientific personnel. Many of the scientists now in the [Department of Energy] nuclear weapons laboratory complex received their training while working on particle accelerators.⁸

Quantum field theory, anyone?

Other physicists were glad about the SSC's demise because its huge cost sucked money from the smaller, table-top experiments of condensed matter physics. The little guy versus Big Science. Jeff Schmidt cites a seemingly pure study of matter, 'The interaction of electromagnetic radiation with solid materials':⁹

The objective of the proposed program of theoretical research is an increased understanding of the interactions of electromagnetic radiation, particularly infrared, with matter.

Abstract, pure, and disinterested research? The War Department knows wherefore it spends its money. Among the benefits it saw:

The infrared optical properties of these materials are important to . . . [understanding] the interaction of materials subjected to laser beams.¹⁰

Follow the laser beams to the Normandy room session or onto a front-page *New York Times* article about American snipers in Iraq:¹¹

In an age of satellite-guided bombs dropped at featureless targets from 30,000 feet, Army snipers can see the expression on a man's face when the bullet hits.

Their weapon of choice is 'an M-14 rifle equipped with a special optic sight that has crosshairs and a red aiming dot'. A sniper explains the results:

'I shot one guy in the head, and his head exploded.'

Paraphrasing duPont's slogan: Better living through optics and GPS.¹²

7. As it was long and accurately known. It was renamed in 1947 to the Defense Department. See Orwell, 1984.

8. Charles Schwartz, 'Political Structuring of the Institutions of Science'. In Laura Nader (editor), *Naked Science: Anthropological Inquiry into Boundaries, Power, and Knowledge* (New York: Routledge, 1996).

9. Jeff Schmidt, *Disciplined Minds: A Critical Look at Salaried Professionals and the Soul-Battering System that Shapes Their Lives* (Lanham, Maryland: Rowan & Littlefield, 2000), pp. 73–74.

10. Schmidt, p. 74.

11. 'In Iraq's Murky Battle, Snipers Offer U.S. a Precision Weapon', 2 Jan 2004, p. A1.

12. 'Better things for better living, through chemistry', introduced in 1939.

What to teach?

Maybe we should not teach physics. Or we should teach people enough physics so that they are not intimidated by scientists and they feel confident enough as citizens to control science.

It is ironic that I cannot talk to you about this topic in person because I am teaching a physics course. I am equally caught in this dilemma and am serving the system.

I mostly teach approximation and order-of-magnitude physics. A favorite example of the students is to estimate how many barrels of oil the United States imports every year. I have used this question for years, but the invasion of Iraq has made it more relevant. One reasonable method is to estimate the number of cars (one per person), the annual miles driven per car, and convert their product into gallons and barrels. How big is a barrel? Break it into length, width, and height and multiply. Eventually you get 3 billion barrels per year.

How many barrels of oil does the US import annually?

$$3 \times 10^8 \text{ people} \times 10^4 \text{ mi/yr} \times \frac{1 \text{ gal}}{30 \text{ mi}} \sim 10^{11} \text{ gal.}$$

A barrel has diameter roughly 0.5 m, so

$$V_{\text{barrel}} \sim 1 \text{ m high} \times 0.5 \text{ m wide} \times 0.5 \text{ m deep} \sim 250 \ell \sim 60 \text{ gal.}$$

So annual auto consumption:	<i>1.5 billion barrels</i>
Other transportation, refining inefficiencies:	$\times 2.$
All other uses:	$\times 2.$
Fraction imported:	$\times 0.5.$
Imports:	<i>3 billion barrels.</i>

Students learn to break complicated problems into subproblems. They learn the power of simple techniques (here, just multiplication) and enjoy applying physics to the world. Note how I appeal to the ‘power’ of this technique. The connection between physics and power is difficult to evade!

Physics also guards entry to well-paid, professional careers such as engineering and medicine. By eliminating abstruse mathematics, the order-of-magnitude approach connects physics to the real world and makes physics less intimidating. It is humane in a limited way.

Limited, because these estimation skills are what management consultant firms such as McKinsey look for in their interviews. One London firm asks my students: *How many hairs are there on a dog?* Microsoft, a convicted corporate criminal, uses similar questions in its interviews. People who can answer such questions have developed a quantitative confidence; they demonstrate that they solve new problems without fear. But whose problems?

Nor is order-of-magnitude analysis limited to studying the oiligarchs. Fermi estimated the size of the first atomic bomb by dropping scraps of paper and seeing how far backwards

the shock wave pushed them. The English fluid dynamicist G. I. Taylor estimated the size of the same blast from fireball photographs published in *Life* magazine. Leading war physicists – such as Bethe, Feynman, and Fermi – were brilliant at approximation.

Again, whose problems am I preparing students to solve?

I mitigate the damage that I do by extending the oil problem. I ask students to estimate how much the United States spends on its military forces that guard Persian Gulf Oil. They rightly guess \$100 billion. We convert it to the more manageable figure of 35 dollars of military spending per barrel of oil imported. This cost is almost exactly the price of a barrel on the so-called open market. If the US government is so concerned to obtain cheap oil for Americans, why not end the Persian Gulf protection force, use the \$100 billion to buy the oil, and give it to Americans for free? I leave this puzzle to you.

How much damage have I undone? I don't know. My attempts to go farther are subtly but strongly resisted.

As a protest against the war on Iraq, I constantly wear an A4-sized sign saying 'Oil-garchy' in big red letters:



Oil-
igarchy

I have worn it since March 2003 when the invasion began, and I wear it while teaching thermodynamics to the 180 sophomore physics majors. Students ask about it in and after class, and I have put my answer on the course website.¹³ I explain that as an American citizen, a British citizen, and as a teacher of physics, a subject that enables war, I feel a triple obligation to protest.

Fancy formulas, such as the Maxwell relations, are out in this course. I teach thermodynamics through estimation, group discussion, and class arguments over physics. One problem, for example, asks students to estimate the thickness of ice formed on lakes during a cold winter; another to estimate how long a turkey takes to cook.

The conservatives in the department dislike, even despise the non-traditional approach and say that the course is, in their words, too political. They cite my oilgarchy sign and point out that my course website condemns exams for ruining learning and making students feel miserable about themselves.¹⁴ The progressives see that students might learn a lot with the new teaching style (it's the first Cambridge physics course taught this way, so no one yet knows for sure). Yet the progressives, who, like most of Britain, oppose the war, also want me to remove the sign and the other so-called political aspects. With reason on both points, they point out that such prudence will make it harder for the conservatives to scupper the course and also might make people take my political message more seriously.

If the conservatives get their way, I would not teach the students to solve problems skillfully, and the students would have no conception of the political and social role of physics. If the progressives get their way, I would train the students to be skilled problem

13. <http://www.inference.phy.cam.ac.uk/sanjoy/teaching/thermo>.

14. See Alfie Kohn, *Punished by Rewards: The Trouble with Gold Stars, Incentive Plans, A's, Praise, and Other Bribes* (Boston: Houghton Mifflin, 1993) and <http://www.alfiekohn.org>.

solvers, and even enjoy physics, but with no conception of the political and social role of physics. Which alternative is worse?

So in class I show the War Department statement about the Superconducting Supercollider and we discuss the connection between physics and war. Can 15 minutes, in one lecture out of hundreds that students attend in the year, compete against the prestige, funding, and high salaries in war-financed research (weapons of mass destruction) or in bond and currency speculation (weapons of financial mass destruction)?

Rule of thumb

To paraphrase John Bright, the anti-tariff and antiwar Victorian MP:¹⁵

The US government, like all powerful governments, has done good things, but it has never done a good thing merely because it was a good thing.

Since I teach approximation I will speak roughly: The US government serves the powerful interests that run it, unless a massive popular movement forces on it an unwelcome policy. For example, withdrawing from Vietnam.

Funding for physics increased greatly after World War 2. Physics education reform began around the same time and accelerated after Sputnik. No popular movement forced the government to fund physics or education reform. I therefore wonder: So why the funding? One answer is that physicists serve the state. The state worries when either the supply or quality of servants falls: *I do say, it's so hard to find good help these days*. To make more and better help is one job of PER, a field where I have many friends and colleagues, but a field that I see as dangerous.

Cognitive revolution

PER arose from the cognitive revolution in psychology. Allen Newell, one of its pioneers, worked at RAND studying the human mind as one piece of a large 'information-processing system' that was the precursor to NORAD.¹⁶

Another pioneer was Jerome Bruner. During World War 2 he worked for the Psychological Warfare Division in the Office of War Information.¹⁷ To education reform he brought the skills of a psychological warrior. One flagship NSF-funded curriculum of the 1950s, PSSC Physics,¹⁸ was designed for a comprehensive assault: filmstrips, textbooks, readings, and workshops would together overcome student ignorance and educational conservatism. In Bruner's words:

we [suggested] the analogy to a weapon system – proposing that the teacher, the book, the laboratory, the teaching machine, the film, and the organization of the craft might serve to form a balanced teaching system.¹⁹

15. Bright's quote in Albert Jay Nock, *Our Enemy the State* (1935), Part III, Chapter 2.

16. Douglas D. Noble, *The Classroom Arsenal: Military Research, Information Technology and Public Education* (London: Falmer Press, 1991), p. 42.

17. John Rudolph, *Scientists in the Classroom* (New York: Palgrave, 2002), p. 98.

18. Physical Science Study Committee, *PSSC Physics: Teacher's Resource Book and Guide* (Boston: D. C. Heath, 1960).

19. Rudolph, p. 99.

As historian John Rudolph concludes:

The modern Cold War weapon system was, in the minds of all these reformers, the epitome of rational instrumentation – a powerful model to be emulated in seeking solutions to educational problems.²⁰

I conceive of education as growth in exploratory powers, curiosity, and confidence, described so well by Hassler Whitney²¹, Louis Benezet,²² and John Holt.²³ However, in the Sputnik-era reforms, the student mind was a target to be measured, mapped, re-engineered, and overcome; and cognitive psychology provided the ammunition.

PER As Ideological Facelift

But why PER?

In 1958, only 18% of Americans thought that their government was ‘run by a few big interests looking out for themselves.’²⁴ But after the Vietnam war, many institutions of American society took a drubbing. The President resigned rather than let us know what other crimes he was involved in. The secret police (the FBI) was exposed spying on American citizens. The CIA was exposed overthrowing the governments of Guatemala, Iran, and Chile to install torturing kleptocrats friendly to American corporations.

In 1980 the 18% who thought the government was run ‘by a few big interests’ had become 77%. Our ruling institutions needed an ideological facelift. The presidency of Jimmy Carter and its concern for human rights came at the right time. As rhetoric about human rights flowed liberally, so did torture equipment for the Shah and tanks and planes for Indonesia to slaughter in East Timor.

Science suffered a similar sag in prestige. Dow Chemical became notorious for manufacturing Agent Orange and napalm. In *Silent Spring*, Rachel Carson exposed how corporations poisoned the environment with the products of science. Scientists, the servants of the discredited state, lost public trust, and science itself acquired a bad odor.

Where would the state get more servants? Would the rest of society trust these servants? Science needed many ideological nips, tucks, and lifts.

Developing at the right time from the cognitive revolution, PER arose to make a kinder, gentler physics. Students would work in groups. Teachers would find out what students knew and teach accordingly. Students would do hands-on experiments and inquiry lessons; they would learn how scientists investigate the world, and they would be inducted into the so-called scientific method and epistemology. Students would become happy,

20. Rudolph, p. 99.

21. Hassler Whitney, ‘Coming alive in school math and beyond’, *Educational Studies in Mathematics* 18(3):229–242 (1987).

22. L. P. Benezet, ‘The Teaching of Arithmetic I, II, III: The Story of an Experiment’, *Journal of the National Education Association* 24:241–244, 301–303 (1935); 25:7–8 (1936). The articles are online at (<http://www.inference.phy.cam.ac.uk/sanjoy/benezet/>).

23. John Holt, *How Children Learn* (Penguin, 1983); and *How Children Fail* (Penguin, 1983).

24. Earl Babbie, *You Can Make a Difference: The Heroic Potential Within Us All* (New York: St. Martin’s Press, 1985), Chapter 3. Online at (<http://www1.chapman.edu/wilkinson/socsci/sociology/Faculty/Babbie/YCMAD/>).

creative problem solvers and would learn that true science, unlike the authoritarian science represented through the old teaching style, is a force for reason and good.

But this new science is not so new. For example, the Views about Science Survey (VASS) claims to measure how ‘expert’ a student’s views about science are. No question mentions the connection between science and war, because such a connection is outside the expert (i.e. scientist) view of science. Yet in 1986, of recently graduated physics bachelors working in science or engineering, one-half worked on war projects.²⁵ If physics is what physicists do, does your PER-based physics course teach this connection? Or do you strictly teach problem solving?

1984 vs Brave New World

Imperial rulers can choose from two strategies to coerce the people to work for the elite: *1984*, which uses physical force; or *Brave New World*, which uses psychology. PER is a timely hybrid: It employs advanced social science to further advanced physical science.

Physical science dominates in the 1984 approach. We prefer it for the browner peoples of the far empire: Vietnam, Cambodia, Indonesia, Iran, Iraq, and the very dark at home. Thanks to the so-called war on terror, the less dark at home may also feel the lash. But normally the richer of the home population get a brave new world of Fox ‘News’, the Super Bowl, Big Brother, bargains on DVD recorders, and Hollywood movies and celebrities to amuse them into passivity. As Aldous Huxley warned:

The most important Manhattan Projects of the future will be vast government-sponsored enquiries into what the politicians and the participating scientists will call ‘the problem of happiness’ - in other words, the problem of making people love their servitude.²⁶

One example is PER, which wraps service to power in a humane shell.

War budget

In the fiscal year 2002, we – via our government – spent almost \$600 billion on death. That figure includes the nominal war budget plus its many disguises including veterans pensions, foreign ‘aid’ to buy our weapons, nuclear-weapons programs in the Department of Energy, and interest on the national debt due to past war spending.²⁷

Killing consumed about one-half of the government budget even before we invaded Iraq. In 1967 Martin Luther King warned:

A nation that continues year after year to spend more money on military defense than on programs of social uplift is approaching spiritual death.²⁸

One year later, he was shot dead, probably by the US government.²⁹

25. Charles Schwartz, ‘Social responsibility in physics’, *Social Responsibility*, vol 2(1). Online at <http://socrates.berkeley.edu/~schwartz/PhysBklt.html>.

26. Huxley’s Foreword to *Brave New World* (1946).

27. Robert Higgs, ‘The Defense Budget Is Bigger Than You Think’, <http://www.independent.org/tii/news/031222Higgs.html>.

28. ‘Declaration of Independence from the war in Vietnam’, 4 April 1967, Riverside Church, New York, NY.

29. See Bill Pepper, *An Act of State: The Execution of Martin Luther King* (London: Verso, 2003).

Table 1. US military spending in Fiscal Year 2002.

\$billions	Where (from Higgs, 'Defense budget')
344.4	War Department itself
138.7	Portion of interest on national debt due to past wars
50.9	Department of Veterans Administration
18.5	Defense-related parts of the Department of Energy budget
17.6	State Department and international assistance programs related to 'defense'
17.5	Agencies later incorporated into Department of Homeland Security
8.5	Other homeland security
596.1	Total

Hippocrates

Modern science and the modern, absolute state arose together in the 17th century. We got the heliocentric theory and Louis XIV, the Sun King, who proclaimed that 'The state is I'.³⁰ Both science and the state worship Law with a capital L. Rulers, whether the soft American or hard Russian variety, depend on science for ideological and physical power.

As long as there is an elite, physics will serve it and cement its rule. When we develop a society without an elite, we can reconsider whether to teach and fund physics. Until then should we follow Hippocrates? He advised doctors as their first commandment: *First do no harm*. A step in stopping an evil is refusal to cooperate.³¹ Don't teach physics. By teaching physics, traditionally or in the reformed sense of PER, we train more servants of the state and we legitimize science. As we thereby arm the state against ourselves, we move farther from a peaceful, cooperative, and enjoyable world.

30. Lewis Mumford, *The Myth of the Machine: The Pentagon of Power* (London: Secker and Warburg, 1970), especially Chapters 2 and 7.

31. Étienne de la Boétie, *The Politics of Obedience: The Discourse of Voluntary Servitude* (New York: Free Life Editions, 1975 [1552–53]). Online with an introduction by Murray Rothbard at (<http://www.mises.org/rothbard/boetie.pdf>).