

THE IMPOSSIBLE TAKES A LITTLE LONGER

*Dudley
Herschbach*

My father had a favorite saying: "The difficult we do immediately, the impossible takes a little longer." The second phrase appealed to me as a kid, I suppose because of its whimsical incongruity and heroic ring. Decades later, the appeal is stronger still. Again and again, I've seen intrepid, persevering innovators achieve wonderful things that had been regarded as "impossible." Leon Lederman is such a dauntless innovator, both as a scientist and educator. It is a special pleasure to offer homage to him and his efforts to enhance science education, which he has long pursued with inspiring verve, devotion, and joy.

This essay deals chiefly with observations and proposals pertaining to high school science teaching and learning. These stem from opportunities to talk with many students and teachers at high school science fairs and summer programs, as well as my experience teaching freshman chemistry at Harvard University over the past twenty years. First, however, I recount a story of an "impossible" educational triumph. Beyond its explicit message regarding educational strategy, this story implicitly conveys key aspects of the scientific enterprise, including the practical value of curiosity-driven research and the kinship of science and the humanities as liberal arts.

A BRILLIANT EDUCATIONAL EXPERIMENT

The story (Bruce 1990; MacKay 1997) involves Alexander Graham Bell, Helen Keller, and Keller's teacher, Annie Sullivan. Bell patented the telephone in 1876 at the age of twenty-nine, and thereafter devoted many years to pursuit of other inventions. But Bell regarded his life's work as the education of the deaf. His mother and his wife were deaf, his father and grandfather were teachers of speech and elocution. His family had emigrated from Scotland after both of his older brothers had died of tuberculosis, and settled near Toronto. Bell, in 1871, began teaching the deaf in Boston and the next year founded his own school there. It was an effort to develop a device to help his deaf students distinguish between the letters *p* and *b* that led to his invention of the telephone. As his biographers emphasize, all the technologies needed to produce the telephone existed by 1872, and several expert electricians were pursuing kindred devices. In later years, Bell liked to say that he would not have conceived the principle of the telephone if he had known more about electricity but less about the mechanics of human speech.

Helen Keller, deaf and blind since an illness at nineteen months, was six when brought to Bell by her parents to ask his opinion as to whether she could be educated. Bell instituted the arrangements that led to Annie Sullivan becoming Helen's teacher. Annie was then twenty years old, still suffering the effects of trachoma, which had made her temporarily blind for a few months (and would make her permanently blind in her old age). Annie had no teaching experience and not much to guide her except her good sense and acute sensitivity (Lash 1997). Yet only a month after she joined Helen at her parents' home in Tusculumbia, Alabama, in March 1887, came the marvelous moment when Helen discovered things had names, as Annie held her hand in a stream of water. Within three months, Helen was writing brief letters. Within three years, she had an astonishing command of idiomatic English.

This, and what followed in Helen's life, was justly hailed as a

miracle. But Bell had a different view. Especially in the early years, and for decades after, he helped and supported Helen and Annie in many ways. Helen dedicated her first autobiography to him. Annie wrote of the “immense advantage” it was to have his

Library of Congress, Prints and Photographs Division, Gilbert H. Grosvenor Collection of Photographs of the Alexander Graham Bell Family, [reproduction number LC-G9-Z1-137,816-A]



Helen Keller and Annie Sullivan with Alexander Graham Bell, July 1894, when Helen was fourteen years old, Annie twenty-eight, Bell forty-seven. With her left hand, Helen is reading Annie's lips, with her right hand, communicating with Bell.

advice, and her gratitude for his “happy way of making people feel pleased with themselves.” Bell insisted that Helen’s mastery of idiomatic English was “. . . not a case of supernatural acquirement [but] . . . a question of instruction, . . . a brilliant experiment” by Annie (Bruce 1990). He concluded that the key was Annie’s “. . . constant spelling of natural, idiomatic English into Helen’s hand without stopping to explain unfamiliar words and constructions, and her encouragement of Helen’s reading book after book in Braille . . . with a similar reliance on context to explain new language.” Bell stressed that this was equivalent to the way a hearing and sighted child learns. Annie’s own description of her teaching confirms that she purposely *never explained anything, unless Helen asked a question*. Thereby Annie helped Helen to discover and actively exercise her ability to discern clues and context and to learn on her own.

SCIENCE AS DECIPHERING NATURE’S LANGUAGE

The reticent teaching style of Annie Sullivan is intrinsic to frontier research in science. Nature is a reticent teacher, who speaks to us abundantly but in many alien tongues. She does not offer explanations; it’s up to us to ask probing questions and to generate our own understanding. In frontier research, we try to discover or add to knowledge of the vocabulary and grammar of some strange dialect. To the extent we succeed, we gain the ability to decipher many messages that Nature has left for us, blithely or coyly. No matter how much human effort and money we might devote to solving a practical problem in science or technology, failure is inevitable unless we can read the answers that Nature is willing to give us. That is why basic curiosity-driven research is an essential and practical investment, and why its most important yield are ideas and understanding (Herschbach 1996).

We are all born blind and deaf to much of Nature’s language, and it takes persistent groping and guessing to learn something of it. In my classes, I like to emphasize this. I ask how many students have already studied a foreign language, and recommend that they

approach science the same way: "Once you get it in your ear, it gets easier and easier; otherwise, harder and harder!" Actual counts have shown that in introductory science textbooks for high school or college, the number of new words or ordinary words used with special meanings exceed the vocabulary of a typical one-year language course. Likewise, the array of interlocking concepts met in a science course functions much like grammatical rules. In my freshman chemistry course, I point out that our triad of major topics has some resemblance to the curriculum that Harvard had in the seventeenth and eighteenth centuries, chiefly Latin, Greek, and Hebrew. The universal scope and rigor of thermodynamics resembles Latin; the elegance and poetic character of quantum theory underlying electronic and molecular structure resembles Greek; the pragmatic and forthright style of chemical kinetics resembles Hebrew.

SCIENCE AMONG THE LIBERAL ARTS

The "impossible" empowerment of Helen Keller by language exemplifies in a compelling way the highest aim of a liberal arts education: to instill the *habit of self-generated questioning and thinking*, of actively scrutinizing evidence and puzzling out answers. That is also the essence of a genuine scientific literacy. It accords with a favorite definition equally applicable to science and the humanities: "Education is what's left after all you've learned has been forgotten." This defines the aim to be understanding rather than ritualistic training; cultural perspective and self-reliant thinking rather than conventional knowing. The "what's left" aspects of science and mathematics offer much that transcends any technical particulars. For both novice scientists and students destined for other careers, teachers should emphasize the human adventure of intellectual exploration, replete with foibles and failures, but ultimately achieving wondrous insights. This is important not merely as seasoning for hearty servings of lectures, homework problems, and laboratory work but to nurture perspectives akin to the liberal arts.

A fervent appeal to cultivate common ground, shared by science and liberal arts, was made by Isidor Rabi, one of Leon Lederman's mentors, in a lecture I heard in 1955 as a beginning graduate student:

To my mind, the value of science or the humanities lies not in the subject matter alone, or even in greater part. It lies chiefly in the spirit and living tradition in which these different disciplines are pursued. . . . Our problem is to blend these two traditions. . . . The greatest difficulty which stands in the way is communication. The nonscientist cannot listen to the scientist with pleasure and understanding.

Only by the fusion of science and the humanities can we hope to reach the wisdom appropriate to our day and generation. The scientists must learn to teach science in the spirit of wisdom and in the light of the history of human thought and human effort, rather than as the geography of a universe uninhabited by mankind (Rigden 1987).

Rabi later discussed these concerns with C. P. Snow, who developed them further in his famous *Two Cultures*.

I've pursued a liberal science approach in my freshman course (Herschbach "Liberal Education" 1996) to bring out "what's left." This is not only in response to Rabi's appeal, but because I feel the chief aim should be to entice students to take ownership of scientific ideas. That is fostered by presenting science in a more humanistic mode. I typically introduce each major topic with a story, usually having the character of a parable. Many of the parables deal with historical episodes or current research discoveries; some are fictional, designed to indulge in whimsical fun while delivering a serious message. Often the stories emphasize the role of analogy and guesswork or show how error and failure are prevalent in science but can lead to progress if "wrong in an interesting way." Usually the parable also poses questions for students to work out.

For example, when discussing the gas laws, I ask students to consider a fancied task that might have been asked of Hercules (Herschbach 1999). What if that mighty hero, after completing his

legendary twelve labors, had been asked to weigh the Earth's atmosphere? The students discover that just a couple of elementary ideas suffice to estimate this, and are impressed by the magnitude (six billion megatons). Then we discuss a moral. If Hercules had failed in this "thirteenth labor," it would testify that even superhuman strength and courage cannot prevail when what is needed is an intellectual concept. Would not such a lesson improve on that conveyed by the ancient myth?

WHAT MAKES "IMPOSSIBLE" POSSIBLE?

Science enjoys a tremendous advantage: the goal—call it truth or understanding—*waits patiently to be discovered*. Thus, ordinary human talent, given sustained effort and freedom in the pursuit, can achieve marvelous advances. Far more formidable are enterprises such as business or politics; there the objectives may shift kaleidoscopically, so a brilliant move often proves a fiasco rather than a triumph because it comes a little too soon or too late. The patience of scientific truth has another important consequence. Frequently, what might appear as the most promising approach does not pan out; there are unanticipated roadblocks. Then it is vital to have some maverick scientists willing to explore unorthodox paths, perhaps straying far from the route favored by consensus. In science, it is not even desirable, much less necessary or possible, to be right at each step. At the frontier, scientists are heading in wrong directions much of the time, optimistically looking for new perspectives.

Science as encountered in typical high school or college introductory courses is strikingly at odds with this adventurous character of research as well as the spirit of liberal science. Such courses too often come across to students as a frozen body of dogma. The questions and problems seem to have only one right answer, to be found by some canonical procedure. The student who does not easily grasp the "right" way, or finds it uncongenial is likely to become alienated. There seems to be very little scope for a personal, innovative experience.

Nothing could be further from what actual frontier research is like. At the outset, nobody knows the “right” answer, often not even the right question or approach. So the focus is on asking an interesting question or casting the familiar in a new light. In my freshman chemistry course, I explain this to the students and ask them to write poems about major concepts, because that is much more like doing real science than the usual textbook exercises. I also show them quite a few poems that pertain to science, often without intending to. For instance, here is a quatrain by Jan Skacel, a Czech poet (Kundera 1966):

Poets don't invent poems;
The poem is somewhere behind;
It's been there a long, long time.
The poet merely discovers it.

The social organization of science also has a major role in fostering “impossible” achievements. An especially persuasive case for this was given by Michael Polanyi in his classic essay (Polyani 1962), *The Republic of Science*. He contrasted the hierarchical systems customary in practical affairs with the chaotic freedom of science. In the hierarchical organizations, units are directed by a chain of officers who report up the chain and assign tasks. Science proceeds very differently and much more efficiently. Each unit is on its own, free to pursue its own interests. Nonetheless, the independent units are coordinated by an *invisible hand*, because each has the opportunity to observe and apply the results found by the others. This creates a community of scientists that amplifies individual initiatives.

Again, there is an ironic contrast between such intrinsic cooperation and the artificial competition among students that is imposed in typical courses. Instead, I use an absolute grading scale, so students compete against my standard, not each other. Students thereby are encouraged to help each other in study groups as well as in some work that is done in teams. Conducting class discussions in which groups of three or four students consult with each other before proposing or endorsing a solution to a

problem usually proves instructive and lively fun. Moreover, that mode turns out to encourage students to formulate and defend guesses. That is fundamental for science, but it is actually inhibited by the usual academic rituals. I like to tell my classes:

Not so many years from now, most of you will be considered expert in something. Then you will find that clients often come to ask your opinion, not because of what you know, but because they think as an expert you can guess better than they can.

EMPOWERING STUDENTS AS TEACHERS

The National Science Foundation is required to carry out, at intervals of a few years, a survey comparing the performance of U.S. students in science and mathematics with those of other nations. For more than two decades, the results have repeatedly shown a dismaying pattern: U.S. fourth graders perform well above the world average, eighth graders about average, but twelfth graders far below average. A major contributing factor is the widely deplored shortage of qualified high school teachers of science and mathematics (Gregorian 2001). Many efforts have been undertaken to recruit science teachers and enhance their training. Among these are the excellent "Teach for America" program (Shapiro 1993) launched in 1988 by Wendy Kopp when she was a Princeton undergraduate, and a markedly successful Teachers' Academy in Chicago (Lederman 1998; Sparks and Hirsh 1997), cochaired by Leon Lederman. Yet, nationwide, the problem remains daunting.

I do not believe we can provide an adequate corps of science teachers in the foreseeable future. However, I am convinced that this gap could be significantly offset by empowering able students as teachers to a much greater extent than occurs today. This conviction has two distinct sources: recent science fairs and reflections on my own high school days.

More than a decade ago, I was recruited by Glenn Seaborg to join the board of a small nonprofit outfit, Science Service, in Washington, D.C. As well as publishing the weekly *Science News*,

written for laypeople, it is the premier sponsor of high school science fairs. For sixty years it has conducted the Science Talent Search (STS) originally sponsored by Westinghouse and recently by Intel. For nearly as long it has run the International Science and Engineering Fair (ISEF), now also sponsored by Intel. This brings together more than twelve hundred students from fifty countries (95 percent from the United States), winners of hundreds of local, state, and regional fairs in which about a million other students took part. A host of adult volunteers, among them many parents, teachers, and scientists—including Leon Lederman—gladly contribute to the infrastructure of these fairs.

The STS and ISEF finalists are fine ambassadors for science. Many of them have done impressive, original projects, often facilitated by summer research opportunities or links with university laboratories found via Web searches. Without prompting, these students frequently express concerns about high school science courses, at their own schools and others. Quite a few STS and ISEF alumni attend Harvard. Five years ago, they launched a *Journal of Undergraduate Science*, with alternate issues comprised of articles that had originally been submitted for STS or ISEF projects. Those special issues were sent to one thousand high schools, to show students and teachers what good projects are like. Recognizing the need, the editors provided for each article in those issues an extensive supplementary guide, explaining pertinent vocabulary, background, and concepts in a way accessible to typical high school students and teachers. This effort, entirely a student initiative, could be a harbinger. Modest funding and provision of Web links would enable a network to be created with which college science students can provide significant help to both students and teachers at their former high schools.

The other source for my optimistic conviction is my own high school experience. It was five decades ago, in a rural area; not many of the students expected to go on to college. Most of the science and math courses were taught by current or former athletic coaches, often the case even now (Rogers 2001). On my first day of high school, the first class was algebra. The teacher began by saying: "I don't know much about algebra!" Within a week or so, a

few students indeed were well ahead of the teacher. That was not a problem for him; as a former army officer, he viewed his job as making sure the troops measured up to standards. He got the capable kids to explain things to others and to him. The result was a free-flowing discussion, in which nobody was inhibited in asking questions. Much the same happened in other courses. In chemistry we had a teacher with admirable command of the subject, but he, too, put great responsibility on the most able students to lead the class. Although we had no opportunity to take part in science fairs, we were challenged by our teachers to become genuine partners in the educational enterprise. The value of "making a virtue of necessity" seems just as compelling today (Lederman 2001).

A striking demonstration of what gifted high school students can contribute to enhancing science literacy comes from another Lederman project. Fifteen students from the Illinois Mathematics and Science Academy undertook to write biographies of leading

The Nobel Foundation



Nobel Medal: Reverse face of the Nobel Medal for physics or chemistry, depicting Scientia gazing upon the face of her teacher, Natura.

American scientists. Each young author chose a favorite scientist to study and interview, and produced a lively account of their life and work, written for middle school and high school students. The result is a remarkable book (Lederman and Scheppler 2001) of portraits of inspiring scientists, doubly engaging as a legacy of roots and wings insightfully received by a new generation.

A NOBEL BENEDICTION

Leon Lederman took part in the Nobel Prize Centennial festivities held in December of 2001, in Stockholm, as a member of a panel discussing the challenges looming in the coming century. Witnessing Lederman and other laureates acknowledging the “impossible” problems ahead as well as new opportunities for science in the service of humanity, I was prompted to reflect on an aspect of the prizes that is seldom noted.

Images of the gold Nobel Medal are often displayed, but usually only the side depicting the profile of Alfred Nobel. The reverse face of the medal deserves attention as it intends to convey the significance of the awards (Lagerqvist 2001). The medals for physics, chemistry, physiology or medicine, and literature were all designed by a Swedish artist, Erik Lindberg, in 1902. The reverse face of each of the four medals bears along its upper border a Latin inscription: “*Inventas vitam iuvat excoluisse per artes.*” In English this may be approximated as “It is a pleasure to have brought cultivation to life through the discovered arts.” This inscription, adopted by the Nobel Foundation for the science prizes as well as the literature prize, emphasizes the cultural kinship of science and the humanities.¹

For the physics and chemistry medals, the reverse face depicts two elegant women in diaphanous gowns, both perched among billowing clouds, one erect, the other kneeling. The erect figure, designated “*Natura*,” holds in her right hand a cornucopia. The kneeling figure, “*Scientia*,” wears a laurel crown and has in her left hand a scroll. She reaches up with her right hand to unveil the face of Nature, which she beholds intently. The unveiling motif,

familiar in classical antiquity, aptly represents the aim of scientific research. It pertains just as well to science education. For me, this reaches beyond metaphor. Lindberg's earnest and lovely figures readily morph into another immortal pair: teacher and student, Annie Sullivan and Helen Keller.

NOTES

1. Langerqvist states that the inscription is "a revision of Virgil's (Aeneid, 6:663) *inventas aut qui vitam excoluere per artes.*" The English translation, that I have quoted, was kindly provided by Dr. Richard F. Thomas, Professor of Greek and Latin at Harvard University. He also pointed out that the Latin *artes* itself is a broad term that can include science and technology as well as arts and crafts.

REFERENCES

- Bruce, Robert V. *Bell: Alexander Graham Bell and the Conquest of Solitude*. Ithaca, New York: Cornell University Press, 1990.
- Gregorian, Vartan. Teacher Education Must Become Colleges' Central Preoccupation, *The Chronicle Review, The Chronicle of Higher Education* (August 17, 2001), pp. B7-B8.
- Herschbach, Dudley. Imaginary Gardens with Real Toads. *Annals of the New York Academy of Sciences* 775 (1996): 11.
- Herschbach, Dudley. Teaching Chemistry as a Liberal Art. *Liberal Education* 82 (1996): 1-9.
- Herschbach, Dudley. The Thirteenth Labor of Hercules, in *The Thirteenth Labor: Improving Science Education*, eds., E. J. Chaisson and T-C. Kim. Amsterdam, The Netherlands: Gordon and Breach Publishers, 1999, pp. 61-70.
- Kundera, M. *The Art of the Novel*. New York: Grove Press, 1966, p. 99.
- Lash, Joseph P. *Helen and Teacher*. New York: Addison-Wesley Publishers, 1997.
- Lagerqvist, Lars O. *Nobel Medals*. Stockholm, Sweden: The Royal Coin Cabinet, 2001, pp. 20-21.

- Lederman, Leon. Lessons Learned: The Teachers Academy for Mathematics and Science. *Phi Delta Kappan*: October 1998: 158.
- Lederman, Leon. Revolution in Science Education: Put Physics First! *Physics Today* 54 September 2001: 11-12.
- Lederman, Leon M., and Judith A. Scheppler, eds. *Portraits of Great American Scientists*. Amherst, New York: Prometheus Books, 2001.
- Mackay, James. *Sounds Out of Silence*. Edinburgh, Scotland: Mainstream Publishing, 1997.
- Polanyi, Michael. The Republic of Science: Its Political and Economic Theory. *Minerva*, 1 1962: 54.
- Rigden John S. *Rabi, Scientist and Citizen*. New York: Basic Books, 1987. pp. 256-257.
- Rogers, T. K. "The View of Physics from High School," *APS News* 10 (August/Sept. 2001): 8.
- Shapiro, Michael. *Who Will Teach for America?* Washington, D.C.: Drew Fairchild, Inc., 1993.
- Sparks, Dennis, and Stephanie Hirsh. *The New Vision for Staff Development*. Alexandria, Va.: Association for Supervision and Curriculum Development, 1997, p. 49.