

The Mystique of Physics: Reluminate the Enlightenment

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FEATURE

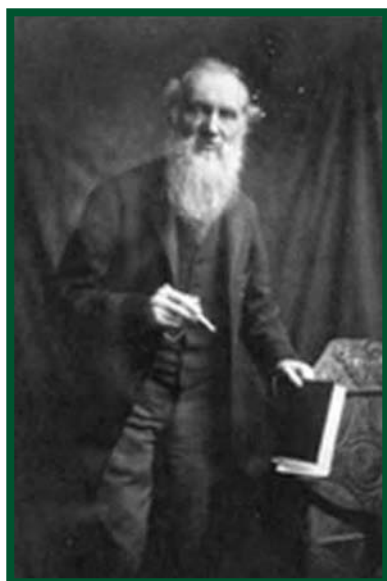
by John S. Rigden, Department of Physics, Washington University, St. Louis, MO

ABSTRACT

There is a mystique to physics because people are inherently receptive to the qualities that make physics special. It is this receptivity and the resulting mystique that makes Einstein the standard of greatness. However, neither the mystique nor the receptivity can be taken for granted. The near-reverent confidence that people have afforded physics is currently being challenged.

What does this suggest for the physics classroom?

Physics in the modern sense took its form during the 19th century. It started in 1801 with Thomas Young's demonstration that light was a wave. What kind of wave? No one knew. Then in 1888, Heinrich Hertz answered the question. While the electromagnetic theory of light was the crowning achievement of 19th century physics, it was just the top drawer of a chest full of new physics: Optics, electromagnetism, thermodynamics, the kinetic theory, and the energy principle were all brought to essential completion. The expansion of physical knowledge that occurred from 1800



William Thomson,
Lord Kelvin

Credit: AIP Emilio Segre Visual Archives, Zeleny Collection

to 1900 is stunning.

Physicists of the 19th century also developed a research style and established a professional culture that continues to the present day. In addition to all of this, the activities of 19th-century physicists brought physics to the vanguard of science.

With Leyden jars, voltaic batteries, wires, compasses, magnets, and Rühmkorff coils, physicists produced electrical displays to fascinated audiences in exhibition halls and auditoria from London, to Paris, to Philadelphia. Michael



John Rigden

Faraday in England, Hans Christian Oersted in Denmark, André-Marie Ampère in France, Alessandro Volta in Italy, and Joseph Henry in the United States were among the individuals who became recognized as physicists by members of the general public. As these shocking showmen manipulated the electrodes of their equipment, they exhibited an impressive command of the sparking devices and they conveyed to their audiences that the flashing discharges were no mystery at all, but due to unseen laws of physics. Most important, however, 19th-century physicists communicated to the public that they understood the electrical forces and were in command of Nature's electrical phenomena.

William Thomson "used Carnot's theories and Joule's experiments to make the science of thermodynamics the exemplar of a whole new way of doing physics." [1] Thermodynamics was developed in such a way that Einstein identified it as a model of what physical science should be. Thomson was delighted by the way thermodynamics gave the universe a direction in time and the public became familiar with "heat death." The idea of energy appeared in the 19th century and for a time, intangible energy competed with tangible force for primacy. The conservation of energy not only embraced all of physics, but reigned over all science. The energy concept, rooted in physics, demonstrated the synthetic pow-

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Max Planck

Credit: AIP Emilio Segre Visual Archives, W. F. Meggers Collection

ers of physics and put on display the range of its laws. As a result, physics was recognized at the end of the 19th century as the foundational science. Physicists were seen as the ones who could understand natural phenomena from the cracking retort of a Rühmkorff coil to the whispering glow of a cathode-ray tube; physicists were seen as the ones who could identify the physical laws causing these phenomena; and physicists were seen as the ones who could be trusted to harness the forces that the

physical laws embraced.

When Max Planck introduced the idea of the quantum to an audience of physicists assembled in Berlin in December of 1900, Planck basked in an aura that surrounded physics, an aura that did not exist for Thomas Young 100 years earlier. Thanks to 19th-century physicists, physics had become part of the general culture and the general public regarded physics as the principal source of reliable knowledge about the natural world.

The achievements of the 19th century did not come out of the blue. The Scientific Revolution of the 17th century and the Enlightenment of the 18th century prepared the way for the grand accomplishments of 19th-century physicists.

The Scientific Revolution put science on an empirical footing. For centuries, the celestial domain was considered to be perfect; therefore, the philosophical reasoning went, the planets must orbit the Earth in a circle, the most perfect geometrical form. Johannes Kepler struggled for over five years to fit Tycho Brahe's data for the planet Mars to a circular orbit. Kepler failed; Kepler succeeded. Kepler failed when he assumed the orthodox orbit sanctioned by the presuppositions of Middle-Age authorities; Kepler succeeded when he gave priority to one data point that missed his circular orbit by a mere eight minutes of arc. To Kepler's predecessors, operating from a different mind-set, the tiny discrepancy of a mere eight minutes of arc would have been ignored. In fact, Kepler, himself, acknowledged that he could have "patched up" his hypothesis; but that was not Kepler's mind-set. As Kepler wrote, "...since it was not possible to ignore them, those eight minutes point the road to a complete reformation of astronomy." [2] Indeed, Kepler created his Laws of Planetary Motion which were the foundation of the new astronomy.

What a delight it would be if we knew exactly, in detail, the intellectual steps that brought Isaac Newton to the conclusion, contrary to 2,000 years of accepted wisdom, that the terrestrial and celestial domains could be bridged. What gave him the boldness to suggest that every mass in the universe attracts every other mass in the universe? What gave him the audacity to claim that a hedgehog attracts a comet? Newton created a universal law that brought heaven and earth together into one self-aware system. Self aware? I think so. Sixty-six million years ago a large asteroid struck planet Earth. This strictly chance event changed life on this planet. Today, a sphere with a radius of 66 million light years is centered on the Earth and the surface of this sphere is expanding at the speed of light. Every star inside the sphere knows and every star outside that sphere has yet to learn about this dinosaur-ending event. At this very moment, new stars are making subtle adjustments as the frontier of this expanding sphere brings the news that Earth's mass has increased.

Newton laid bare a law of Nature, a law applicable throughout the universe and he did it with the power of his mind.

The Scientific Revolution transformed science methodology from philosophical proclamations to scientific experiments. Instead of proclamations that material objects have innate ideal forms that determine their behaviors, the behavior of objects came to be understood in terms of physical causes that led inexorably to physical effects. Once causal patterns are understood, scientific theories provide qualitative and quantitative linkages so that given a particular cause, a specific effect can be predicted.

This powerful methodology excited the people of Scotland, England, France, Germany, and the United States and convinced them that it was the morning of a new day. People across the Western nations were so enthralled by what Newton had done that it spawned the grand climax of the Scientific Revolution, a period of Western history known as the Enlightenment.

The Enlightenment was made for *homo sapiens*, the thinking animal. Immanuel Kant was asked, "What is the Enlightenment?" and he responded, "Thinking for oneself." What prompted people to reject tutelage by authority and to accept "thinking for oneself?" The Harvard historian, Crane Brinton, in his wonderful book, *Ideas and Men*, answers this question by pointing to the work of two late 17th-century Englishmen: Isaac Newton and John Locke. [3]

During the Enlightenment habits of mind concerning the natural world changed. And the change-agent was Newton. The universality of Newton's Law of Gravitation established the idea that Nature is governed by natural laws, an idea that was enormously appealing to people of the Enlightenment. Gone were the capricious spirits that were unpredictable and in

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their place was deterministic physical law. Alexander Pope wrote the couplet,

Nature and Nature's laws lay hid in night:
God said, *Let Newton be!* And all was light.

When seen in context, this couplet becomes more than a jingle, it becomes the banner for a new age.

John Locke was the champion of Reason. The human sense organs constantly receive input from the environment. Individual sensations, however, do not provide a guide for making intelligent decisions. It is through Reason that individual sensations can be interconnected, can be coordinated, can be linked into patterns that make sense. It is Reason that brings the minute details of Nature's unseen laws into their abstract forms and it is through Reason that the abstract is rendered concrete.

The core ideas of the Enlightenment were Newton's Nature and Locke's Reason. In his classic book, *The Making of the Modern Mind*, John Herman Randall wrote that during the Enlightenment, "Men saw in the world no more chaos, no more confusion, but an essentially rational and harmonious machine. It was an intoxicating discovery." [4]

Habits of mind are not established by cell phones and garage door openers. Habits of mind are the product of ideas. The ideas that Nature is law-like and that Reason can establish those laws are the legacy of the Enlightenment and they are entrenched in the modern mind. Citizens living in the West wake up every morning and carry the unconscious belief, into their day, that physical laws govern Nature and that the human brain, through Reason, can reveal those laws.

The Scientific Revolution and the Enlightenment changed the way people think. Propelling both of these historical eras was physics. A profound shift occurred between the onset of the Scientific Revolution and the climax of the Enlightenment, a shift from truth imposed by authority to truth sought by laboratory science. The physicists of the 19th century built on the tremendous accomplishments of the 17th and 18th centuries and they brought physics to the forefront of science and convinced people that only through physics could the workings of Nature be revealed, understood, and harnessed.

Against this rich background I ask: Could the people of the 21st century reverse the transformation that occurred 200 years ago by rejecting the methods of science in favor of the assertions by authority?

It is not my purpose to examine the challenges that now confront the science instructor and the science classroom. Today, a number of state legislatures, many state departments of education, and many, many local school boards are currently exerting their authorities as they consider actions that would mandate *what* is taught and *how* it is taught in the science classroom. Equally troubling, the very definition of science is being challenged with the goal of bringing into the science

classroom material that lies outside the scope of the current definition. This could change science as we know it.

I believe these challenges are serious.

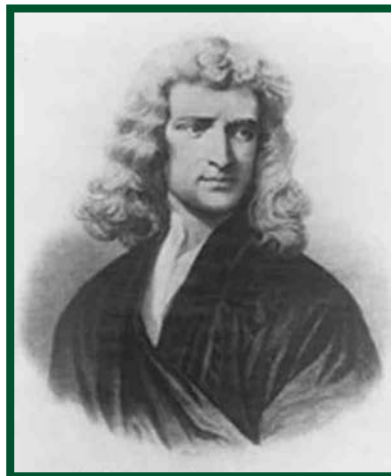
The crucial issue is not the belief in a Divine Designer; in fact, to examine the intricacies of Nature and to see evidence of design is thoroughly rational. The Divine Designer belief is, per se, no threat to science. If,

however, it is denied that physical laws drive natural processes, if it is denied that physical laws initiate chains of cause and effect that culminate in the beautiful world we observe, if it is denied that science is mechanistic and deterministic, and if these denials become part of the science classroom, then science as we know it is dead. Are the delicate filigrees of frost on a cold window pane caused by anything other than natural mechanism driven by physical law? Are the cosmic wonders revealed by the Hubble space telescope anything other than physical laws working over billions of years?

The Theory of Evolution and Big Bang Cosmology are two subjects that are in the cross hairs of those who want to bring changes to the science classroom. Physics teachers have testified about their reluctance to mention the words "Big Bang" in their classrooms. IMAX movie theaters, often located in science museums, will not use the words "Big Bang" for "fear" of the repercussions. So what can be done in response to this challenge? What should be the strategy of physics teachers? Of physics societies?

Debates pitting faith-based beliefs against empirical-based beliefs, have not worked and, in my judgment, will not work. They have not worked because, as always, debates degenerate into point-counterpoint exchanges that only embolden the debaters. Debates heat emotions, but freeze minds. In the context of passionate belief, debating is a negative strategy.

We must adopt a positive approach. A positive approach does not begin by telling faith-based believers they are wrong. As I have said, the faith-based belief in a Divine Designer is a rational way to regard the natural world. It is not a scientific way, but it is rational. Where faith-based people go wrong is to presume that they know how the Divine Designer organized



Sir Isaac Newton

Credit: Original engraving by unknown artist, courtesy AIP Emilio Segre Visual Archives, Physics Today Collection

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Sir Arthur Stanley Eddington

Credit: AIP Emilio Segre Visual Archives

the natural world and they know how the Divine Designer has guided the natural world to its current state. For centuries faith-based believers knew—absolutely knew—that God placed Earth at the center of the universe. The believers were wrong. Now faith-based believers recognize that the Divine Designer’s plan for the universe far exceeds what they had imagined. A positive approach does not denounce Earth-centered cosmology; rather, without even mentioning Earth-

centered cosmology, a positive approach shows that a Sun-centered system demonstrates an internal coherence and a simplicity that allow many interconnected conclusions to be drawn by both qualitative and quantitative means. With no reference to the Divine, a positive approach implicitly demonstrates that a Sun-centered solar system has design elements far superior to an Earth-centered system.

To develop a positive approach, I suggest we take lessons from the Enlightenment and adopt an Enlightenment strategy. The appeal of the two big ideas of the Enlightenment—Nature governed by physical law and Reason elucidates the laws—cannot be exaggerated. The certainty of a world controlled by known physical laws is far superior to a capricious world and the power of Reason to elucidate these natural laws has tremendous appeal to *homo sapiens*, the thinking animal. It is physicists who the general public expects to discover the Laws of Nature and this brings a mystique to physics that no other science can claim. It also brings a mystique to physicists. (Ask a person in line at the grocery store to name a great physicist. They will name Einstein and probably Newton. Some may also name Galileo, Feynman, and Hawking. Now, ask the same person to name a great chemist. Or a biologist other than Darwin.) Physicists bask in the mystique of physics. I believe we should take advantage of the awe and reverence that people bring to physics.

To utilize the mystique that accrues to physics, we should understand what gives rise to the mystique.

In the process of seeking and finding Nature’s laws, physicists ask and answer many Big Questions that fester in the minds of all people. Who hasn’t looked into the night’s sky and wondered: What is space? How big is space? Where are we in space? What is time? Did time have a beginning? Does it have an end? What are the basic building blocks of matter?

What is light? These are questions that only physics answers and that endows physics with a mystique. (Note: In recent years biology has started to address one big question: What is life? However, physics has been grappling with big questions for centuries.)

Only physics can claim universality. Examine the light from a distant star and you find the same hydrogen atoms as you find in Cleveland, Ohio, and emanating from those distant hydrogen atoms is the same H_{α} line as Rydberg saw in Lund, Sweden. Quantum mechanics is operating in Cleveland, quantum mechanics is operating in Lund, and quantum mechanics is operating on distant stars. Physics can demonstrate, with empirical evidence, the universality of its laws. More mystique.

In the process of seeking and finding Nature’s laws, physicists extend human experience to unimaginable extremes of time, space, and size. From the age of the universe to the lifetime of the top quark, time duration goes from 15 billion years to 10^{-24} second; from the known universe to the gluon, space dimensions go from the unimaginably big to the unimaginably small; from black holes to neutrinos, masses go from the equivalent of millions of Suns to almost no mass at all. Still more mystique.

I believe, however, that much of the mystique that accrues to physics is because physics dramatically demonstrates and *validates* the power of human reason. *Homo sapiens* thinks to survive. Since humans depend on reason, it is deeply reassuring to all people to witness a human mind embrace Nature with an abstraction and to validate the product of mind with a concrete measurement. Newton, through the power of pure reason, concluded that across the universe, every mass attracts every other mass. But Newton did not leave it there. He demonstrated that a range of disparate phenomena could all be supported on the same physical foundation—the inverse-square law. It worked, indeed it worked...except for the planets Mercury and Uranus. The anomalies represented by these two planets were so small that they could be ignored. Ignored? No way. A tiny disagreement, a mere eight minutes of arc, launched modern astronomy.

Let us take note that the anomalies of Mercury and Uranus marred the Theory of Newtonian Gravitation for over 150 years. Did physicists say, “It’s just a theory,” and reject it? No, not at all. Physicists understand what theory is and they understand that a theory like Newtonian mechanics is a huge umbrella under which many features of the physical world take their places in logical and predictable ways.

Eventually, Einstein took care of Mercury, but 70 years before Einstein’s feat, John Couch Adams from England and Urbain Jean Joseph Leverrier from France independently set out to explain the erratic behavior of the planet Uranus by assuming the presence of an unseen source of gravitational

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attraction. Both men produced definitive results. Adams's results were ignored by the British establishment. Leverrier sent his calculations to the Berlin Observatory. Once again, take note: Leverrier did not simply say, "My calculations prove that something is out there." Not at all. Leverrier pinpointed a location: right ascension $22^{\text{h}} 46^{\text{m}}$; declination, $-13^{\circ} 24'$. During the night of September 23, 1846—the evening of the same day that the Berlin Observatory received Leverrier's results—the big Berlin telescope turned skyward to Leverrier's pinpoint location. The observatory staff had just completed an extensive new star map and when Johann Gottfried Galle looked through the eyepiece of the telescope, he described to his assistant a star of eighth magnitude. "That star is not on the map!" said Galle's assistant. On the map or not, the eighth planet Neptune joined the solar system. Two days later, Galle wrote to Leverrier, "The planet whose position you have pointed out *actually* exists." [5] This is the stuff of high drama and this engenders mystique.

High drama and great science. The discovery of the eighth planet further justified physicists's belief in Newton's Theory of Gravitation. Letters poured into Paris. "Your name [Leverrier] will be forever linked with the most outstanding conceivable proof of the validity of universal gravitation;" [6] "It is the most noble triumph of theory which I know of;" [7] "This discovery may be justly considered one of the greatest triumphs of theoretical astronomy." [8]

Consider another example: Albert Einstein. After years of intense, unbroken mental concentration, Einstein concluded that massive objects alter the space around them and that light passing through that space would depart from its straight line motion and follow instead the contours of the altered space. But did Einstein leave it there? No, not at all. Einstein calculated that light passing the Sun would deviate from its straight-line path through an angle of 1.75 arc seconds. A definite prediction. And there it stood as the Great War raged on. When the war ended, Arthur Eddington took his equipment to the site of a total eclipse off the west coast of Africa. At the moment of totality, Eddington went to work and he measured the apparent position of a star by means of the light that had passed the Sun eight minutes before it entered his apparatus. His measurements indicated that the star's light had deviated from its straight-line path through an angle of 1.63 arc seconds. Eddington's experiment confirmed Einstein's prediction. The front pages of newspapers throughout the world carried the news.

The news of Einstein's intellectual feat allowed war-weary people everywhere to heave a sigh of relief and once again they could say, with conviction, that, "All is right with the world," and once again they could marvel at the display of human reason. Einstein became an instant celebrity and the mystique of physics was further enhanced.

Since the Enlightenment, physicists have vastly expanded human understanding of space, time, and the material world. As a positive strategy to respond to the challenges facing the science classroom, I propose a long-term approach. By long-term, I mean forever. The canonical one-week workshop won't do it.

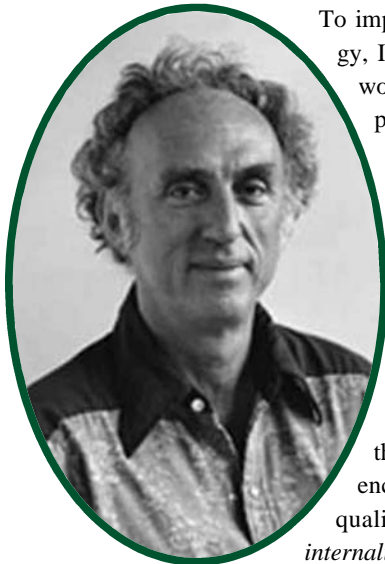
Those determined to bring faith-based beliefs into the science classroom *do* have a long-term approach. From a simple anti-evolution stance (a negative and ineffective approach), to a creationist position (a positive approach, but blatantly religious), to the current Intelligent Design approach (a positive approach with subtle religious overtones, but a politically polished approach with great rational appeal), the faith-based believers have honed their approach. Their objective is to initiate what they call a "scientific revolution" whose effect is "nothing less than the overthrow of materialism and its cultural legacies" in favor of a "broadly theistic understanding of nature." [9] This objective is supported by major U. S. foundations and is endorsed by the President of the United States and leading senators. The faith-based strategy is meeting with success.

Any positive strategy worth mounting is a strategy worth sustaining. A long-term approach can, bit-by-bit, build up people's understanding of science and how it works. A long term approach can incrementally influence how people think about science, enable people to differentiate between what is science and what is non-science, and it can give them a basis to "think for themselves." We have enough new physics to have a new Enlightenment. I propose that physics instructors take steps to reluminate the Enlightenment.

The objective of any long-term strategy is to educate today's students so that, as tomorrow's citizens, they can think rationally and correctly about science. To this end, we must provide students with some course content that, by its nature, demonstrates what makes physics physics and, at the same time, engenders confidence in the results of physics. In any long-term strategy designed to influence the larger culture, we must start where the students are: we must start with the 1.5 million students in introductory physics courses at all levels.

Think for a moment about the current introductory course. I ask: How many students understand that Newton's theory of universal gravitation spawned the Enlightenment and established the way they themselves think about Nature? I ask: How many students leave their introductory courses cognizant of the determining role that evidence plays in physics? I ask: How many students leave introductory physics and know how error bars influence the conclusions physicists draw from experimental data? I ask: How many students leave introductory physics with any sense of what physicists believe and why they believe it? I ask: How many students leave introductory physics prepared to compare and contrast faith-based and empirical-based beliefs?

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Martin L. Perl

Credit: AIP Emilio Segre Visual Archives, Physics Today Collection

To implement a long-term strategy, I begin with a call to bring words into the introductory physics course. We are obsessed with the quantitative to the exclusion of the qualitative. The currency of the qualitative is words and words are powerful vehicles. The currency of the quantitative is symbols and numbers, also powerful vehicles. But there is a profound difference. To discuss a concept qualitatively, students must *internalize* the concept so that it

becomes their own. Only then can students select *their own words* and put nouns and verbs together into sentences that capture

the subtleties, nuances, and meaning. By contrast, to discuss a concept quantitatively, students must know the *external* rules that govern the quantitative nature of the concept and follow the rules.

The qualitative originates from within; the quantitative from without.

If we want tomorrow's citizens to influence the thinking of their friends and neighbors, we must complement the education of today's students with the qualitative so that, in their own words, they can carry on an informed dialogue with sentences that are accurate and compelling. The quantitative does not accomplish this end. Humans do not converse in formulas; they converse in words.

To enable future citizens to think correctly about science, their education must take them beyond equations. Physics instructors can select a few topics and develop them in sufficient breadth and depth so that students not only learn some physics, but are also influenced by how physicists go about their work. What is theory? What makes a good theory? How do physicists use theory? In a positive approach, the best answers to these questions would be provided implicitly. From the way a topic is presented, students would infer their own answers to these questions and their own answers could alter their thinking and, at the same time, have sticking power. What is evidence? What makes evidence compelling? How do physicists use evidence? Again, these questions would be presented so that students could draw their own conclusions.

Physics is blessed with many topics that could be integrated into the introductory course curriculum and could educate students rather than merely train them. Each topic could be

treated in a self contained way. If there were three topics per semester and if each topic were given three class days, we are talking about nine class days out of the semester's 40 days. A small price to pay for the benefits that could result. Furthermore, the selected topics could bring introductory physics out of the 19th century into the present. Here is an example.

Martin Perl won the Nobel Prize in 1995 for the discovery of the tau lepton. He has written a first-person account of his discovery in *Physics in Perspective*, the journal that Roger Stuewer and I edit. In this account a reader learns a lot about physics.

Martin Perl decided to do research with leptons because he wanted "to measure or discover fundamental facts in particle physics." [10] He did not believe that physical theory was robust enough to handle hadrons and their complex quark structures. Perl was also intrigued by the puzzle inherent in the two known leptons—the electron and the muon—a puzzle that remains unresolved to the present day. He began dreaming of a third lepton that "might teach us the secret of the electron-muon puzzle." [11] To pursue his dream, however, Perl needed big-scale equipment which required big-scale funding.

Perl's tau search started in 1963 when he arrived at SLAC and it ended with the discovery in 1979. As the story unfolds, one learns physics in both a narrow sense and in a broad sense. From this example students would learn that there are unresolved basic questions in physics; they would learn about the bond between funding and research results; students would learn that large-scale equipment requires a large group working together and, according to Perl, that comes "at a human cost"; [12] students would learn about the international nature of physics and the competitive nature of physics; they would learn how technology impacts physics; they would learn how systematic errors plagued experimental results so that subtle differences between the muon and electron were possibly obscured; students would learn how physicists presupposed that, since there were only two generations of hadrons, there should also be only two generations of leptons; they would learn how specific evidence finally confirmed the tau; however, they would also learn that it took two years from the first evidence of the tau particle to prove its existence. Why two years? Because physicists demand compelling evidence before they accept a new feature of Nature. None of these things, all part of the warp and woof of contemporary physics, make any appearance in our introductory courses.

The tau story has drama. Think of trying to discover something that may not exist; think about the challenge of detecting a particle expected to live for less than a trillionth of a second; think about finding a way to prove that the tau actually exists; think about adding a third generation to the lepton family...and its implications. Martin Perl's discovery of the tau lepton is a

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story that, properly told, can captivate students and stay in their minds for a long, long time.

The discovery of the tau is one of many possible examples that would provide broad insights into physics. From the past, for example, there is Kepler and the ellipse—a riveting drama of how powerful presuppositions knuckled under to empirical evidence; there is Newton and the discovery of Neptune another gripping episode that demonstrates how physical laws can be used; Maxwell and the speed of light, Hertz, electromagnetic waves, and the ether; J. J. Thomson and the electron. More recently, good examples include: Einstein, Compton and the light quantum; Einstein and the nature of space; the development of the Standard Model; the discovery of the top quark; Einstein, Bell, Aspect, and quantum entanglement; Feynman’s “sum-over-histories” description of Nature, “...one of the great unifying principles in the history of science.”[13]

Examples such as these could be presented to students with the same expectations as we present Newton’s Second Law. Newton’s laws of motion are presented with a quantitative rigor with the expectation that students will be able to apply them successfully. Examples such as the discovery of the tau lepton could be presented with qualitative rigor with the expectation that students could discuss in their own words the subtleties and nuances from its initial discovery through to its confirmation. Examples such as I have suggested would not only provide students with a welcome respite from the grind of juggling equations, but would also plant seeds in their minds that would bring them confidence about the claims of physics and give them something to ponder when the efficacy of science is challenged.

On July 7, 2005, the Roman Catholic cardinal archbishop of Vienna, Christoph Schönborn, laid out the position of the Catholic Church on the subject of evolution. However, the argument the cardinal developed was more general than evolution and implicitly, it embraced all science. In the *New York Times* the cardinal began by quoting the late John Paul II. “We believe,” said the Pope, “that God created the world according to his wisdom. It is not the product of necessity whatever, not blind fate or chance.” Cardinal Schönborn concluded: “Scientific theories that try to explain away the appearance of design as the result of ‘chance and necessity’ are not scientific at all, but...an abdication of human intelligence.” [14]

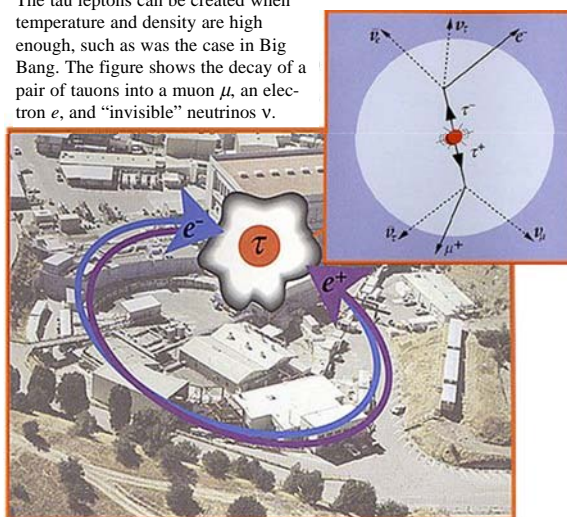
Both the Pope and the cardinal denied necessity. Both the Pope and the cardinal are mistaken. If you believe that the physical world is a consequence of physical law, then what we observe is the consequence of necessity. Masses attract out of necessity; energy is conserved out of necessity; the neutron decays out of necessity; and out of necessity, DNA in the gametes determines the characteristics of the resulting organism. There is no choice, there are no alternatives. The laws of physics undergird all science; if the laws of physics, operating out of necessity, are denied in any tributary of science, then the main stream of the entire scientific enterprise is dangerously compromised.

The Enlightenment showed that Reason and the reasoned approach to unlocking the secrets of Nature had enormous appeal to *homo sapiens*, the thinking animal. The physicists of the 19th century brought physics to the forefront of people’s thinking and left them with the confidence that the claims of physics could be believed. I suggest we reluminate the Enlightenment. I suggest we emulate 19th-century physicists. I suggest we capitalize on the mystique of physics. I suggest we provide students with positive examples that demonstrate what physicists believe and why they believe it.

[1] Iwan Rhys Morus, *When Physics Became King*, University of Chicago Press, 2005, 126.
 [2] Arthur Koestler, *The Sleepwalkers*, Universal Library 1963, 322.
 [3] Crane Brinton, *Ideas and Men: The Story of Western Thought*, 2nd Edition, Prentice Hall, 1963, 289.
 [4] John Herman Randall, *The Making of the Modern Mind*, Houghton Mifflin 1940, p. 274.
 [5] Morton Grosser, *The Discovery of Neptune*, Harvard University Press, 1962, 119.
 [6] *Ibid.* 119.
 [7] *Ibid.* 120
 [8] *Ibid.* 121
 [9] Jodi Wilgoren, *New York Times*, August 21, 2005, p. 1.
 [10] Martin L. Perl, The Discovery of the Tau Lepton and the Changes in Elementary Particle Physics in Forty Years, *Physics in Perspective* 6, 401-427, 405.
 [11] *Ibid.*, 407
 [12] *Ibid.*
 [13] Freeman Dyson in *Classic Feynman*, W. W. Norton, 2005, p. 8.
 [14] Christoph Schönborn, *The New York Times*, July 7, 2005, A26.



The tau leptons can be created when temperature and density are high enough, such as was the case in Big Bang. The figure shows the decay of a pair of taons into a muon μ , an electron e , and “invisible” neutrinos ν .



In the SPEAR collider electrons e^- and positrons e^+ crash head-on in a little “Big Bang,” whereupon, among many possible reactions, taus are created in pairs.

The Tau Neutrino

Credit: The Royal Swedish Academy of Sciences