Post-pandemic science and education

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GUEST EDITORIAL

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Existential threats our society faces: While the onset of a global pandemic should not have come as a great surprise, the chaotic federal response and the heartbreaking loss of life have shaken the faith of many in US institutions and will result in a changed nation and a very different world. Beyond this, a pandemic is only one of several potentially existential threats that we face, also including social breakdown, conflicts and crises over food and other resources, and runaway global warming. There is too little broad understanding of these threats, let alone wise, effective action to address them. It seems paradoxical that this national failure has come from a society with signal and public achievements in computing, biomedicine, technology, and physics—achievements by a scientific subculture that seems disconnected from our current political leadership and that appears irrelevant or even threatening to a disturbingly large fraction of the electorate.

Foundations for solutions: Why this disconnect? A full answer is far beyond the scope of this editorial. A more important question is how can we rectify this disconnect? How can we, as a nation, inoculate against the sugar highs of polarizing propaganda in support of the *status quo ante* and foster a healthier diet of wise choice and informed, successful action? We (Blandford and Thorne, B&T) see three essential foundations for solutions. First, we (in the US) need more politicians with critical thinking and problem-solving backgrounds. Second, we must change American culture so as to facilitate broad, rational, national discussions of hard choices, discussions informed by fact and frankness, not fiction and fantasy. Third, we must grow a workforce that contains the experience and competence to address the threats. The time to begin building these foundations is now, and scientists can contribute majorly. In the words of Sun Tzu, "In the midst of chaos, there is also opportunity."

Political shift needed: Our nation's manifest political failures are several. The proper roles of government—addressing problems wisely and fostering an equitable society—have been subsumed by the goals of acquiring and maintaining power. The mode of thinking that dominates Washington politics today is driven by ideology, expediency, and battles against perceived adversaries. Decisions are rarely informed, at least publicly, by the rational, evidence- and data-based thinking that we try to teach our science students. This is due in part to the backgrounds of the politicians. Too few come from problem-solving fields like engineering, medicine, and science. While we all can surely agree that a world run by a gang of Sheldon Coopers would be Hell on Earth, having many more engineers, doctors, and scientists walking the corridors of political power would be a great improvement, not just because of the expertise they could contribute, but through their rational approaches to the challenges that lie ahead. More of us should become political candidates and win elections.

Cultural shift needed: The deficiency of the political culture is really a symptom of a more fundamental problem. Too few of us in the United States are able to understand the difficult choices that confront us today, too few have the ability to think through those choices rationally, and too few even try. We should not be quick to blame this on laziness or moral depravity; our world really has become quite complex. The control system of Model T was simple and direct; that of a Model S is a complicated computational marvel. The divide between those who can deal with today's complex issues and the rest of society may be widening just as fast as the better-publicized gulf between the rich and the poor. Moreover, most experts are segregated into independent priesthoods and cannot parse issues that extend beyond their specialties. How much basic biology and atmospheric chemistry do typical physicists really understand today, let alone citizens who have not had the benefit of a science education? This must change.

Educational shift needed: Today is not the first time we Americans have faced a challenge like this. In 1957, the Soviet Union launched the first Sputnik satellite. Although the full context and the response were more nuanced, there is no denying that societal alarm over the satellite's beeping signal helped trigger a major transformation in science education in the United States, and American society benefitted greatly. Today's world is quite different and its threats are more real and profound, but a similar transformation must and can happen again.

While it is impossible to know right now the scale and nature of what we will be facing post-Covid, we (B&T) believe that there will be three imperatives: to transform government, to rebuild the economy, and to make society more equitable. Science has a critical role to play in all three of these, as, of course, do the humanities (especially ethics).

WHAT IS TO BE DONE?

Science and science education: First, we scientists must now begin to think seriously about rebuilding our nation and society in the post-Covid era. We (B&T) believe that science (including engineering, information technology, and medicine), used wisely and with attention to its adaptive and corrective nature, must play a prominent role in this reconstruction—not so much explicitly in the spirit of "Scientists say that…," but rather implicitly, as a firm basis for public policy that is implemented by a dedicated civil service.

Second, as science educators, we must institute a nationwide, crash program (as in the post-Sputnik era) to infuse society with science-educated citizens who are imbued with curiosity about the world around themselves and understand the nature and power of critical thinking; citizens who have learned to probe in search of truth and be skeptical of assertions made without basis in fact; citizens who have discovered how easy it is to be proved wrong; citizens who appreciate that often the wisest among us are those who have made the most mistakes most rapidly in search of truth or at least of deeper understanding; and citizens who thereby have the tools to distinguish reliable information from propaganda and wishful thinking. We must embark on this with humility instead of our all-too-frequent arrogance. That arrogance—or perceived arrogance—has contributed significantly, we think, to a large portion of American society turning against science and rational thinking and embracing propaganda and wishful thinking.

One of the strongest reasons for optimism lies in the mature and constructive response of so many young people to today's challenges. Many students, contemplating a scary future, are demanding change from their seemingly complacent elders, and we should be supporting them. Some of our students will become leaders and decision makers—in government, in business, in technology, and in society more widely. We must ensure that they understand the power of science and the scientific method and instinctively turn to science for guidance when it is relevant. We must educate broadly this new generation of science-literate leaders. They must see science in action in a variety of fields and applications—pure science; applied science; science in the everyday world of weather, ocean waves, and earthquakes; and science in engineering and technology—, so that they understand instinctively the breadth of science's power.

Expansion and revamping of science education: This proposed expansion of science education at all levels will require a large increase in the nation's number of science teachers. It is important that college curricula be changed to reflect the needs of these new teachers. There are many opportunities for us, as science educators, to be creative in partnering with industry and with scientists and educators in other countries and in schools of education.

This expansion can only happen successfully if we scientists and science educators work together as a community with common goals.

One of the few benefits of quarantining has been a broadened appreciation among parents (scientists among them) for the work of school teachers. Many university-level science educators and research scientists, who have too often adopted a hierarchical stance, attempting to dictate what should be taught and how this should be achieved, now get it. High-school and community-college science teachers must be acknowledged more publicly for what they do and as belonging to the same profession as research scientists. They must be fully included as members of a community that discovers new elementary particles, develops new types of lasers, and formulates new curricula. Their perspective is crucial as we all grapple with educational content and assessment, outreach, and professional development in a changing world. We research leaders can learn much by listening to high-school teachers. We need to practice inreach as well as outreach.

Revamping physics education: As physicists, we should be asking how we can play our part in transforming science education.

In elementary and middle school, our primary goal should be to communicate as artfully as we can what science can do; that it is neither magic nor religion but, in the words of Thomas Huxley, "Science is nothing but trained and organized common sense." We should not only target the students but through them, their parents and grandparents.

In high school and beginning undergraduate instruction, we physics educators need to teach the broad unity and power of science. We must better integrate physics with mathematics and engineering, biology and chemistry, medicine, and computer science. However, we should never lose sight of what makes physics distinct as a discipline, maintaining the strong connection between fundamental principles and applications. The deeper one understands the former, the less one has to remember about the latter, and the easier it becomes to contribute to a new area. This is a very different methodology from that practiced in machine learning for example; in our view, it is as important today as ever. Physics should be seen as learning for a lifetime, like a foreign language, not a sequence of quizzes and exams to be conquered and then set aside. As with learning a new language, the sooner one starts, the better. We should also encourage students to think for themselves about the role of physics in a changing world and be pleased and not be surprised if they come to different conclusions from ours.

We must broaden greatly physics education. One reason is to enable our graduates to contribute effectively, as science-savvy community members, to the restructuring that society needs in the post-Covid era. In addition, our current narrow physics curricula leave most of our students ill-prepared to deal with life and careers after college. It is natural for undergraduate and beginning graduate physics students to see their careers confined to a narrow and straight path. However, we as educators know that their roads will be long and winding and most of them will be employed in activities quite different from their initial goals. They need to be exposed to physics much more broadly in order to make wise choices and contribute strongly in new directions. Even for the minority who stay true to their youthful goals, progress frequently lies at the interface with other fields, and an early investment in broadening can repay enormous dividends.

At the advanced undergraduate and graduate levels, physics is a superb launching point for careers in almost every area of science, technology, finance, and business. Correspondingly, the number of physics bachelors and advanced degrees that we now award is far too small for the range of problems where physicists could meaningfully contribute. A rapid, large growth in our number of majors will be demand-driven if we educate our students much more broadly. We will bring in more and more students who will connect to other disciplines and infuse society with many more science-wise citizens. A rapid growth is achievable. Look at computer science.

We (B&T) offer a few examples of subjects that might be part of a broader curriculum relevant to the challenges ahead. Top of the list today has to be basic virology (using the physics of viruses as the entree) and epidemiology (using techniques of statistical physics). Near the top are the heavily entangled topics of climate change and energy generation/distribution/consumption. Then there are subjects that have largely disappeared from US university physics curricula, while their contemporary importance has burgeoned: Optical technology—particularly nonlinear optics–now plays a dominant role in communication and information processing. Statistical physics is a crucial foundation for large swaths of modern science and technology, and closely related statistical principles underlie economics and finance. The natural world is largely fluid—the atmosphere, the oceans, the earth's deep interior, and, of course, much of biology including human beings. Technology is also infused with fluids: aerodynamics, engines, nuclear reactors, and so on. Understanding and controlling the complex interplay between the natural world and technology will hugely impact our future. The related field of plasma physics is central to controlled fusion and the solar-terrestrial relationship. Both are probably vital to human survival in the long term.

Collaboration is another crucial aspect of our vision for physics education in the post-Covid era. The highly individualistic contributions of the great physicists of history are comparatively rare today. Most physicists are employed in groups, many of which are large and need to be wisely organized and managed. We must acknowledge this more in how we teach physics. At the same time, we and our students should recognize what can be lost if organization charts and group thinking come to dominate a collaboration.

Revamping physicists' relationship to society: We conclude by returning to three closely linked aspects of physicists' relationship to the society in which we live.

The first is *communication*. Over the last two decades, we have become far more proficient in explaining advances in science and technology to nonscientists and this has become a rewarding part of the job for many of us, especially our younger colleagues. Among those of our fellow citizens who already have some science background, the interest in our message and success in understanding are high, but we are still not reaching enough of the population. To do so will require more of us to contribute, experimenting with new approaches and recognizing that communication is a two-way street. Moving beyond outreach, many more of us must engage in community building with our fellow citizens, bringing our science-based ways of thinking into the mix.

The second is *diversity*. We in physics are still failing to include women and minorities fairly and robustly. In addition to ensuring equity, having colleagues from all backgrounds is essential if we want to spread our science message to all of society; and diverse backgrounds can bring new viewpoints that foster new directions for solving problems. The most effective place to catalyze diversity is middle school.

Third, physics is, by default, an *international* activity, part of a global human culture. From the robust superstructure of large organizations like CERN, to the delicate filigree of inter-personal trans-world collaboration, our practice is better than, and quite incompatible with, the chauvinism and nationalism that are being stoked right now and must be combatted in wise and winning ways.

It will not be easy to engineer these political, cultural, and educational shifts, but the need is great, the opportunity is real, and we must start today. To do so, will honor the memory of all those who have died under Covid.

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Editor's note: B&T co-authored a textbook aimed at broadening physics education "Modern Classical Physics" published in 2017 by Princeton University Press.