

Physics Education at MIT:

From Bell's Phonautograph to Technology Enhanced Active Learning

Anthony P. French

The Beginnings



The MIT Physics Department was one of the foundation departments of the Institute. It was established, along with the Institute itself, in 1865. MIT's first President, William Barton Rogers, was also Professor of Physics and Geology. He was assisted by EDWARD PICKERING, who in 1869 set up a teaching laboratory in physics and mechanics. This laboratory, rather than lecture courses, was the basis of physics instruction in those early years. A manual based on it (entitled *Physical Manipulation*) published by Pickering in 1873 was, so far as is known, the first physics lab manual ever published in America, and for many years was the accepted text used in other laboratories being established in the more progressive colleges and technical schools.

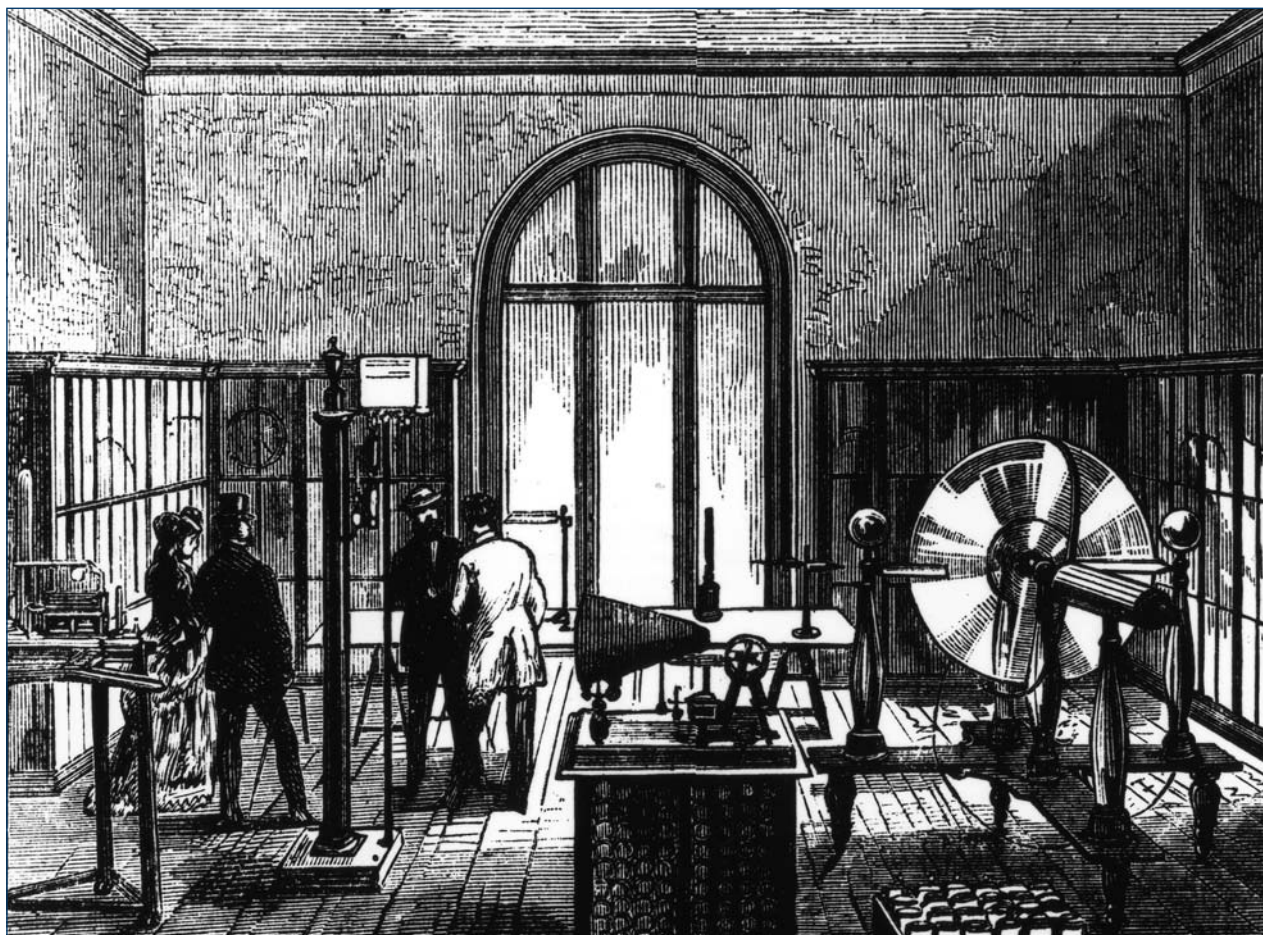


FIGURE I
MIT Physics Laboratory (Leslie's Newspaper, 1869). The apparatus (center) is Alexander Graham Bell's phonograph, a precursor to the telephone.

A key member of the Department in Pickering's time was CHARLES CROSS, who became a physics instructor upon his graduation in 1870 and later served as Department Head for 40 years (1877–1917). It was in Cross's lab that Alexander Graham Bell worked, together with Cross, in experiments that helped lead to Bell's invention of the telephone in 1876.

Early in his headship of the Department, Cross (in 1882) organized the Institute's first course in electrical engineering. It was listed in the Catalogue as Physics B, but two years later it acquired its own identity and became the basis of a separate department formally established in 1902 — the Course VI that we have known ever since. Subsequently, two other departments — Chemical Engineering and Aeronautical Engineering — developed from courses taught in the Physics Department.

A Transitional Period

During the 1920s the demand for people trained as physicists became greater than the supply. There was also a need to expand and elevate physics research at the Institute if MIT was to maintain its national status. The physics

curriculum was revised to allow students greater latitude in preparing for either academic or industrial employment.

The Department Revitalized

In 1930 MIT acquired a new President — Karl Taylor Compton. A physicist himself, he was a brother of the Arthur Compton all physicists know as discoverer of the effect named after him. Karl Compton had been President of the American Physical Society from 1927 to 1929. He proved to be an outstanding leader of the Institute, and the Physics Department was one of the main beneficiaries.

One of Compton's first steps was to lure the theorist JOHN C. SLATER from Harvard and make him Head of the Physics Department — a position that Slater held until 1951. Slater's friend GEORGE R. HARRISON was brought in at the same time to lead the development of experimental physics. Others already on the faculty or appointed soon afterward were J. A. STRATTON (who transferred from Electrical Engineering and later became MIT's President), PHILIP MORSE, NATHANIEL FRANK and FRANCIS SEARS. Slater was determined to raise not only the research quality of the Department but also the teaching of physics at all levels. With a team like this his success was assured. At this time, two years of physics were required of all students at the Institute, and Stratton, before he joined the Department, had been involved in a study to raise the standard of the mechanics taught in the first year. N. H. Frank was given the task of implementing this plan, and the result was his ground-breaking text, *Introduction to Mechanics and Heat* (1934). It turned out that this was too strong medicine for many students, and the failure rate was uncomfortably high. But a remedy was at hand in the person of Francis Sears, who was a master teacher and undertook the task of modifying the course without compromising its intellectual integrity. The result was the beginning of a series of books by Sears on basic physics that became best-sellers and were adopted by colleges and universities all across the country. Many readers of this article will probably remember the books written by Sears, some of them in partnership with Mark Zemansky of City College, New York. "Sears-and-Zemansky" became almost a single household word. But Frank's *Mechanics*, together with his subsequent *Introduction to Electricity and Optics* for second-year physics, remained standard texts for stronger students.

Slater himself was a prolific author of more advanced textbooks. He first joined with Frank in authoring *Introduction to Theoretical Physics* (1933), designed for students in their senior year. Slater went on to publish a total of fourteen physics texts between 1933 and 1968. He had an extraordinary talent for composing his massive books at the typewriter, with very little need for editing or revision. Another important contribution to physics pedagogy by Physics Department faculty at this time was the book *Principles of Optics* by Arthur Hardy (with Fred Perrin) (1932).



FIGURE 2

Nathaniel Frank (left) with John Slater, circa 1930.

WW II and After

The years 1941–1945 saw many of the Department faculty taking leave to carry out research directly related to the war effort, and returning from that feverish environment with renewed energy and determination. Money poured in from funding agencies, making it possible not only to finance research but to recruit new faculty. At MIT one of the first appointees was Professor JERROLD ZACHARIAS, who had been a member of the famous MIT Radiation Lab but had also become affiliated with Los Alamos toward the end of the war. With Slater's backing, he in turn used this opportunity to augment the Department with several outstanding nuclear physicists, including VICTOR WEISSKOPF and BRUNO ROSSI. The young alumni MARTIN DEUTSCH and HERMAN FESHBACH also returned from their wartime activities at this time to join the Department's junior staff. The overall result was a tremendous advancement of both research and teaching in physics at MIT. The scope and level of physics graduate education were greatly strengthened, and in the nature of things this had an influence on the structure and content of the undergraduate program. Richard Feynman (class of 1937) was recorded as saying that topics (especially in quantum theory) considered to be unapproachable below graduate level when he was a student were now routinely included in undergraduate courses.

Zacharias and the PSSC

The main concern of this article is physics education in and for MIT, and more generally at university level, but it would be unthinkable to omit a pre-university project, originating within our Department, that had a major effect on physics education nationwide. Zacharias applied to the American

Photo courtesy of MIT Museum.



FIGURE 3
Jerrold Zacharias (left) with Francis Friedman (1957).

educational scene the sort of organizational know-how that he had brought from the radar and atomic-bomb projects. In 1956 (one year before Sputnik, as he was always proud to recall) he assembled a group of high-school and college teachers of physics and called it the Physical Science Study Committee (PSSC). The goal was to create a new and complete high-school physics course, strongly based on observation and experiment, that would encourage students to think and act like professional scientists. The project would produce many novel experiments and pieces of simple apparatus, numerous instructional films, ancillary monographs, and a textbook (with detailed and extensive teachers' guides). Zacharias's chief partner in the project was another MIT physics professor, FRANCIS FRIEDMAN, a theorist of great breadth and insight, who died far too young in 1962. Friedman became the chief author of the textbook.

The project was not designed primarily to increase the numbers of students taking high-school physics, but rather to provide a deeper understanding of basic physics for those who did take it. In this goal it succeeded brilliantly, and many authors and teachers borrowed from it. The textbook, *PSSC Physics*, was translated into 17 other languages.

A Wealth of Teachers and Authors

It is a normal feature of academic life that university teachers write books based on the lectures they have given. But the MIT Physics Department has an exceptionally rich record in this area. John Slater led the individual score, but many others leap to mind. Especially prominent among them is the classic two-volume work, *Methods of Theoretical Physics* (1953), by Philip Morse and Herman Feshbach, over which many readers must have sweated and profited. Other well-known but more specialized books from this era included *Electromagnetic Theory* (1948) by J. A. Stratton, *Theoretical Nuclear Physics* (1952) by Blatt and Weisskopf, *Thermodynamics and Statistical Mechanics* (1952) by William Allis and M. A. Herlin, and *The Atomic Nucleus* (1955) by Robley Evans.

The special role that physics plays in the undergraduate curriculum at MIT encouraged the writing of various additional texts at the first- and second-year level. Among them were *Optics* (1957) by Bruno Rossi and *Introduction to Mechanics, Matter and Waves* (1960), by Uno Ingard and William Kraushaar. Later there came *Mechanics* (1972) by Daniel Kleppner and Robert Kolenko, suited to the capabilities of mathematically better-prepared freshmen.

For upper level undergraduates, this same period saw the publication of *Statistical Mechanics* (1963) by Kerson Huang, *Thermal Physics* (1964) by Philip Morse and *Introduction to Nuclear Physics* (1966) by Harald Enge.

Especially noteworthy, also, was a 3-volume work, *Physics, with Illustrative Examples from Medicine and Biology* (1973–79) by Felix Villars and George Benedek, designed as an alternative sequence of introductory physics courses for the increasing numbers of students having an interest in the life sciences.

The above is only a selective list, and apologies are due to the many authors not listed here.

Some Sweeping Changes at the Institute

The structure of undergraduate education throughout MIT was strongly affected in 1964 by the recommendations of the Committee on Curriculum Content Planning (CCCP), a committee set up in 1962 and charged with reviewing all aspects of this education. For many years the so-called core requirements for all undergraduates had included two years of mathematics, two years of physics, and one year of chemistry. The Committee recommended (and the MIT faculty approved) the drastic step of halving all these numbers, in the interests of giving more flexibility to student programs. This obviously had a major impact on the Department's educational responsibilities.

The Science Teaching Center

In 1961 Professor Francis Friedman obtained National Science Foundation support for a program at MIT to develop educational materials at college level that would build on the foundation created by the PSSC course and similar high-school projects in chemistry and biology. Despite its name, the Center initially devoted all of its effort to physics, and it was in effect an extension of our Department. Among its products were demonstration films of two dramatic relativistic phenomena: the asymptotic approach to the limiting value c for the speed of accelerated electrons (Prof. William Bertozzi, 1962) and the Einsteinian time dilation for cosmic-ray muons (the late Prof. David Frisch, with Prof. J. H. Smith from the University of Illinois, 1963). Several years later Zacharias himself made a third film — “The Stern-Gerlach Experiment” (1967) directly demonstrating the magnetic splitting of a beam of cesium atoms.

One major project was an extended discussion on ways of presenting basic quantum mechanics to sophomores. Professors Arthur Kerman and Louis Osborne, in particular, were central to the debate, as they were already (in 1963) teaching a pilot course in the subject.

Another activity during the 1960s was the relatively early use of computers for physics education. The most notable outcome was a set of short computer-generated films on the motion and scattering of one-dimensional wave-packets in various potentials. This collection, developed primarily by Center staff members Judah Schwartz and Harry Schey and produced by The Education Development Center at Newton, Mass., achieved wide distribution and use outside MIT.

Some years later, interest grew in combining various parts of the Center's work in the form of instructional texts. This ultimately led to the publication of four books, with Anthony P. French as principal author, on relativity, Newtonian mechanics, vibrations and waves, and (with E. F. Taylor) on quantum physics.

The existence of the Center as such came to an end in 1973.

The Quest for Improvement of Freshman Physics

The effective teaching of physics to freshmen has always been a top priority at MIT, but until the early 1960s there was only one form of the first-year program. Little account was taken of wide variations that existed in the academic background of the entering students. One innovation (in 1964) was a changed course content based on the work of the Science Teaching Center; it preceded the rigorous Newtonian mechanics with a more general introduction similar to the first part of the PSSC course. This course did not survive. A few years later, however, several important developments occurred. The Department launched (a) a new two-semester sequence designed for students who did not expect to take any subsequent physics courses, and (b) another two-semester sequence catering to above-average students (based on the Kleppner/Kolenkow mechanics and E. M. Purcell's great textbook on electromagnetism). At the same time the main-line course, taken by a majority of students, reverted to its traditional curriculum. The new option (a) never attracted large numbers of students, even though part of it was taught by the late PHILIP MORRISON, the most exciting lecturer in the Department, and was discontinued in 1978. Option (b), however, was very popular from the outset, and has become the favored choice for a large fraction of those who plan to complete an undergraduate major in physics.

Another significant innovation was the Villars/Benedek physics program with a biomedical slant. This began at about the same time as the options (a) and (b) above, and was offered until 1984. Thus for a number of years students had four choices for their introductory physics. History repeated itself in a sense more recently. In 1990 Professor JOHN KING created an alternative version of first-year physics enriched with a set of take-home experiment kits for both mechanics and electromagnetism. At about the same time the Department introduced a special form of first-semester physics that allowed students to spend an extra month on the course and take their final examinations in January instead of December, which was helpful to those with weaker high-school backgrounds in physics.

Over many years, also, between about 1970 and 1990, experiments were made with non-traditional methods of instruction. Educational research had shown that the traditional system of big introductory lectures, supported by numerous recitation sections, is of limited effectiveness as a teaching tool. Students may enjoy the ambitious demonstrations but do not necessarily gain

much insight or mastery of knowledge. Various alternative modes of instruction were generated nationwide, and several were tried at MIT with limited success. Finally, in about 2000, an adaptation of a method called “Studio Physics,” originated at Rensselaer Polytechnic by Professor Jack Wilson, was developed at MIT by Professor John Belcher and has the name TEAL (Technology Enhanced Active Learning). This scheme completely does away with the large general lecture. Instead, all the instruction, including practical work, is carried on in a single room furnished with a dozen or so round tables, each table accommodating three groups of three students. There is a computer for each trio of students, plus the equipment for any experiment being conducted that day. Collaboration and discussion among the students in a given trio is an integral part of the learning experience. The TEAL system is now on the way to handling the bulk of the introductory physics teaching at the Institute.

In Conclusion

Our Department is justly renowned for its high achievements in many different fields of research. But its dedication to its educational role is also unquestionable. The chief reward for any teacher is of course the knowledge that he or she has had an inspiring or formative effect on students. However, more formal recognition is not unwelcome. The highest annual award by the American Association of Physics Teachers, the outstanding physics teaching organization in the world, is the Oersted Medal, established in 1936. Nine of the 70 recipients of this award have been MIT department members, well ahead of any other physics department in the country. It is a record that speaks for itself.

ANTHONY P. FRENCH *was born in Brighton, England, in 1920. He attended Cambridge University, receiving a B.A. (Physics) in 1942 and a Ph.D. (Nuclear Physics) in 1948. In 1942 he joined the British atomic bomb project (Tube Alloys) at the Cavendish Laboratory and was sent to Los Alamos in 1944 as a member of the British Mission. He returned to the U.K. in 1946, worked for two years at the new Atomic Energy Research Establishment, and then became a faculty member at Cambridge University for seven years, doing nuclear research at the Cavendish Lab. He was also a Fellow and Director of Studies in Natural Sciences at Pembroke College, Cambridge.*

In 1955 he emigrated to the U.S. to join the University of South Carolina, where he served as Physics department head. Since 1962 he has been at MIT, engaged chiefly in undergraduate teaching and the development of physics curricula and teaching materials, especially the MIT Introductory Physics series of textbooks. He also edited Einstein: A Centenary Volume (1979) and co-edited Niels Bohr: A Centenary Volume (1985).

From 1975 to 1981 he served as chairman of the Commission on Physics Education of The International Union of Pure and Applied Physics, and in 1985–86 was President of the American Association of Physics Teachers (AAPT). He is also a Fellow of the American Physical Society. For his work in Physics Education, he has received the University Medal of the Charles University, Prague (1980), the Bragg Medal of the Institute of Physics, London (1988), the Oersted Medal of AAPT (1989), and the Melba Newell Phillips Award of AAPT (1993). He has been Professor Emeritus at MIT since 1991.

MIT's Oersted Medal Recipients*

1961	Jerrold R. Zacharias
1962	Francis W. Sears
1963	Francis L. Friedman
1965	Philip Morrison
1976	Victor F. Weisskopf
1989	Anthony P. French
1997	Daniel Kleppner
1997	Edwin F. Taylor
2000	John G. King

*The Oersted Medal award, established in 1936, is the most prestigious award of the American Association of Physics Teachers.