From the Editor

Despite the upsurge of the Delta variant, things are getting back to normal for most of us in our profession. This semester classes are by default in person here at the University of Minnesota, and we are having again real seminars and colloquia. Perhaps not on the positive side, faculty and committee meetings have resumed.

There is still a lot of fear and a certain “I do not want to take any risks whatsoever” attitude. People who are helping us, by selling us groceries, delivering packages, taking care of our health and many other necessary things, are taking risks and were taking much bigger risks at the height of the pandemic. We should well reciprocate by accepting the very small risk involved in teaching their masked and vaccinated children in person.

I am pleased to have something different in this issue: an article by Dennis Overbye, science writer for the New York Times, and responsible for publishing all the news that’s fit to print in physics, I suppose. Also, an article reflecting on current events on fusion. And our usual book reviews and news items.

This newsletter is very highly dependent on readers’ contributions. Articles and suggestions for articles should be sent to me, and also letters to the editor. Letters addressed to me should specify if they are for publication or not. I get some that are obviously unsuitable. The APS production people prefer MSWord formats. Book reviews should be sent to the reviews editor directly (ahobson@uark.edu). All topics related to Physics and Society, broadly understood, are welcome. Controversy is fine: content is not peer reviewed and opinions given are the author’s only, not necessarily mine, nor the Forum’s or, a fortiori, not the APS’s either.

Oriol T. Valls, the current P&S newsletter editor, is a Condensed Matter theorist at the University of Minnesota.

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It highlights the importance of the Optional Practical Training (OPT) and J-1 visa programs to the US scientific enterprise through stories about talented international students and scholars who chose to study and/or work in the United States.

OPT enables highly skilled international students who completed their studies in the United States to gain work experience for a period of time and is used as a recruiting tool by high-tech companies. Businesses such as Amazon, Microsoft, and Intel are among numerous tech firms that annually employ thousands of recently graduated international STEM students under the OPT program. J-1 visa holders are typically researchers, students, and professors who participate in work- or study-related programs in the United States.

The APS GA report cites the importance of international students and scholars to the US scientific enterprise.

“The benefit these international students and researchers provide to the United States is clear and measurable. As of 2018, immigrants had founded more than half (50 of 91) of the privately-held billion-dollar startup companies in the United States, and 21 of these 91 companies had a founder who first came to the United States as an international student,” the document notes.

Francis Slakey, Chief External Affairs Officer for APS, said the Society looks forward to using the report as part of a roadmap toward keeping the “United States as the destination of choice for the world’s best and brightest.”

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Senior Public Relations Manager
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Dennis Overbye

The following article is an edited transcript of an invited talk that New York Times science correspondent Dennis Overbye gave at the virtual 2021 APS March Meeting in a symposium on communicating science to the public that was sponsored by the Forum on Physics and Society.

Thank you for inviting me here.

I was all ready to get on a plane to come to Denver to give this speech a year ago, when the world ended. It’s now been more than a year since I went to the office.

For the last few years I have gotten away with calling myself the cosmic affairs correspondent of the New York Times. It’s an aspirational title, but my bosses seem to think that it’s cute. I sometimes describe my beat as anything bigger than the solar system or smaller than an atom. It’s the best job I ever had. It’s the only job I’ve ever been able to keep.

We are fascinated by ourselves. We like to think of ourselves as the center of the universe, at least the media universe for those of us who work at the Times.

So I’m going take you on a little trip down memory lane.

You might have heard in recent years, from a certain former President, for example, that we are failing or that the entire news business is failing. There was a reason for that. First it was the internet, that took away all our advertising, then it was the financial crisis.

A few years ago we started having buyouts and layoffs every couple of years (Fig. 1). When it started we had about 1200 reporters, editors and other kinds of helpers in the newsroom. That was big for a daily newspaper. There were rumors a decade ago that our bosses had decided more like 800 was the optimum number.

But that was back when all we did was publish a newspaper.

In 2011, after a years long debate we started charging digital readers. Many respected and senior journalists were convinced nobody would ever pay for news. But what choice did we have?

Things were slow at first. Things changed round about 2016, as you can see (Fig. 2).

There are now 1700 reporters, editors and other helpers in what we call the newsroom. Many of them have jobs and titles, like digital and video producers, social media experts and audience development people. Podcasts and even TV have become a big part of the business. There are consequences to this success. Most of you read us on your smart phones now.

As a result, young people, say in Silicon Valley, don’t even know where or how to buy a physical newspaper, as I found out a while back. I was in a coffee place in Mountain View dying for a copy of the Times. I had two articles in that day – one on the front page and the other in Science Times and I was desperate for a copy. The manager couldn’t help me. Finally he just yelled out to the crowd. “Where could this man buy a newspaper?”

Silence.

Finally a retired-looking gentleman sitting in the corner raised his hand and offered to give me his newspaper.

These days the whole news report is designed around the phone. We want your eyeballs – fast. On the home page there

![A Slimmed-Down Newsroom](https://example.com/fig1.jpg)

*Fig. 1. The steep decline and the beginning of the turnaround.*
are no bylines. You have to click to see who wrote the piece, if it’s your favorite author or whatever. More importantly for the business, it tells you exactly when this article was posted. Like 6 minutes ago. That’s how long a scoop lasts in today’s world.

Back to science. We’re a small part of the Times newsroom, but we like to think we’ve always punched above our weight.

Science has always been part of the Times mandate. Back in the day the newspaper even sponsored South Pole expeditions. And the first ever embedded reporter was atomic Bill Laurence (Fig. 3), who wrote about the Manhattan project from the inside.1 We were charter members of the famous conspiracy to pretend astronauts had landed on the Moon.

Here I am trying to carry on the tradition, with my head at the business end of the Large Hadron Collider (Fig. 4).

Since 1978 when science won a smackdown with fashion, we’ve produced a weekly Science Times section. Along with all the alarming news we can sell to the front page.

All told we produce something like 40,000 words of science and medical news a week — half in Science Times on Tuesday and half spread out during the other days of the week.

Still we’re a small desk and on a small desk you are always wishing for something that will vault you on to the front page, the big time (Fig. 5). In the last year, I am told we have produced half again as much science material as in a normal year. The exact numbers are classified.

I got only a small piece of this action. What I like to call comic relief. More than just the pandemic and the election happened this year. Mars, Venus, SpaceX. I wrote 58 stories this year.

For some reason 16 of them were about black holes. Black holes eating stars, black holes eating other black holes. Black holes that were bigger or smaller than they were supposed to be, that weren’t where they were supposed to be. I remember when hardly anybody believed in black holes – back in the 60’s and 70’s. Now black holes are the cat videos of astronomy.

I’ve been told people are eager for something that takes them out of their own head and reminds them that there is a universe out there, that what happens here on this planet isn’t the end-all or be-all. There is more to the universe than just us. Our job is to take the universe seriously and not ourselves. There is a lot of work to be done.

I’m not at all sure how successful I and we are, when for example back in 2012 nearly 60% of Americans 18-24 years old thought astrology is “very” or “sort of” scientific. I suspect the numbers would be worse today.

I also spend a lot of time worrying about what we’re NOT covering. They say that journalism is the first draft of history. It’s not such a great version sometimes. Historically we’ve missed a lot even though embargoed press releases rain down in our inboxes every day.
April 25, 1953.

On that date James Watson and Francis Crick published a short paper in Nature disclosing the double helix structure of DNA. It didn’t help us that they buried the lead, as we say in the business, mentioning only in passing at the end that this double helix explained how genes and mutations were passed along. This was biology’s moment. And we missed it.

How much more do we miss, or as a person piped up once asking me how much does the Times lie to us? I was asked this over the campfire at a very exclusive gathering of executives and other movers and shakers. We had been talking about health care with a man who used to run the biggest health company in the world (who was not the one who posed the question). My hosts were alarmed but I was thrilled. It was worth the price of the plane ticket just to be asked that question by people who run the country and the corporations in this country. All we know, I said, is what people like you are willing to tell us.

We have always needed helpers to make sure we don’t miss big moments.

We like to say we are enabling democracy, by giving people the tools to make the decisions about the great issues of the day like climate change, disarmament, public health.

The Times has a vast, diverse audience. It runs from Derek Jeter to Hillary Clinton to Ed Witten. In my dreams everybody who reads me will find something to take away. I don’t think it is my job to teach physics or cheerlead for bigger budgets. I often say it is the job of scientists to watch the universe, and my job is to watch the scientists. We should take the universe seriously – it is where we live – but not ourselves.

NOTES


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Fusion Frenzy- A Recurring Pandemic

Daniel L. Jassby

“Common sense ain’t common.”

—Will Rogers

A FRENZIED HISTORY

We are in the midst of a fusion energy pandemic, wherein a host of so-called “fusion startups” claim that they will put fusion electric power on the grid by 2030, and these fantasies are believed by credulous onlookers.

Actually, fusion energy fever is a pandemic that once recurred every decade soon followed by disenchantment. The first episode occurred behind locked doors of national labs in the 1950’s, instigated by Ronald Richter’s erroneous 1951 claim of achieving a fusion reactor [1] as well as by the work on developing thermonuclear weapons. The second outbreak began around 1960 following the declassification of worldwide secret work at the 1958 Geneva Conference on Atomic Energy. The next wave of hysteria roiled the global fusion world around 1970 following the release and confirmation of the startling T-3 tokamak results. The last fusion delirium began around 1980, predicated on the inexplicable belief that fusion energy would somehow obviate future oil supply crises such as those of the 1970’s.

In each episode manicual expectations petered out in a few years, although strong plasma physics programs and modest technology development persisted globally. For a detailed discussion of this history, see Braams & Stott [2] and the recent book by Reinders [3].

After the 1980’s pandemic withered away, fusion hysteria was suppressed for nearly three decades as enthusiasms were sublimated to the ultra-expensive ITER and NIF projects. But a half-dozen years ago the virus re-appeared and began to build to amazing strength. Proclamations by fusion startups and even established labs of glorious achievements projected for the near future have today reached an unheard-of frenzy.

SYMPTOMS OF FUSION FRENZY

Here are 10 current symptoms of the pandemic of fusion fever:

1. Unprecedented rate of formation of so-called fusion energy startups. They have found a cheerleader in the newly formed FIA (Fusion Industry Assoc.) [4].

2. Universal claims by these startups of commercial electricity production by 2030, at a time when ITER [5], the only reactor-scale fusion project in the real world, will be merely nurturing its adolescent plasmas.
3. Government-sponsored proposals for a Fusion Pilot Plant in the US [6] and a similar facility (STEP) in the UK [7] that would introduce fusion electricity production by 2040, indicating that the fusion establishment has been caught up in the frenzy.

4. Frequent claims by establishment laboratory directors as well as private concept promoters that the scientific issues of fusion reactors have all been settled, and only some pesky engineering problems need to be resolved.

5. Startups MIFTI [8] and ZAP [9], formerly merely touting modest neutron production from their plasma pinches, are now anticipating imminent electric power production.

6. Continual barrages of press releases from startups and established fusion labs, describing expected experimental results or impressive computer modeling, and hailing the latest hardware component as tantamount to commercial electricity production.

7. Websites of most fusion startups are “all hat and no cattle”, feature exuberant boasting of future achievements and fantasized energy products, but showing modest if any actual fusion performance [10]. The more recent startups have built no experiments whatever, but their boasting is indistinguishable from that of the longer-term contenders.

8. Many websites of so-called fusion companies, whether or not they have demonstrated a single fusion reaction, promise that their power reactors will produce electricity “N times cheaper than coal,” where N = 2 to 5.

9. Combining fantasy space with outer space, several start-ups such as Helicity Space Corp. and Princeton Satellite Systems are now claiming to be developing fusion rocket engines based on the very difficult D-He3 reaction, but have made essentially zero progress in attaining relevant parameters. The uberdelusional FIA is now promoting “Fusion Energy for Space Propulsion” to be developed by 2030 (naturally) [11].

10. A U.S. Congressional Fusion Energy Caucus was formed recently to work for increased funding of research and demonstration projects that would supposedly enable the U.S. to become the first country to commercialize fusion power [12].

While there are a handful of feverish startups in the EU and east Asia, the latest outbreak of fusion frenzy has been largely confined to the US and the UK. American hucksterism once scorned by the UK is now embraced by it. Just as Richter in 1948-51 was able to deceive Argentinian President Peron into believing that he knew how to make a fusion reactor, the Richterite CEO’s of First Light Fusion, General Fusion and Tokamak Energy have similarly bamboozled UK Prime Minister Johnson, who like Peron is now boasting that his country is an energy superpower.

Most entries in this self-proclaimed fusion race promote non-tokamak concepts. As for real tokamaks, General Atomics’ DIII-D and Culham’s JET have continued to produce barrages of fusion neutrons. But instead of neutrons, tokamak startups Tokamak Energy and Commonwealth Fusion Systems are producing barrages of press releases as the major part of their claim to saving the world. In fact the storm of press releases from all players is probably unprecedented even in the fantasy world of controlled fusion R&D, where significant results are in short supply and groundless projections are commonplace.

FUSION REALITY

So what has induced the recent and ongoing frenzy in the field of phantom fusion energy?

Has there been any critical new discovery? No.

Has any new fusion concept appeared that is convincingly superior to the tokamak? No.

Has there been any monumental experimental breakthrough that would enhance the prospects of tokamak reactors? No.

In MCF (magnetic confinement fusion) and MIF (magneto-inertial fusion) the three most important fusion-related metrics are fusion energy gain Q, neutron production rate, and the “triple product” of density x (confinement time) x (ion temperature). These parameters reached their record values in tokamaks by 1998 [13]. Since then there have been significant increases in pulse length in several tokamaks with high temperatures maintained for tens of seconds, but with the “triple product” steadily decreasing during the pulse. That achievement does represent important engineering advances in heat removal and maintaining the tokamak current, but it’s hardly revolutionary.

The greatest fusion-related progress in the past quarter-century has been made in laser-driven ICF (inertial confinement fusion) at the NIF (National Ignition Facility) at Livermore, which has increased fusion-neutron production per pulse by three orders of magnitude over previous laser-based installations, while increasing Q by nearly two orders of magnitude [14], even before the lone “supershot” of August 2021. Ironically, the laser-ICF fusioners have opted to sit out the present craze. They were apparently burned by their assertions a decade ago of laser-based fusion power reactors being deployed in the 2020’s, predicated on their confidence...
at that time that NIF would shortly demonstrate thermonuclear ignition [15].

The recent NIF supershot [16] will further inflame fusion frenzy. If this startling result can be reproduced or enhanced in the next year or so, it is bound to focus attention on short-pulse ICF fusion concepts featuring very high density with compression, But any practical power-producing application is many decades away, if ever, as is the case for MCF schemes. Meanwhile there is no scientific or technological justification for the current fever among MCF and MIF advocates for their pet contraptions, so how did this delirium arise?

**PROMOTERS’ SUCCESS IN MASS PSYCHOLOGY**

Analogous to their exploitation of the oil supply crisis of the 1970’s, fusion promoters have lately taken advantage of the world’s crusade to develop non-carbon energy sources. Asserting that only they can save the planet, promoters and propagandists of fusion enterprises (both private and publicly supported) have worked themselves and each other into a mania of grand projections and promises, in order to sell their programs to investors and government funding agencies. It is a bubble that is totally untethered from any meaningful progress in the real world of MCF and MIF.

Terrestrial fusion energy may never have been a serious contender in energy development, but during each pandemic the subject becomes a subfield of the social sciences, principally psychology (self-delusion of the practitioners) and mass psychology (propagandizing the public with the messianic aura of “the energy source that powers the sun and stars”) while overlooking insuperable obstacles and the very undesirability of terrestrial fusion [17].

The promoters and propagandists have been so successful that it’s assumed both by practitioners and observers of R&D programs that terrestrial fusion energy is perfectly feasible and beneficial. A seemingly great debate has arisen, but it does not concern feasibility or desirability. The debate questions whether fusion reactors can be deployed widely by 2040, or not (alas!) before 2050, whether fusion reactors will be economically competitive, and whether fusion can provide “dispatchable” electricity [6].

**TOKEN ELECTRICITY OUTPUT IS IMPOSSIBLE IN THE NEAR TERM**

The above debate is totally disingenuous and only a red herring, for in 70 years of fusion energy R&D no-one has ever produced a joule of electricity from a terrestrial fusion source. Unlike solar fusion which produces no neutrons, 80% of the energy of terrestrial fusion is in the form of barrages of neutron bullets, and there is nothing analogous to the photovoltaic effect that can convert arbitrarily small amounts of solar radiation to electricity. Presumably, the energy of neutron streams must first be thermalized in the annular solid or liquid “blanket” that surrounds the reacting plasma to produce sensible heat that can be converted to electricity.

There is an axiom of fusion energy R&D that states:

> Any fusion device and its auxiliary systems consume colossal amounts of electrical energy.

A corollary to that axiom states:

> While effective fusion generators can turn electrical energy into neutron streams, only gigawatt-level neutron streams can regenerate net electrical energy.

ITER provides a good example of the massive and largely irreducible electricity drains endemic to any fusion facility. The various ITER systems will consume at least 300 MW(e) [electric] during a power pulse and 500 MW(e) for the first 20 s of that pulse [18, 19].

In view of the above axiom and its corollary, all one might reasonably ask from fusion proponents is to demonstrate a token amount of electricity production, such as a mere 1 ten-thousandth of the continuous electrical power input—e.g., 1 kW(e) for a facility absorbing 10 MW(e).

In fact nobody can make even that modest a demonstration prior to D-T operation in ITER. Here’s why:

- Tokamaks are the most prolific producers of fusion neutrons, but the pulse length and duty factor of the largest existing tokamaks are too small for the neutrons to generate sensible heat in the blanket, even with highly reactive D-T operation. In the entire MCF and MIF worlds, only the JET tokamak can use tritium in the foreseeable future. Preparing for tritium use in any MCF device appears to be as complicated and time-consuming as any NASA campaign for a manned lunar landing. After two decades of preparation including many years of postponement, JET restarted tritium operations in late 2020 [20]. Essentially pure tritium plasmas with relatively low neutron yields were produced for months, but D-T operation began only in August 2021. There will be at most ten 5-sec pulses per day with a duty factor less than 1% and there is no provision for converting neutron radiation.

- As for D-only operation, neutron power entering the blanket is overwhelmed by heat efflux originating from plasma particles and radiation. While there is plenty of heat to remove during D-only operation, more than 99% of it comprises the recycled external energy injected to maintain the plasma temperature.

- The vast majority of startups cannot produce any neutron radiation, while the rest can generate only token amounts [10].

- Unlike the MCF and MIF worlds, tritium is commonly used in laser-driven ICF experiments because there
is less than 1 milligram of tritium in the fuel capsule. The NIF has shown that ICF can produce at least 100 kJ of fusion energy per pulse [14], but technological constraints allow only one or two high-power shots per day so that heat generation from neutrons intercepting the reaction vessel is insignificant.

- At present the highest intensity continuous D-T source of any type is Phoenix’s neutron generator, which fires D beams into a gaseous tritium target to produce up to 4 x 10^13 n/s, corresponding to about 100 W of fusion power [21]. The neutron radiation impinges on a surrounding vessel surface of approx. 3,000 cm^2, so that the energy intensity is only about 30 milliwatts per cm^2. This tiny flux is dwarfed by heat derived from beam particles and electromagnetic radiation striking the wall.

**PROPOSED TOKEN POWER DEMONSTRATION ON ITER**

Sometime after 2035, it should be possible to demonstrate token electric output (kilowatts) from fusion energy in ITER with its planned 400-s pulses and D-T operation, using a small portion of the interface surrounding the reacting plasma. But that demonstration must avoid using any of the 50 to 90 MW of beam and radiofrequency wave power injected into the plasma that eventually emerges in particles and radiation. In ITER about 60% of that power will enter the blanket, the remainder exiting the magnetic divertor. Thus the blanket coolant systems will be removing tens of megawatts of heat even without fusion radiation.

The 440 blanket modules in ITER will be kept at relatively low temperature [22], while up to six test modules intended to investigate tritium breeding [23] will be preheated so that they can operate at reactor-level temperatures. An electric power demonstration would require its own module, whose temperature beyond a certain distance from the plasma interface would be raised only by fusion-neutron heating. Inserted into an equatorial port, this “power module” would have plasma-facing dimensions of 1.7 m x 1.0 m.

The plasma-facing wall of the power module might consist of a beryllium oxide shell bonded to tubes containing water coolant, comprising a structure 10-cm thick that would remove all the heat deposited by particles and radiation. At that distance the neutron energy flux will have dropped to approximately 65% of its incident strength. The bulk of the module could be a solid lithium compound or simply water enclosed on all sides except the front by an insulating jacket that would allow adiabatic heating by the fusion neutron radiation, about 90% of it occurring between 10 and 30 cm from the plasma interface.

At ITER’s objective of energy gain Q = 10, fusion-derived heating would be unambiguous. But an electricity demo should not depend on reaching high Q. In ITER Q = 10 is likely to be attained only in a few pulses or “shots,” much as Q = 0.2 to 0.5 was realized in only a few shots on TFTR and JET in the 1990’s. The vast majority of ITER’s D-T pulses will have much lower Q.

At Q = 2, for example, the fusion neutron power alone will be about 2.5 times the non-fusion particle and radiation energy impinging on the blanket, and 100% of the total power deposited beyond 10 cm as indicated above. With the minimum plasma heating power of 50 MW, the neutron power flow entering the test module will be about 280 kW, dropping to about 180 kW where the other heat sources become insignificant, and continuing to lose all of its strength over the next 25 cm. If a substantial fraction of this dissipated energy can be converted to electricity with 10% efficiency, then an output of several kW could be demonstrated.

The average neutron power deposition will be approximately 0.5 W/cm^2 at 10 to 30 cm from the plasma under these nominal conditions. In a well insulated medium having the product of density and specific heat the same as water, neutron thermalization will produce a temperature increase ~ 1/10 deg. C per second, amounting to a 40 deg. C increase by the end of a 400-s power pulse.

Because of low duty factor for D-T shots (at most 20%), the temperature increase will fade drastically in the half-hour between pulses, so that electric power must be generated on the strength of the deposition during a single pulse. It will probably be most practical to use thermoelectric conversion, with electric output from thermopiles [24]. One side of each thermopile would be kept at constant low temperature by localized water coolant, but there would be no other active cooling. There ought to be enough power generated by the thermopiles to operate their own coolant pump.

The heating rate is proportional to fusion gain Q and could be several tenths of 1 deg. C per second in outstanding shots. Certain nuclear-certified liquid media such as Dowtherm G have products of density and specific heat just half those of water and would show twice the temperature rise and therefore twice the voltage output in a thermopile.

Strangely, the $25 billion ITER project has no plans for even token electricity demonstration, while declaring on its website that it “aims to demonstrate that hydrogen fusion can be harnessed for electricity production on a massive scale.” Perhaps the project would be embarrassed by an electric power output at least four orders of magnitude smaller than the consumed power of 300 MW(e).

**THE FUTURE OF FRENZY**

For 70 years fusion energy programs worldwide have claimed to be developing a source of electrical power, while their experimental devices consume megawatts to hundreds of MW of electricity. Simultaneous demonstration of even a token amount (kilowatts) of electrical power production
is impossible during the next 15 years, prior to operation of ITER with D-T fuel in long pulses. Producing 10 kW of electrical power on ITER while consuming 300 MW(e) is the closest anybody will come to a so-called fusion pilot plant by 2040. The assertions of sizable net power production in the near term made by startup fusion enterprises that can barely produce fusion neutrons as well as by established laboratories that are afraid to use tritium have zero basis in reality. That these claims are widely believed is due solely to the effective propaganda of promoters and laboratory spokespersons.

The recurrent bouts of fusion fervor are multi-year perturbations in the plodding centuries-long odyssey toward a fusion reactor objective that’s undesirable even if feasible. There is no vaccine to prevent fusion fever, but it has always abated on its own. As noted previously the last occurrence swept over the world in the early 1980’s, including passage of the Magnetic Fusion Engineering Act by the U.S. Congress and plans for deployment of power-producing DEMO’s before 2000. While there was a flurry of activity resulting in new facilities for magnet development, radiation testing, etc., the fusion power phantasm collapsed within a decade when the prospect of astronomical costs and overwhelming technological obstacles chilled fusion fever.

The present outbreak has broader support from private enterprise and several governments, but it too will die out before 2030 because of a lack of substantial performance that will discourage all but a few billionaires. While national governments worldwide will support their low-key R&D programs along with ITER indefinitely, something like “herd immunity” may suppress fusion frenzy for a few decades. Then triggered perhaps by success with ITER in the 2040’s or more likely by a presently unforeseen event another wave with new players and new variants of fusion contrivances will engulf the world. To quote Mark Twain circa 1875, “History doesn’t repeat itself but it does rhyme.”

REFERENCES

[1] For references concerning Ronald Richter, see Wikipedia entry for “Huemul Project.”

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How We Teach Science – What’s changed, and why it matters


John Rudolph is a Professor at the University of Wisconsin–Madison, where he teaches in the departments of Curriculum & Instruction and Educational Policy Studies and is a faculty affiliate of the Holtz Center for Science and Technology Studies. This book, like his research, focuses on the practice and history of science education in American high schools.

*How We Teach Science* has ten chapters along with an introduction and conclusion. The ten chapters are broken up into four “periods” of science reform for American high schools from the late nineteenth century through the twentieth century. Each period gets 2 – 3 chapters. What becomes clear in the second half of the book is that a lot of the drivers for change were political and social, the space race and the cold war for example. And the driver for change in many of the periods came from colleges. As someone who has worked with in- and pre-service high school teachers and followed physics education it was pleasing to see that the physics community in many cases took the lead in reforming science education over the last 100 plus years. It was also nice to learn details about the big names in science education (Conant, Schwab, Dewey, etc.) I was aware of their work but I lacked any knowledge of what, why and how they went about developing changes.

The book is well researched and 20% of the 300 pages are chapter notes. As an historian, the author does a nice job writing about the big changes such as the Morrill Land Grant Act and the founding of the NSF, but also sprinkles in nice details from many local newspaper articles from different times in history.

The author describes four periods: 1) Laboratory learning, 2) Scientific Method, 3) Inquiry, and 4) The Nature of Science. Of course, there is great overlap in the periods. What is made clear (and depressing) is what was going on in the literature was very different than what took place in the classrooms.

Period one emphasis was on learning science by doing labs, making measurements. In one of my first jobs, I remember the first lab the students performed was solely on making measurements and errors. I am sure this lab came from the early 1900s! During this period, we see a shift away from science in the high schools being technical training toward science being part of the liberal arts. A sub-theme that runs through the book is the movement of science away from the technical and toward being something all students need to get into college and then later what all students need to be good citizens in life. Many new schools were built during this period, and they featured science wings with big lab benches all having gas and water at each station.

Period two moved away from all labs toward engaging students about how scientist do science, the scientific method. This method of teaching really stuck with high school teachers and did not change throughout the other later periods where the reforms were trying to move away from the scientific method. Words like “project based” and “daily life problems” were the focus of this period. You will find a lot has not changed over the years as you read this book.

Period three’s focus was on inquiry. There are many pages about how that was defined, and the different reform groups did not always agree. Periods 3 and 4 are post-World War two and the author makes a big point that the playing field changes after the war. Before the war science was generally seen as something of great value and done for pure exploration and joy. Post war it was about results followed by a period of mistrust in science (that seems to still be with us). In this period the laboratory reemerged as very important, but the “cookbook” labs were replaced by open ended labs. The students were asked to take this equipment use it to go find something out. Of course, times were different, the lab manual started with how to cut, drill, and fasten sheet metal and how to handle glues and resins! High school students were expected to build their own apparatus from scratch. I found the way in which vendors of science supplies reacted to the different reforms to be an interesting part of the story.

Period four is about teaching the “nature of science”. Science literacy for all with a combination of knowledge coupled with the methods scientist use (variations on the scientific method). Focus is on science is important for everyone’s future. As we move through the different periods it becomes clear how important the societal aspects drive the science reform. The revelation from this period is that the USA is losing its edge, test scores are falling, etc. It also is clear that the economy is being driven by science. Therefore, the focus in this period pivots toward high school science education as important for the pipeline of future scientist that will be important for America’s economy.

The book makes nice connections between what is happening in history/society and the connection to science reform. What is happening on a national level and what takes place in the high school classroom can be very different. It was clear from the book that in many high schools the language of how to teach science changed with reforms but the actual practice in the high schools was disparate. Of course, the background and training of the high school teachers is of extreme importance, which the book mentions but does not delve into. For us in the physics community, the importance of recruitment and training of physics teachers is highlighted by the work of PhysTEC (https://www.phystec.org/), if I am allowed to put in a plug for my PhysTEC friends.

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What is energy? How is energy used by humanity? What energy resources are available? What are the inherent challenges of each resource? The Physics of Energy is a comprehensive textbook covering everything from the basics of energy to the challenges of climate change and implementing renewable energy sources for our existing power grid. The book’s three parts cover the physics of energy, sources of energy, and issues and externalities of society’s energy system. The explanations of humanity’s energy challenges and possible solutions start with first principles. Policies and economics are not directly discussed in the text. Instead, references are provided for the further exploration of such issues.

The authors start at the most fundamental level by reviewing the first two years of physics undergraduate courses as they relate to energy. Here, the book focuses on the physics while emphasizing its practical context. For example, the second chapter gives a brief overview of mechanical energy using a simple cross-country car trip. Kinetic and potential energy, air resistance and frictional losses, rotational mechanics, and flywheel storage are all reviewed in this context with more details than one would typically find in an introductory physics course.

The first part also covers electromagnetic energy, waves, light, thermodynamics, and energy in matter. There are several chapters on thermodynamics, heat engines and thermal energy extraction. Heat engines were essential to the development of modern industrial society. Discussion of Internal combustion engines focuses on where theory has limits in the real world. Similarly, presentation of the Rankine and Brayton cycles includes real world losses and departures from the ideal.

The book’s second part focuses on energy sources, beginning with the fundamental forces of nature. The authors focus on the strong and weak forces, which are often overlooked in introductory physics courses, and on the elementary particle processes behind nuclear power and radiation. Quantum phenomena in energy systems help explain the existence of uranium, the decay of uranium, sunshine and how photovoltaic cells function.

The book presents nuclear decay, fission and fusion in the context of nuclear power. It describes present and future nuclear reactors including the thermodynamics of reactor cycles. The discussion of fusion begins with stellar energy sources and then moves to possible future power plants using magnetic confinement. The discussion of nuclear power includes natural and manmade sources of radiation exposure, risks of spent nuclear fuel, and topics to inform societal choices concerning nuclear weapons, electricity generation, and medical diagnostics and treatment. The text does not push certain choices over others, but instead sticks to the physics leaving readers to make their own decisions.

A brief theoretical interlude asks “What is energy?” and “What is energy’s role in the universe?” The authors define energy as a conserved quantity that is associated with the time evolution of a system, and then describes a brief history of the universe’s energy inventory from the Big Bang to today.

Solar energy currently meets only a tiny fraction of humanity’s energy needs, but this contribution is growing rapidly. The discussion of solar energy includes its connection to nuclear processes in the sun, radiation, atmospheric absorption and technologies that use solar thermal energy and photovoltaics.

Life, through photosynthesis, converts solar radiation into chemical energy used by humans for food and biofuel. The authors discuss biofuels as a renewable energy source while remembering that modern agriculture requires extensive and often non-renewable energy inputs. Energy flow in the biosphere is one form of energy flow in Earth systems.

The authors then discuss energy flow in the oceans, atmosphere, and Earth’s interior, focusing on the underlying physics of the individual systems and how they can be used as possible resources. They present the challenges in extracting energy from these sources by drawing on basic geophysics, physical oceanography and, in the case of wind turbines, fluid dynamics.

The third section presents energy system issues and such “externalities” as the climate. The authors discuss Earth’s energy budget and the manner in which physical processes affect this budget. These processes include changes in Earth’s albedo, the carbon cycle, the greenhouse effect, and positive and negative feedback cycles. Learning from the past, a detailed look at Earth’s past climate provides a testing ground for future climate models. Computer models of the climate can incorporate standard climate physics and anthropomorphic effects, but non-linear effects prevent models from accurately predicting the future. There is a good discussion of what current models can predict and of possible future events (e.g. collapse of the West Antarctic ice sheet) that make predictions uncertain. The authors present proposals on how climate change might be mitigated, and the implications of a changing climate such as ocean acidification, rising sea levels, and ecosystem impact.

This discussion of climate change leads naturally into energy efficiency, reduced energy use, and new sources of humankind’s energy. The authors do not push specific policy changes, but instead provide options given the constraints...
of physical laws. They present case studies to illustrate how physics can help analyze energy efficiency and large-scale, high-density energy resources.

The authors emphasize that energy storage is the main challenge to implementing large-scale renewable energy. They investigate grid-scale storage (pumped hydro, compressed air, thermal storage) and mobile energy storage (batteries, fuel cells, flywheels, capacitors) that could be used for transport. For each storage method, they pay special attention to performance specifications such as energy density, capacity, efficiency, power, longevity, and safety.

The final chapter focuses on our present electricity generation, how the electrical grid works, unavoidable losses through transmission, and the challenges of incorporating variable energy sources such as wind and solar into the existing framework.

The challenge of providing sustainable energy has never been more important. The Physics of Energy is an excellent textbook to arm scientists, concerned citizens and those making informed economic, technological and policy decisions to deal with the energy challenges we face today and in the future.

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