



Capturing the Wisdom of Feynman

The sole survivor of the three authors who brought *The Feynman Lectures on Physics* to life describes how his hopes of introducing modern physics to undergraduate students were realized beyond his dreams.

Matthew Sands

The whole thing was essentially an experiment.” That is how Richard Feynman characterized the set of lectures he delivered to the introductory physics classes at Caltech from 1961 to 1963.¹ That experiment was part of a program for developing a new course that would, it was hoped, introduce incoming students to many of the key ideas of 20th-century physics. As it turned out, the lectures provided the basis for a three-volume set of books: *The Feynman Lectures on Physics*, whose impact has gone far beyond those students at Caltech. I offer this memoir on how the *Lectures on Physics* came to be.

I first met and became friends with Feynman in 1944 at Los Alamos Laboratory, where we worked on the Manhattan Project. Six years later, we found ourselves together again at Caltech. In my first years there, I was asked to teach only graduate courses and soon became quite dismayed at the curriculum required of the students. During their first year, graduate students took courses only in mechanics and in electricity and magnetism, and E&M covered statics but did not address radiation theory at all. I thought it was disgraceful that these hotshot students were not exposed to modern physics—whose ideas had been around already for 20 years or more—until their second or third year.

So I began a campaign to reform Caltech’s graduate curriculum. I asked Feynman to join the campaign, and we outlined a new program and eventually persuaded the physics faculty to adopt it. First-year students took a course in electrodynamics and electron theory taught by me, introductory quantum mechanics taught by Feynman, and, as I recall, a course in mathematical methods taught by Robert Walker. I think that the new curriculum was quite successful.

Sputnik spurs changes

In the late 1950s, Jerrold Zacharias, the retired director of MIT’s Laboratory for Nuclear Science, was stimulated by the introduction of the Soviet Sputnik program to push for revitalization of the US high-school physics curriculum. He and others assembled the Physical Sciences Study Committee, which included physicists, scholars, and writers, to reform the curriculum. The committee generated many new materials and ideas, as well as some controversy.

As the PSSC project was nearing completion, Zacharias and colleagues (including, I believe, Francis Friedman and

Philip Morrison) decided it was time to tackle a revision of introductory university physics. They organized a couple of large meetings of physics teachers, which resulted in the formation of the Commission on College Physics, a national committee of a dozen university physics instructors. The commis-

sion, which was supported by NSF, was charged with stimulating national endeavors for the modernization of physics teaching in colleges and universities. Invited by Zacharias to those first meetings, I later served on the commission and eventually became its chairman from 1964 to 1966.

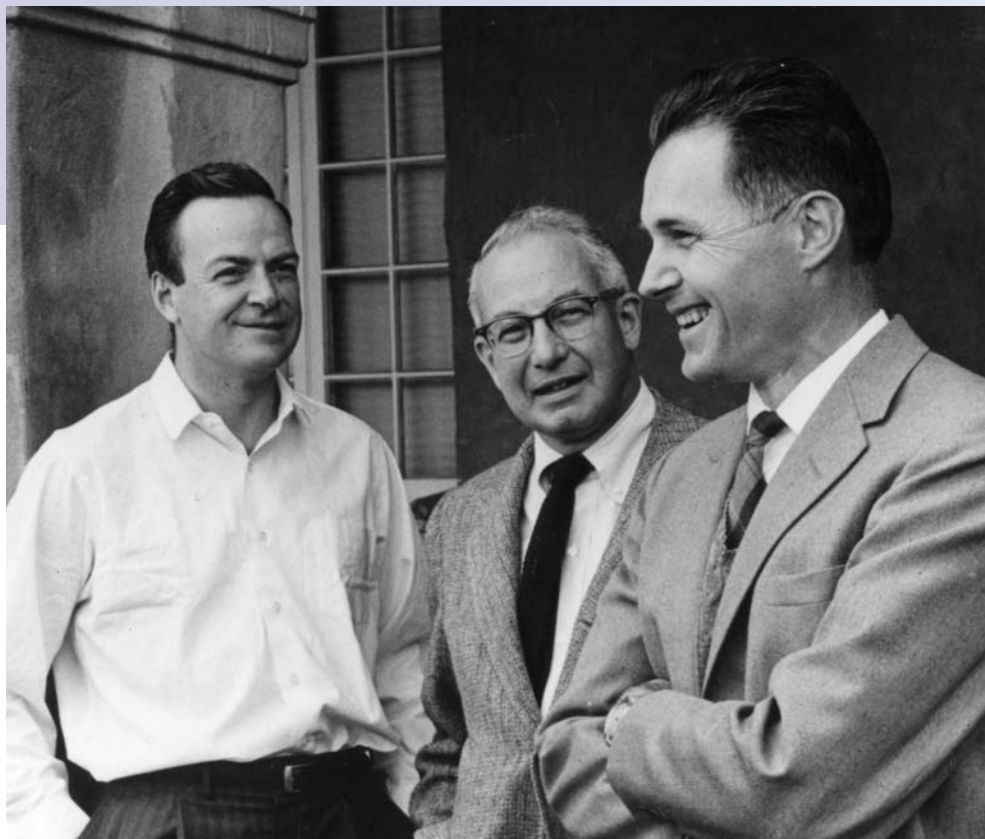
Those activities prompted me to begin thinking about what could be done with the Caltech undergraduate program, with which I had long been rather unhappy. The introductory course in physics was based on *Mechanics, Molecular Physics, Heat, and Sound* (Ginn, 1937), a fine book by Robert Millikan, Duane Roller, and Earnest Watson that had little or no modern physics. Furthermore, the course was taught without lectures, so instructors had little opportunity to introduce new material. The strengths of the course were twofold: It provided a set of intricate problems, compiled by Foster Strong, as weekly homework assignments, and it offered two weekly recitation sections in which students discussed the assigned problems.

Modernizing the undergrad program

Like other physics faculty each year, I was assigned to advise a handful of physics majors. On talking with the students, I was often dismayed to hear that by their junior year, they were becoming discouraged about continuing to study physics. Their discouragement stemmed at least in part from studying physics for two years without encountering any current physics ideas. I decided not to wait for the national program to mature but to try to do something at Caltech. In particular, I wanted to see some of the content of modern physics—atoms, nuclei, quanta, and relativity—brought into the introductory course.

After discussions with a few colleagues—notably, Thomas Lauritsen and Feynman—I proposed to Robert Bacher, then head of the physics department, that we should start a program to reform the introductory course. His initial response was not very encouraging. He said, in effect, “I have been telling people we have a very fine program that I am proud of. Our discussion sections are staffed by some of our senior faculty. Why should we change?” I persisted and was supported by a few others, so Bacher relented, accepted the idea, and had soon secured a grant from the Ford Foundation for, if I remember correctly, more than \$1 million. The funds were earmarked for the costs of devising new equipment for the introductory labs, developing new course content, and, in particular, supporting temporary faculty who would be picking up the regular duties of those who were devoting time to the project.

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At Caltech, circa 1960, are (left to right) Richard Feynman, Robert Bacher, and Robert Leighton. (Courtesy of AIP Emilio Segrè Visual Archives.)

On receiving the grant monies, Bacher appointed a small task force to lead the program: Robert Leighton as chairman, H. Victor Neher, and me. Leighton had long been involved in the upper-division program—of which his book *Principles of Modern Physics* (McGraw-Hill, 1959) was the mainstay—and Neher was known as a brilliant instrumentalist. At the time, I was miffed that Bacher had not asked me to lead the committee. I guessed his reason may partly have been because I was already busy running the Synchrotron Laboratory, but I have always thought he was also worried I might be too radical and that he wanted to balance the project with Leighton's conservatism.

The committee agreed from the start that Neher would concentrate on developing new labs, about which he had many ideas, and that we should work toward presenting a lecture course the following year. Our reasoning was that the lectures would provide the best mechanism for developing the new course content. Leighton and I were to design a syllabus for the lectures. We began by working independently to produce course outlines, but we met weekly to compare progress and try to reach a common ground.

Impasse, then inspiration

It soon became clear that a common ground would not be easily found. I viewed Leighton's approach as a rehash of physics course content that had been in vogue for 60 years, and he thought that I was pushing impractical ideas—that freshmen were not ready for the modern content I wanted to introduce. Fortunately, I was bolstered in my resolve by frequent conversations with Feynman, who was already well known as an impressive lecturer and was particularly adept at explaining modern physics ideas to a general audience. I would frequently stop at his house on the way home from Caltech to sound him out on what I was thinking. Feynman was generally supportive and would often make suggestions about what might be done.

After several months of effort, I became rather discouraged; I didn't see how Leighton and I could ever agree

on a syllabus. Our concepts for the course seemed to be completely at odds. Then one day I had an inspiration: Why not ask Feynman to give the lectures for the course? We could provide him with both Leighton's and my outlines and let him decide what to do. I immediately proposed this idea to Feynman: "Look, Dick, you have now spent 40 years of your life seeking an understanding of the physical world. Here is an opportunity for you to put it all together and present it to a new generation of scientists. Why don't you give the freshman lectures next year?" He was not immediately enthusiastic, but he and I continued to discuss the idea over the next few

weeks, and he was soon caught up in the notion. He would say maybe we could do this or that. Or this would fit in here, and so on. Finally, he asked me: "Has there ever been a great physicist who has presented a course to freshmen?" I told him that I didn't think so. His response: "I'll do it."

Feynman will give the lectures

At the next committee meeting, I presented my proposal with great enthusiasm, only to be dismayed by Leighton's cool response. "That's not a good idea," he said. "Feynman has never taught an undergraduate course. He wouldn't know how to speak to freshmen, or what they could learn." But Neher saved the day. His eyes lit up with excitement: "That would be great! Dick knows so much physics, and knows how to make it interesting. It would be fantastic if he would really do it." Leighton, now persuaded, supported the idea wholeheartedly.

Some days later I faced the next hurdle: I presented the idea to Bacher. He didn't think much of it. He considered Feynman too important to the graduate program to be spared. Who would teach quantum electrodynamics? he asked. Who would be working with the theoretical graduate students? And besides, could Feynman really bend down to the level of the freshmen? At that point, I lobbied senior members of the physics department, who put in supporting words to Bacher. And then I used the argument dear to academics: If Feynman really wants to do it, do you want to say that he should not? The decision was made.

With six months remaining before the first lecture, Leighton and I shared our thoughts about the program with Feynman. He started to work intensively on developing his own ideas. At least once each week, I stopped by his house to discuss his ideas. He sometimes asked whether I thought a particular approach would be accessible to the students or whether this or that sequence of material would work best. I recall one such example: Feynman had been working on how to present the ideas of wave interference and diffraction, and was having difficulty finding a suitable mathe-



Students respond to Richard Feynman (far right) during one of his lectures in 1963. (Photo from Realites/Courtesy of Caltech Archives.)

mathematical approach that was both straightforward and powerful. He asked me whether I thought freshmen would be able to work with the algebra of complex numbers. I reminded him that students admitted to Caltech had been selected primarily on their demonstrated abilities with mathematics, and I was confident they would not have problems dealing with complex algebra as long as they were briefly introduced to the subject. Feynman's solution to the quandary was the delightful lecture called "Algebra," which took students on a tour of mathematics, beginning with integers and concluding with the imaginary exponential (see volume 1, chapter 22), material he was able to use in later lectures on oscillating systems and physical optics.

Early on, though, a small problem surfaced. Feynman had a long-time commitment to be absent from Caltech the third week of the fall semester, and so would miss two class lectures. The problem was easily solved: I would substitute for him on those days. However, to avoid breaking the continuity of his presentation, I would give the two lectures on subsidiary topics that, although useful to the students, would not be related to his main line of development. (As a result, chapters 5 and 6 of volume 1 are somewhat anomalous.)

For the most part, Feynman worked alone to develop a complete outline of his talks for the entire year, filling in enough detail to cover any unforeseen difficulties. By September 1961, after working intensively on the program, he was ready to begin his first year of lectures.

Working out the kinks

Originally, the plan was that Feynman's lectures would form the starting point of an evolving revised program for the two-year introductory course required of all incoming students. In succeeding years, other faculty members would take over the responsibility for each of the two years.

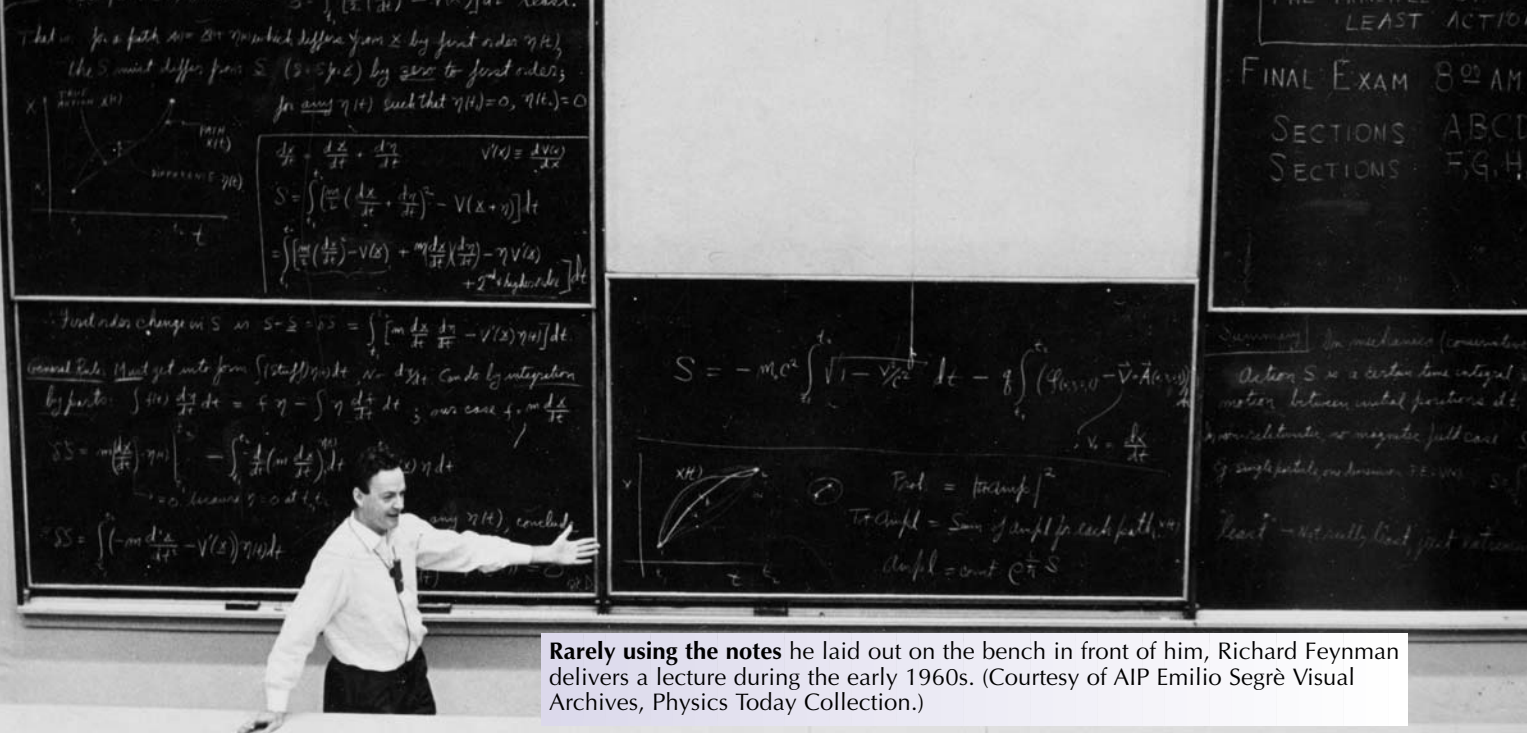
Those faculty would eventually develop a course—with a textbook, homework exercises, a laboratory, and so on.

For the two years of the lectures, the course followed a rather traditional weekly plan: Two one-hour lectures by Feynman, a one-hour discussion session led by a faculty member or a graduate student assistant, and a three-hour laboratory directed by Neher.

During each lecture, Feynman carried a microphone, suspended from his neck and coupled to a tape recorder in another room. Photographers periodically snapped the contents of the blackboard. Both the photography and the tape recording were managed by Tom Harvey, the technical assistant in charge of the lecture hall. Harvey also helped Feynman devise an occasional demonstration for the lectures. Typist Julie Cursio then transcribed the recorded lectures.

That first year, Leighton took on the responsibility for having the transcripts of each lecture edited quickly for clarity so that students would have the printed lecture notes for study. The initial plan involved assigning the editing of a lecture to one of the graduate students who led the discussion sections and labs. That plan, though, didn't work out because the students took too long to edit and the resulting product reflected their ideas more than Feynman's. Leighton quickly changed the arrangement by taking on much of the work himself and by recruiting various faculty members from physics and engineering to edit one or more of the lectures. I also edited several of the lectures that first year.

The second year of the introductory course saw some changes. Leighton began giving the lectures to the first-year students and, in general, managed the course. Fortunately, the students now had available from the beginning the transcribed notes of Feynman's lectures from the



Rarely using the notes he laid out on the bench in front of him, Richard Feynman delivers a lecture during the early 1960s. (Courtesy of AIP Emilio Segrè Visual Archives, Physics Today Collection.)

previous year. I became responsible for looking after the details of the second-year course, for which Feynman was now giving the lectures. And I was left with the responsibility of producing the edited transcripts in a timely manner. Because of the nature of the second-year material, I concluded that it would be most appropriate to take on the task myself.

I also sat in on nearly all of the lectures, as I had done during the first year, and took one of the discussion sections for myself, so that I could see how the course was going for the students. After each lecture, Feynman, Gerry Neugebauer, and I—occasionally joined by one or two of the graduate teaching assistants of the course—went to lunch at the student cafeteria and discussed what might be suitable homework exercises on the subject of the lecture. Feynman generally had several ideas in mind, and others would emerge from the discussion. Neugebauer was responsible for collecting the exercises and producing a problem set each week.

Lecturing style

It was a great pleasure to sit in on the lectures. Feynman would appear five minutes or so before their scheduled start. He would take out of his shirt pocket one or two small pieces of paper—perhaps 5×9 inches—unfold them, and smooth them out at the center of the lecture bench at the front of the lecture hall. Those were his notes for his lecture, although he rarely referred to them.

As soon as the bell rang to announce the start of the class, Feynman began his lecture. Each one was a carefully scripted, dramatic production that he had clearly planned in detail, and usually followed this order: introduction, development, climax, and denouement. And his timing was most impressive. Only very rarely would he finish more than a fraction of a minute before or after the end of the hour.

Even his use of the chalkboards at the front of the lecture hall appeared to be carefully choreographed. He would begin at the upper left of the left-hand board and, at the end of the lecture, would have completely filled the middle and right-hand boards. The greatest pleasure, though, was watching how he developed the original sequence of ideas and presented them with clarity and style.

Making a book

Although we had not contemplated that the lecture transcripts would become a book, that idea came into serious consideration around the middle of the second year of lectures—in the spring of 1963. The thought was stimulated in part by inquiries from physicists from other schools about whether transcripts could be made available to them, and in part by suggestions from several book editors. The editors had apparently gotten wind of the lectures and had very likely seen copies of the transcripts.

After some discussion, Leighton and I decided that the transcripts could be turned into a book without an excessive amount of work. We asked the interested publishers to submit their proposals. The most attractive one came from the Addison-Wesley Publishing Co (A-W), which said it could provide us with hardbound books in time for the class of September 1963—only six months after the decision to publish. Also, because we were not requesting royalties, A-W proposed that the books could be available at a rather low price.

Such a rapid publication schedule would be possible because A-W had complete facilities, with in-house editors and typesetters, and photo-offset printing. Also, the publisher proposed a novel (at that time) format consisting of a single wide column of text together with a very wide margin on one side of the page, which could accommodate figures, tables, and other ancillary material. Because of that format, what would normally be galley proofs could be used directly for the final page layouts, without any need to reset textual material to accommodate figures and the like.

The A-W proposal won the day. I took on the task of making any necessary revisions of and annotations to the lecture transcripts and worked with the publisher to complete various editorial tasks, such as proofreading the typeset material. (At the time, Leighton was heavily involved in teaching the second round of the freshman course.) I revised each lecture transcript for clarity and accuracy, gave it to Feynman for a final check, and as soon as a few lectures were ready, sent the transcripts to the publisher.

I rather quickly sent off the first few lectures, and very soon received the galleys for proofreading. It was a disaster! The A-W editor had done a significant rewrite. She had

converted the informal style of the transcripts to a traditional, formal, textbook style by changing “you” to “one,” and so on. I telephoned the editor, fearing a possible confrontation. After explaining that we considered the informal, conversational style an essential part of the lectures and that we preferred personal pronouns to the impersonal ones, she understood our intention and thereafter mostly left things as they were. It was then a pleasure to work with her. (I wish I could remember her name.)

The next stumbling block was more serious: choosing a title for the book. Visiting Feynman in his office one day to discuss the subject, I proposed that we adopt a simple name like “Physics” or “Physics One” and suggested that the authors be Feynman, Leighton, and Sands. He didn’t particularly like the suggested title and had a rather violent reaction to the proposed authors: “Why should your names be there? You were only doing the work of a stenographer!” I disagreed and pointed out that, without the efforts of Leighton and me, the lectures would never have come to be a book. The disagreement was not immediately resolved. I returned to the discussion some days later and we came up with a compromise: “The Feynman Lectures on Physics by Feynman, Leighton, and Sands.”

Feynman’s preface

Around June 1963, after the second year of lectures had been completed, I was in my office assigning the grades for the final examinations when Feynman dropped in to say goodbye before leaving town (perhaps to go to Brazil). He asked how the students had performed on the exam. I said I thought pretty well. He asked what the average grade was and I told him something like 65%, as I recall. His response was, “Oh, that’s terrible; they should have done better than that. I am a failure.” I tried to dissuade him of this idea and pointed out that the average grade was very arbitrary—it depended on factors such as the difficulty of the problems given, the grading method used, and so on. In addition, we usually tried to make the average sufficiently low so there would be some spread in grades to provide a reasonable curve for the assignment of letter grades—an attitude, incidentally, that I wouldn’t approve of today. I said I thought that many of the students had clearly gotten a great deal out of the class. He was not persuaded.

I then told him that the publication of the lectures was proceeding apace and wondered whether he would like to provide a preface. The idea interested him, but he was short of time. I suggested that he dictate his preface into the Dictaphone on my desk. So, still depressed over the average grade, he recorded the first draft of “Feynman’s Preface,” which you will find in each volume of the *Lectures*. In it, he says, “I don’t think I did very well by the students.” I have often regretted that I had arranged for him to make a preface in this way, because I do not think that it was a very considered judgment. And I fear that his statement has been used by many teachers as an excuse for not trying out the *Lectures* with their students. Incidentally, the famous photograph of Feynman that accompanies the preface was not my idea. It was inserted by the publisher without my sanction.

Volumes 2 and 3

The story of the publication of the second-year lectures is a little different. When the second year ended, Feynman and I decided to split the lecture material into two separate volumes: one mainly on electromagnetism and the other on quantum mechanics. We also thought that the book on quantum physics would be greatly improved if we added some new material and reworked the rest to accommodate it. To that end, Feynman proposed that he

would, toward the end of the following year, give a number of additional lectures on quantum physics that could be blended with the original set to make up the third volume of the printed *Lectures*.

There was an additional complication. A year or so earlier, the federal government had authorized the construction at Stanford University of a two-mile-long linear accelerator to produce 20-GeV electrons for particle physics research. It was to be the largest and most expensive accelerator yet built, with electron energies and intensities many times higher than any existing facility could achieve—an exciting project. For more than a year, Wolfgang K. H. Panofsky, director of the newly created Stanford Linear Accelerator Center, had been trying to persuade me to join him as the deputy director to help build the new accelerator. In the spring of 1963, he prevailed, and I agreed to move to Stanford at the beginning of July. I was, however, committed to seeing the *Lectures* through to completion, so part of the arrangement was that I would take that work with me.

Once at Stanford, my new responsibilities demanded more time than I had expected, so I found it necessary to work on the *Lectures* most evenings if I was to make suitable progress. I managed to complete the final editing of the second volume by March 1964. Fortunately, I had the very capable assistance of my secretary, Patricia Preuss.

By May of that year, Feynman had given the additional lectures on quantum mechanics, and we began to work on the third volume. Because major restructuring and revisions of the transcripts were required, I traveled a few times to Pasadena for consultations with Feynman. We easily resolved questions that arose, and I was then able to complete volume 3 by December.

The student response

From my contact with students in my discussion section, I had a pretty clear impression about how they were reacting to the lectures. I believe that many, if not most, realized that they were having a privileged experience. I saw that many of them were caught up in the excitement of the ideas and learning a lot of physics. That excitement, however, did not apply to all. Although the course was required of all incoming students, fewer than one-half were planning to be physics majors, so many of the others

A New Edition of the *Lectures*

This year, Addison-Wesley will publish *The Feynman Lectures on Physics, Definitive Edition*, which will include updates and fixes from Richard Feynman and other sources. On the initiative of Ralph Leighton (son of Robert and friend of Feynman), this edition will be accompanied by a new supplemental volume, *Feynman’s Tips on Physics*, containing four Feynman lectures that focus on problem solving and were delivered to the class but were not included in the original published version, or indeed ever published before. These four lectures have been transcribed and refined by Ralph Leighton and Michael Gottlieb, with help from me.

I have often been asked how it was that the *Lectures* came to be. I was persuaded to put into writing my remembrances—this memoir—when Ralph Leighton asked me to provide the story as a contribution to the supplement he was preparing for a new edition of the *Lectures*.

[Editor’s Note: Matthew Sands’s memoir, from which this article was adapted, will appear in Feynman’s *Tips on Physics*, by Richard Feynman, to be published by Addison-Wesley in summer 2005; this adaptation is published with their kind permission. The Feynman Lectures on Physics, Definitive Edition, will also be published by Addison-Wesley this summer. See <http://www.aw.com>.]

course. This two-year sequence was an extremely important part of my education. Although I cannot say that I understood it all, I think it contributed most to the development of my physical intuition.

Leaving Caltech

My rather brusque departure from Caltech immediately after the second year of the lectures meant that I had no opportunity to observe the subsequent evolution of the introductory physics course. Therefore, I have little knowledge about the effectiveness of the published *Lectures* with later students. It had always been clear that the *Lectures*, by themselves, could not serve as a textbook. Too many of the usual trappings of a textbook are missing: chapter summaries, worked-out illustrative examples, exercises for homework, and so forth. Those elements would have to be provided by industrious instructors, and some were supplied by Leighton and Rochus Vogt, who took responsibility for the course after 1963. At one time, I had contemplated that those components might be provided in a supplementary volume, but it never materialized.

In my travels in connection with the Commission on College Physics, I often met with physics faculties at various universities. I heard that most instructors did not consider the *Lectures* suitable for use in their classes, although some informed me that they used one or another of the volumes in an honors class or as a supplement to a regular text. I often got the impression that some instructors were wary of trying the *Lectures* because they feared students might ask questions they would be unable to answer. Most commonly, I was told that graduate students found the *Lectures* to be an excellent source of review for qualifying exams.

It appeared that the *Lectures* may have been making more of an impact in foreign countries than in the US. The publisher had arranged for the *Lectures* to be translated into many languages—12, as I recall. When I traveled abroad for conferences on high-energy physics, I often was asked whether I was the Sands of the red books. And I heard frequently that instructors were using the *Lectures* for introductory physics courses.

Another unfortunate consequence of my leaving Caltech was that I could no longer keep up my active association with Feynman and his wife, Gweneth. He and I had enjoyed a cordial collegiality since the Los Alamos days, and in the mid-1950s, I participated at their wedding. On the rare occasions after 1963 when I would visit Pasadena, I would stay with them, or when I visited with my wife and daughter, we would spend an evening with the Feynmans. On the last such occasion, he told us the story of his most recent surgery for the cancer that not long afterward claimed his life.

It is a source of great pleasure for me that now, some 40 years after the lectures were given, *The Feynman Lectures on Physics* is still being printed, bought, read, and, I would venture, appreciated.

I am grateful to Addison-Wesley Publishing Co for agreeing to the publication of this adaptation of my memoir.

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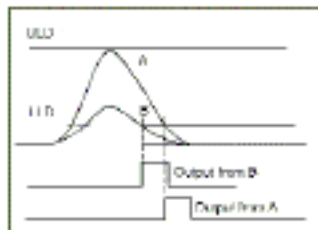
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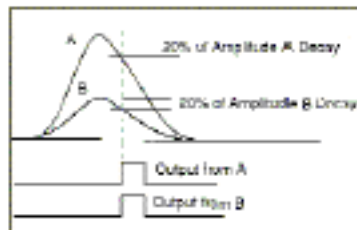
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