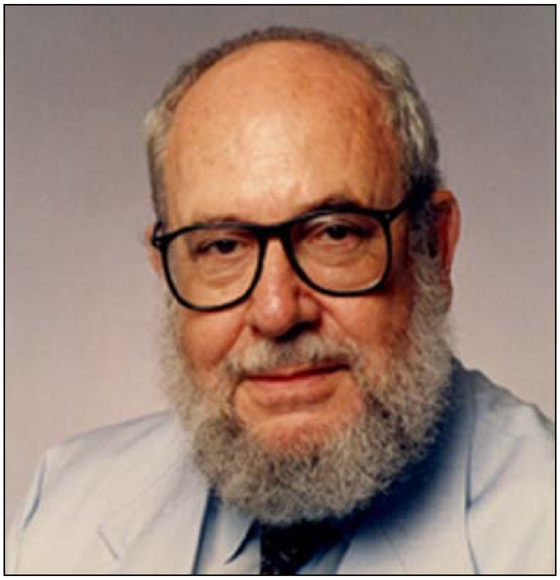

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THOMAS K. CAUGHEY
(1927–2004)

INTERVIEWED BY
CAROL BUGÉ

March 25 and April 2, 1987

ARCHIVES
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California

Subject area

Engineering

Abstract

Interview in two sessions in 1987 by Carol Bugé with Thomas Kirk Caughey, Professor of Applied Mechanics and Caltech alumnus (PhD, 1954). Caughey was born and educated in Scotland (bachelor's degree, University of Glasgow, 1948.) Comes to the U.S. with Fulbright to Cornell, where he completes his master's degree in mechanical engineering in 1952. He then earns his PhD at Caltech in 1954. He recalls Caltech's engineering and physics faculty in the 1950s: H. Frederic Bohnenblust, Arthur Erdelyi, Richard P. Feynman, Tsien Hsue-shen. Begins teaching at Caltech in 1955; recalls Caltech's Engineering Division under Frederick Lindvall; other engineers and physicists; compares engineering to other disciplines.

Return to Cornell and earlier period: outstanding Cornell professors Feynman, Hans Bethe, Barney Rosser, Ed Gunder, Harry Conway; recalls grad student Ross Evan Iwanowski. Problems of physics degree program at Cornell. Professors

Gray and Bernard Hague at Glasgow University. Comparison between American and European educational systems.

His research in dynamics. Earthquake research at Caltech: George Housner and Donald Hudson. Discusses physics and engineering entering a decade of decline; coming fields of genetic engineering, cognitive science and computing, neural networks, and artificial intelligence. Anecdotes about Fritz Zwicky and Charles Richter. Comments on coeducation at Caltech. Caltech personalities: Robert Millikan in his late years; Paul Epstein; Edward Simmons, Richard Gerke; William A. Fowler; further on Zwicky, Hudson; engineers Donald Clark, Alfred Ingersoll; early memories of Earnest Watson. Views on Caltech's future.

Administrative information

Access

The interview is unrestricted.

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Preferred citation

Caughey, Thomas K. Interview by Carol Bugé. Pasadena, California, March 25 and April 2, 1987. Oral History Project, California Institute of Technology Archives. Retrieved [supply date of retrieval] from the World Wide Web: http://resolver.caltech.edu/CaltechOH:OH_Caughey_T

Contact information

Archives, California Institute of Technology
Mail Code 015A-74
Pasadena, CA 91125
Phone: (626)395-2704 Fax: (626)793-8756
Email: archives@caltech.edu

This earthquake-making instrument was part of a project sponsored by the Earthquake Engineering Research Institute under the direction of George W. Housner and Donald Hudson. The machine weighs close to 500 pounds, including its 1.5 horsepower motor. Shaking is produced by a pair of 20-inch swing boxes that counter-rotate unbalanced amounts of lead weights. The machine was designed by Dino Morelli, while Thomas Caughey developed the electrical design. Photo by James McClanahan, 1959.

CALIFORNIA INSTITUTE OF TECHNOLOGY ARCHIVES

ORAL HISTORY PROJECT

INTERVIEW WITH THOMAS K. CAUGHEY

BY CAROL BUGÉ

PASADENA, CALIFORNIA

TABLE OF CONTENTS

INTERVIEW WITH THOMAS K. CAUGHEY

CALIFORNIA INSTITUTE OF TECHNOLOGY ARCHIVES
ORAL HISTORY PROJECT

Interview with Thomas K. Caughey **by Carol Bugé**
Pasadena, California

Session 1	March 25, 1987
Session 2	April 2, 1987

BUGÉ: I would like to begin by asking about your childhood and early education.

CAUGHEY: I was born in Rutherglen, Scotland, which is a town about fourteen miles from Glasgow. It is a very old town; its charter dates back to the twelfth century, and it was the refuge of Robert Bruce, who defeated the English in a decisive battle. I was educated at Rutherglen Academy and at the University of Glasgow, where I received bachelor's degrees in both mechanical and electrical engineering.

BUGÉ: So you had already developed an interest in that direction in your childhood.

CAUGHEY: Yes. Several members of my family were in engineering, either as craftsmen or as professionals. And, of course, at that time heavy engineering was one of the major industries in the west of Scotland.

BUGÉ: So did that influence your childhood—the games you played? Did you do experiments? Were you out building things?

CAUGHEY: Yes, we spent a lot of time building things. We built boats, land yachts, model airplanes; we also did a great deal of electronics, building shortwave transmitters and receivers. This was before World War II. Of course that all stopped with the advent of the war. Then we switched to carrier current systems using the fifty cycle mains, which allowed us to communicate with one another using the power mains. Fortunately the power company did not use carrier current circuit switching at that time, so we didn't cause any problems. It was my early experiences in electronics which led to a life long interest in nonlinear differential and difference equations and their stability.

While I was in college, I was in the naval reserve. After I finished my bachelor's degree in mechanical engineering, the navy sent me back to the university to get my degree in electrical engineering and to do research in acoustics. By the time I finished my studies, the war in the European and Pacific theaters had ended, and the navy assigned me to industry. Altogether, I spent three years in industry working on Walter engines for submarines for the Royal Navy.

BUGÉ: What kind of engines are those?

CAUGHEY: They use alcohol and hydrogen peroxide to generate steam, which is used to drive a steam turbine, which in turn drives the propeller of the submarine. The exhaust steam is condensed, and the non-condensible gases are compressed and stored in tanks on the submarine. Unlike the steam torpedo, the submarine does not betray its presence by the stream of bubbles from the exhaust. We were responsible for designing and building the high speed compressors for the system. The work on Walter engines was closed down shortly after the U.S. Navy introduced the nuclear submarine, which had both superior range and performance. Interestingly enough, the Swedish Navy has built and operates a number of Walter engine-propelled submarines in recent years and has found them to be ideal for short range coastal operations.

BUGÉ: Where was this work done?

CAUGHEY: This work was done at James Howden in Glasgow and Metropolitan Vickers in Manchester.

BUGÉ: What did you do then?

CAUGHEY: By this time I had fulfilled my obligations to the navy. I applied for, and received, an exchange fellowship from my university to McGill University. At the last moment I was asked to stand down in favor of a neurosurgeon—because McGill at that time was very famous for its neurosurgery—and asked if I'd accept Cornell University instead. Since I didn't really care very much which university I went to I accepted the fellowship at Cornell.

BUGÉ: Were you interested in getting out of Scotland at that time?

CAUGHEY: Yes, because I had a rather disappointing experience at Glasgow University. After obtaining my bachelor's degree in electrical engineering, I spent a year in a new postgraduate program which was supposed to lead to a master's degree, which didn't exist at that time. After I had completed the program, the physics department at Glasgow opposed the creation of a master's degree on the grounds that they preferred the students to enter the PhD program directly, a program where they could get three to four years work out of the student. Whereas with the master's degree program, the student could escape after a year, and it was felt that the University didn't get its money's worth. I was disappointed, having spent a great deal of time and effort on a research project which earned me no academic credit. I decided that as soon as I completed my navy obligations, I'd go abroad to complete my graduate education. In particular I liked the graduate study program in Canada and America, where the first one or two years were devoted to taking graduate level courses before one started on the research for the doctoral thesis. In Europe, at that time, there were virtually no graduate level courses. The PhD student spent three years working on a particular piece of research, picking up whatever academic skills he needed by himself.

BUGÉ: You had no interest in pursuing a PhD degree at Glasgow University?

CAUGHEY: No, because I felt that it was a rather narrow kind of training. I liked the idea that a PhD student should be educated broadly and deeply before starting on his doctoral research. A student educated broadly in the fundamentals of science and mathematics is much better prepared for the future than the student who specializes too early in his academic career.

BUGÉ: So you were ready to go and were looking for a fellowship.

CAUGHEY: Yes. I obtained a Fulbright scholarship and an exchange fellowship to Cornell University. I enjoyed my stay at Cornell very much and received a master's degree in mechanical engineering in June, 1952. I decided to transfer to either MIT or Caltech to complete my PhD degree and to broaden my academic experience. I was accepted at both places. To a graduate teaching assistant, MIT would only give one-half-time residence credit. Caltech, on the other hand, would give full-time residence credit. So I decided to come to Caltech.

At Caltech I was the first student in a new program called Engineering Science, a program which permitted students to work in areas which crossed the boundaries of several of the traditional disciplines of civil, mechanical, electrical, chemical, and aeronautical engineering. I wrote my dissertation on problems in nonlinear mechanics and received my PhD in June, 1954.

The Engineering Science program was exciting, very interesting, and at times frustrating. Since I was the first student in the program, my committee was still feeling its way, and, as a result, my program changed frequently. Courses were added and dropped on a weekly basis. Because of the frequent changes, I got to know a lot of the faculty in engineering, mathematics, and physics.

BUGÉ: I would be very interested to hear more about that—whom you met and who impressed you.

CAUGHEY: During my graduate studies, I took courses from most of the faculty in engineering and many of the faculty in physics and mathematics. I was impressed with everyone from whom I took courses. I was especially impressed with Professors [H. Frederick] Bohnenblust, [Arthur] Erdelyi, [Richard P.] Feynman and [Hsue-shen] Tsien—each impressive in a different way.

BUGÉ: So you were really a guinea pig in this program.

CAUGHEY: Yes, I was. In those days Professor Tsien was still at Caltech. The "Chinese dragon," as he was known to the students, was a holy terror. However, he was very fair-minded; if you really knew what you were talking about, he respected you. But if you didn't, he'd tear you apart. In those days my office mate, Erdum Ergin, and I organized a regular student seminar at which the faculty were present by invitation only, unlike the other seminars. The reason for this was that we had a regular graduate seminar where the students had to report on the progress of their research at least once a term. This seminar was ruled over by the triumvirate of Professors Tsien, [Frank] Marble, and [W. Duncan] Rannie, who could, and frequently did, subject the student to an academic inquisition. This was often a terrifying experience for the student reporting on his research. To give the students practice in making reports in a less threatening atmosphere, we set up our own seminar at which members of the faculty were present only by invitation.

I recall one occasion in which I was reporting on my research in this seminar, and Professor Tsien and I got into a heated debate about some point in the theory. The debate lasted several hours. After two hours Professor Tsien said, "Tom, I can't beat you; you're too damn good an engineer." Coming from him, that was high praise.

BUGÉ: Which faculty members were invited to the student seminar?

CAUGHEY: We would invite different professors on different occasions. Sometimes we would invite Dr. Tsien, but not Drs. Marble and Rannie at the same time. On other occasions we'd invite Dr. Marble but not Drs. Rannie and Tsien. This resulted in a less threatening environment for the student making his report.

BUGÉ: Was this a mixture of engineering and science graduate students?

CAUGHEY: This was mainly for engineering graduate students. However, at this time Professor Tsien had started this ambitious new program, Engineering Science, which was to bridge the gap between engineering, physics, and chemistry.

BUGÉ: How was this new program received?

CAUGHEY: At the time it was very well received, and as long as Dr. Tsien was at Caltech we had a very strong program. After Dr. Tsien returned to China, and the new options of applied mathematics and applied hysics were created, engineering science diminished in importance—though it has remained a viable program under the guidance of Professors [Milton] Plesset and [Theodore Y.] Wu. I think that the new options siphoned off a number of people who would normally have worked in the program.

BUGÉ: Why were these new programs necessary?

CAUGHEY: I don't really know, but applied mathematics and applied physics are well established programs at many other universities, so the names are easily identified with specific disciplines. This was not true of engineering science, which tended to mean different things to different people.

BUGÉ: But how did that affect you?

CAUGHEY: After receiving my PhD in 1954, I returned to Scotland with my American wife. Our twin daughters were born during our stay in Scotland, where I worked as a consultant in industry. When we returned to a faculty position at Caltech in 1955, my position was Assistant Professor of Applied Mechanics. Applied mechanics was an earlier, successful attempt to bridge the gap between physics, mathematics, and engineering. In many engineering schools, classical physics and applied mathematics are taught as a service function by the faculty in applied mechanics. This was the case at Caltech until the creation of the options in applied mathematics and applied physics, when some of the teaching responsibilities were transferred to these groups. Specific titles have never been too important in our division.

The engineering division at Caltech is rather unusual in that, unlike at most schools, there are no sharp demarcations separating mechanical, electrical, civil, and aeronautical engineering. Dr. [Frederick C.] Lindvall, the chairman of the engineering division, for many years had the philosophy that we should have as few barriers as possible to impede free exchange amongst the various groups.

BUGÉ: I think that before Dr. Lindvall became division chairman, electrical engineering was part of the division of physics, mathematics, and astronomy.

CAUGHEY: Yes, that is correct. Electrical engineering only became part of the engineering division when Dr. Lindvall became its chairman.

Many of the faculty in engineering have a strong background in physics and mathematics, having been educated as physicists and mathematicians or having had a good grounding in these fields as graduate students. A number of professors in engineering have taught freshman and sophomore physics and mathematics. It was during a time when I and Drs.

Plesset [engineering science] and [Charles H.]Wilts [electrical engineering] were teaching sophomore physics that Professor Feynman decided to do his famous series, "Lectures on Physics." The three of us were invited to help edit the lecture notes, which proved to be a very interesting experience, working with Dr. Feynman and the other editors. The lectures were recorded, transcribed by a team of secretaries, edited by a team of editors, and finally edited by Dick Feynman. The editorial team would check the mathematics, correct the grammar, and take out all of Dick's colloquialisms, which on final editing would have been reinserted by Dick.

It is interesting to note that when Dirac's quantum mechanics was being taught, the only student sections which did not have any difficulty with the subject were the sections taught by the engineers, who taught their students enough of the theory of Markov chains to make the mathematics relatively easy—Markov chains and Markov processes are well known to many engineers within the context of probability and stochastic processes. In this regard, we found that our colleagues in engineering had a somewhat better background in classical physics and applied mathematics than most of our colleagues in physics. Physicists have a tendency to reinvent areas of mathematics, not realizing that it has all been done more elegantly before by other people. I found this to be true of alternate gradient focusing and phase locking in synchrotrons, the mathematics of these problems having been solved many years ago by the nonlinear mechanics community.

BUGÉ: Do you think that this tends to mark science? Could you make a generalization?

CAUGHEY: No, I don't think so. Physics attracts very bright people on the whole. People who go into physics, particularly theoretical physics, tend to be very, very good. To be a physicist means that you have a PhD and that you are probably quite bright; thus the physics community tends to be rather homogeneous. This sometimes leads to a bit of arrogance and the belief that "if it hasn't been done in physics, it hasn't been done." They tend not to look outside of their own field; whereas many engineers who are well educated in science and mathematics have a much broader perspective because they have to deal with a lot of different disciplines.

BUGÉ: Is this true of the professors?

CAUGHEY: Yes, it is true of the professors.

BUGÉ: Are engineering students at Caltech getting the same grounding in the sciences that you got?

CAUGHEY: Yes, in the areas of classical physics and in certain areas of mathematics, they receive a very good grounding. In fact, for many years before the creation of the applied mathematics and applied physics options in engineering, most of our students in applied mechanics and engineering science, for example, had a very strong background in applied mathematics and applied physics. After the creation of these new options, many of our students went into these options, choosing an option whose name more accurately described what they did.

Despite the fact that most Caltech engineers have an excellent background in physics and mathematics, are well educated, and have a strong appreciation of music and the arts, engineers at Caltech are looked down upon by the other divisions. My wife has complained for many years, as have many other wives, that when asked at faculty functions, “In which division is your husband?” and you respond, “In Engineering,” the typical response is, “Oh.”

BUGÉ: Why do you think that this status difference exists? Why do people downgrade engineers?

CAUGHEY: I think that engineers are partly to blame. The engineering community is quite heterogeneous, and the spectrum of abilities is much greater than that in the sciences. A PhD degree is required only for those engineers working in the universities and research institutions. On the whole, engineers tend to be more conservative in their outlook than their colleagues in the sciences, in addition to which they tend to be poorer communicators. The public perceives the engineering community as being a homogeneous group, and engineers make no serious attempt to rectify this misconception.

BUGÉ: Scientists are less conservative and are better communicators?

CAUGHEY: Yes, on the whole that is true. To the scientist, the failure of an experiment may be almost as valuable as one which is successful; whereas, to an engineer, the failure may mean the end of his career. As Professor Theodore von Karman once remarked, "When an engineering project is successful, it is hailed as a scientific triumph, but if it fails, it is castigated as an engineering failure." The nature of their work tends to give engineers a more conservative outlook, which may give them an appearance of dullness and make them less verbal than their colleagues in the sciences.

BUGÉ: That's interesting. I would think that engineers would be just as interested in what works and what doesn't work.

CAUGHEY: That is quite correct. However, many engineering projects must work the first time. There is just no way in which they can be tested beforehand. If you have a billion dollars invested in a project, and it fails and kills eight people, there is no way in which you can walk away saying, "Too bad, but at least we learned some interesting facts." In a way, the engineer gets no credit for his successes and is pilloried for his failures; it is little wonder that he develops a conservative outlook.

I must say that my colleagues and I have always been treated very fairly when we taught for other divisions. Our colleagues in the other divisions share the public perception of engineers and—except on an individual basis—lump us altogether.

BUGÉ: That's interesting, because I've heard the same feeling expressed by people in the humanities here.

Caughey: Unfortunately, I'm sure that's true also.

BUGÉ: It does seem a little bit like Millikan's legacy, that everybody else was kind of second-class, except the scientists, particularly the physicists.

CAUGHEY: Well, there has been that accusation, true or not, that Millikan deliberately kept engineering second-rate compared with physics. However, that doesn't jibe particularly well with the fact that he went out of his way to hire Dr. von Karman, who built our Guggenheim Graduate Aeronautical Laboratory. For many years, a large fraction of important researchers in aeronautics had been trained at Caltech under von Karman.

BUGÉ: But aeronautics is only one small part of the whole package. And I think that Millikan had a wonderful instinct for what was timely.

CAUGHEY: Yes, very true. I think that before World War II the majority of outstanding graduates were in electrical engineering and aeronautics. That situation changed after World War II, when Dr. Lindvall became chairman of the engineering division, and electrical engineering was transferred out of physics. He was able to build a first-rate faculty, which produced outstanding graduates in all the engineering disciplines.

BUGÉ: So you feel that opportunity was not withheld, but that somehow this prejudice lingers on.

CAUGHEY: Yes, that's correct. The engineering profession, as a whole, hasn't done much to counter the public perception. The problem is that if you say you're a physicist, it means something very definite; it means that you have a PhD in physics. Unfortunately, a building superintendent can call himself a maintenance engineer, and a garbage man can call himself a sanitation engineer. The designation engineer is used in such a broad connotation as to be practically useless in identifying the professional engineer.

Another thing that I find distressing is that the Caltech engineers are somehow regarded as not being very cultured. Yet, I would venture to say that more of our Caltech engineering faculty attend classical music concerts and plays, and are as informatively read as, for example, the faculty in humanities and social science.

BUGÉ: Do you say that because the emphasis is now on the social sciences as opposed to what I would consider the classical humanities?

CAUGHEY: Yes, I think it's unfortunate in a way. When I first came to Caltech, the faculty in humanities were gentlemen scholars. I'm not implying that the present faculty are not gentlemen, but the emphasis is different. They don't appear to be as cultured as the people who used to teach undergraduate humanities.

BUGÉ: There does seem to be a great difference of opinion over which would have served Caltech best, to have maintained a tradition of scholars in the sense of gentlemen of learning.

CAUGHEY: Perhaps my engineering conservatism is showing, but I would have liked to see the gentleman scholar retained in addition to the social scientist. Perhaps this is not possible, since it would involve two different yardsticks to measure academic performance.

BUGÉ: Do you think that engineering students enjoy their humanities classes? Because I certainly have the impression that most Caltech students would just as soon not take them.

CAUGHEY: No. I feel, and most of my advisees feel, that it's a change of pace. Most of them do not harbor any resentment at having to take humanities. Most of them regard their courses as being interesting and, apart from the volume of writing they have to do, not too arduous. It's just a different paradigm in which to work.

BUGÉ: I'd like to go back to your engineering science field, because I think that this was a radical change that Caltech was making at that time. I wonder what it was like at the time and how people saw it as it evolved.

CAUGHEY: Initially it was viewed very favorably both here at Caltech and also at many other major universities. It was viewed as a bridge between physics and chemistry on the one hand, and engineering on the other. The biggest problem it faced was that nobody could agree on what constituted engineering science. I think that was perhaps its downfall.

During the sixties and early seventies, particularly during the Sputnik era, engineering science departments flourished at many prominent universities and produced a crop of top-notch students. But with the decline in university fortunes in the seventies, many of these departments were absorbed back into the more traditional disciplines, or simply disappeared.

BUGÉ: What distinguished your education from someone in the physics department who would get a science degree?

CAUGHEY: Very little, I think, except that in my education there was more emphasis on, say, applied mathematics and classical physics and less emphasis on, say, quantum mechanics and modern physics. There really wasn't that much difference. Even today our good students could go to many other good universities and, without much difficulty, earn a degree in physics or applied mathematics. To put it succinctly, the differences between groups in physics or applied mathematics is probably as great, or greater, than the differences between good engineers and physicists or the difference between good engineers and applied mathematicians.

BUGÉ: It seems that the distinction between physics and engineering has widened over the years, even though the work may overlap.

CAUGHEY: Yes, what is regarded as physics at one university may be regarded as engineering at another. A case in point is the kind of work that Amnon Yariv and his group does in applied physics. They do quantum electronics, which is done in physics departments in some schools. Here it is done in engineering.

This can create problems in student programs. We encourage our students to take a subject minor in physics and to take courses in quantum mechanics and modern physics. However, a student working in Yariv's group would not be allowed to take a minor in quantum mechanics since this constitutes a fundamental part of his major studies. Minors are supposed to be broadening and disjointed from the area of major study. It makes one wonder why applied physics is part of engineering and not physics. The distinctions between the two are not really that great.

BUGÉ: Is there an answer?

CAUGHEY: I would hope that all of us would learn a little more tolerance and treat people as people, and not attach labels to them.

BUGÉ: Let me ask you if there are people who stand out in your mind from Cornell or from your education at Caltech, people who were particularly strong influences on you in any way—professors or other students?

CAUGHEY: Dick Feynman was at Cornell at the same time I was. I had the pleasure of hearing both him and Professor Hans Bethe give lectures on quantum electrodynamics. I took a course in numerical analysis from Barney Rosser, who was a logician but had written an excellent book on exterior ballistics based on his work on rocketry during the war. Ed [Dwight F.] Gunder, who was chairman of the mechanics group, taught me dynamics—Gunder worked with Rosser during the war. Harry ["Don"] Conway taught me the theory of elasticity. My old professor from Glasgow University, Gilbert Cook, had been one of the external examiners on Harry's PhD thesis defense at Cambridge University. All the professors I had at Cornell were first-rate.

One of the students who impressed me greatly was Ross [M.] Evan-Iwanowski. Ross, a mathematician by training, had been a member of the Polish air force and spent the war years in a German POW camp. He met his future wife, Hallen, in a displaced persons camp at the end of the war. She was the widow of a Latvian naval officer killed in the war. She had a young son, Serge. Ross and Hallen married, came to the States, and after many hardships and menial jobs, Ross was admitted to the graduate program in mechanics at Cornell. Ross and I translated a number of important Russian papers in mechanics; he was fluent in Russian and did the preliminary translation. I knew some technical Russian, so I was able to help him polish the English. Ross received his PhD in mechanics from Cornell and became a professor of mechanics at Syracuse University. Hallen received her doctorate in French from Cornell and joined the language department at Syracuse. Their son, Serge, graduated from Syracuse University and became an MD—a wonderful success story.

While I was at Cornell, they had recently started an engineering physics degree program. The program, which took five years, was supposed to be a terminal program which would produce students broadly trained in both engineering and physics who would go out into industry upon graduation. The program, which attracted very good students, was somewhat of a failure. All the students stayed on and received PhD degrees in engineering or science.

BUGÉ: PhDs don't generally go out into industry? They stay in research or in education?

CAUGHEY: Most PhDs stay in research or teaching at the universities. Some, however, do go into industry. Industry does not always employ PhDs productively; their talents are often not used to the fullest.

One of the things I've noticed about physicists, chemists, biologists, and lawyers is that they exude a level of confidence about their abilities uncharacteristic of engineers. Perhaps the engineer is more inhibited by the knowledge that he will be held accountable for his actions. I try to encourage my PhD students to develop a sense of quiet confidence in their abilities in the area of their expertise.

BUGÉ: When you left Glasgow, were you aware of a big change in the educational system, the whole approach to education? Or the differences in the students?

CAUGHEY: When I came to Cornell, the thing I noticed was that the first-year graduate students, with some exceptions, were not as well prepared as their counterparts in Europe. But by the time I received my PhD, I noticed that by the end of the second year of graduate school, you couldn't tell the difference in background. The European-trained students had a head start of about a year, but the better American students caught up within two years.

BUGÉ: But they're cut from the pack earlier, I think.

CAUGHEY: Yes, the system is less egalitarian and more elitist.

BUGÉ: By the time you make it to the university, you're one of the elite.

CAUGHEY: That is partly true; however, people of ability can always reach the top. Professor [Andrew] Gray, who inherited Kelvin's Chair of Natural Philosophy at Glasgow, was the master stone-mason who helped build the Gilmour Hill campus when the university moved from its fifteenth-century downtown campus. Kelvin discovered this self-taught man and was so impressed with him that he persuaded the university to admit this forty-eight year old man as a student. The rest is history. Professor [Bernard] Hague, who held the Chair of Electrical Engineering at Glasgow when I was a student, left school at fourteen to become a millwright. He won a Whitworth scholarship to London University, where he received his BS, MS, and PhD degrees. Bernard Hague was a remarkable man, a skilled craftsman, and a talented engineer. He spoke seven languages fluently, played the flute, and was conductor of the university orchestra.

BUGÉ: I think that it's probably a more painful process overall in the States, because you have to go through so many low hurdles, but you never stop going through the hurdles.

CAUGHEY: That is probably correct. However, I've always felt that the American system of graduate education is superior to the European.

During the seventies, we used to get a lot of visitors from Russia, people like V. V. Bolotin from Moscow University. At that time they were interested in trying to introduce into Russia a system more like the American system. Their educational system is modeled after the German—after finishing your formal education, you are assigned to a research institute where you spend three to four years doing research. You don't take any course work; the doctorate is awarded solely on the basis of your research. They felt, as I do, that a system with more formal course work and a reduced emphasis on the thesis would be a more productive way to go. In the past there has been too much emphasis on the thesis at the expense of the general education of the student. The thesis should be just one of the many significant pieces of research the student will do in his or her professional lifetime.

Recently there was a survey of a large number of schools and colleges in which one question asked was, "How many of your graduates have gone on to get a PhD degree, either in one of the fields you offer or in any field?" The three schools which led the list were Caltech, Harvey Mudd, and Reed College—each reporting that close to fifty percent of their graduates had gone on to receive PhD degrees. Harvey Mudd and Reed College are undergraduate schools with virtually no graduate research programs.

Surprising, at first sight, is the fact that only ten percent of the graduates of Harvard University go on to get PhD degrees. The three leading schools prepare students for careers in science and engineering, fields in which more students seek advanced degrees; whereas Harvard educates people in a broad range of fields.

BUGÉ: If the education is so similar in so many ways, what distinguishes the person who will be attracted to engineering versus the person who will be attracted to science?

CAUGHEY: I will give you the traditional answer. The engineer is the person who wishes to produce devices rather than theories. Unfortunately, that is an oversimplification and doesn't quite work at Caltech and many other schools where the engineers produce more theories than devices. In many universities, such as Caltech, the engineer often works in some area of science not represented in the science divisions. For this reason our division at Caltech is called the Division of Engineering and Applied Science. At Harvard it is called the Division of Engineering and Applied Physics.

BUGÉ: What about you? Do you build devices or theories?

CAUGHEY: I've done both. I'm pretty good with my hands, so if my research requires some specialized piece of equipment or electronics not available off the shelf, I'll design and build it. On the other hand, I've done a lot of theoretical work over the years. I find that many good engineers and scientists can do both. There's no need to say that a theoretician is someone who cannot do experiments or that the experimentalist is someone who doesn't understand theory; that just isn't so.

BUGÉ: I have heard that Paul Epstein said that he had absolutely no talent for doing experiments.

CAUGHEY: I can believe that. I have had colleagues who were complete disasters in the laboratory—who didn't know one end of a soldering iron from the other—yet were excellent engineers or scientists.

BUGÉ: I want to ask you about your research.

CAUGHEY: I have always been interested in dynamics, the science of how things move and change in time and space. Since my undergraduate days, my major field of interest has been dynamics. In the process, I have learned a lot about differential equations, which are the equations that govern the behavior of vibrating systems, whether it be mechanical, electrical, acoustical, or quantum-mechanical. All these various phenomena are described by certain differential equations; there's a common thread linking them. In my case, my particular interest was nonlinear stochastic systems, which are systems driven by noise processes. When I was a graduate student I built an analog computer to gain insight into the behavior of nonlinear oscillators under various types of excitation. We observed a lot of phenomena which we didn't fully understand at the time, and which we attributed to a lack of precision in our equipment.

Recently we discovered that the things we observed were manifestations of chaos. This kind of deterministic chaos is characterized by ultra-sensitivity to initial conditions. If you run the experiment with exactly the same initial conditions each time, you will see exactly the same behavior each time. Change the initial condition very slightly, and you may see completely different behavior. This sort of thing was first studied by the French mathematician, Henri Poincaré at the end of the last century, and by George [David] Birkhoff at Harvard in the thirties. Because of better instrumentation, people are now finding that chaos permeates all of life; that any time you have a sufficiently high-order dynamical system, chaos is generic. Thus, a lot of the things we think of as random are not really random at all; they're completely predictable, if only we knew the initial conditions exactly. Most people think of the toss of a coin as an example of a random process—the toss of an unbiased coin yielding heads or tails with equal probability. This is not so theoretically. If we know the initial velocities exactly, we can predict whether we will get heads or tails. Interestingly enough, we can show that as the initial velocities are increased, very small changes in the initial velocities will cause the outcome to switch from heads to tails or from tails to heads. Since we can never know anything with infinite precision, then for all intents and purposes, a coin toss is a random process yielding heads and tails with equal probability.

BUGÉ: Were you associated with earthquake research at one point?

CAUGHEY: Yes, when I returned to Caltech I spent some time working with George Housner and Don [Donald E.] Hudson in earthquake engineering.

BUGÉ: But that was not very long lived?

CAUGHEY: That's correct. Earthquakes are examples of stochastic processes. So after some time I became more interested in the mathematics of stochastic processes and less interested in earthquakes. Dr. Housner has maintained his strong interest in earthquake engineering for almost fifty years and is now recognized as the world leader in earthquake safety.

BUGÉ: In the research that you do now, what sorts of applications might it have?

CAUGHEY: It has implications for earthquake engineering, for rockets during launch and reentry, for vehicles traversing rough terrain, for planes and ships in bad weather, or for any other problem of severe vibration of a random nature.

BUGÉ: Regarding the institute itself, having been here for several years, can you talk about the changes that you've seen.

CAUGHEY: When I came here in 1952, the student body was around 800—approximately 450 undergraduates and 350 graduate students. Over the years, the student body has more than doubled. We now have approximately 800 undergraduates and about 1200 graduate students—the largest increase being in the graduate student population.

Caltech was much smaller, both physically and staff-wise, when I first came here. It was a lot friendlier and small-town, less bureaucratic. Over the years Caltech has become more and more big business with a larger bureaucracy. As my wife points out, when we first came here, Caltech was like a pyramid, with the faculty at the bottom and a very small administration at the top. And now it's like an inverted pyramid with the faculty on the bottom, and the number of administrators escalating as you go up. This, I suppose, is inevitable; the federal bureaucracy requires more and more administrators to handle the ever increasing load of paper work. It's just no longer the close-knit family organization it was when we first came here.

BUGÉ: Did you spend more time socializing with professors and administrators at that time?

CAUGHEY: Yes, it was a friendlier place, and there was more socializing across divisional lines. Over the years it's become compartmentalized, as the various groups have grown, so that one tends to socialize with people in one's own immediate circle.

BUGÉ: Was that even true within engineering?

CAUGHEY: Yes, to some extent. However, since I had taken courses from many of the faculty in engineering, we socialized with many different groups in engineering. In addition, Norman Brooks, Roy Gould and Hardy Martel—fellow students of mine—all received faculty appointments at Caltech. I had a lot of colleagues and friends on the faculty with whom to socialize.

BUGÉ: Do you think that periods at Caltech correspond to changes in the presidencies and the changes in leadership?

CAUGHEY: Only accidentally. I think that we lived in a very affluent, prosperous age when Dr. Lee DuBridge was president. During Dr. Harold Brown's administration, we were in an era of retrenchment. There was a concern for penny-pinching, which affected some of the things which happened during his administration. But as a president, I admired and respected Harold Brown, because within the first two months of his presidency he visited every faculty member on campus and learned about each professor's field of specialization. On subsequent meetings, he would discuss in detail what was happening in one's field. So while some people say that he was cold and impersonal, a lot of us didn't find him that way. He frequently visited with us at lunchtime; he would circulate amongst the tables and was always open to questions and answers and could discuss intelligently anything that was going on at the table.

BUGÉ: That's interesting, because you bring a slightly different perspective to him than I have heard before.

CAUGHEY: With Dr. Marvin Goldberger's presidency, things improved again, largely due to the fact that the financial climate was much better than during Harold Brown's presidency. So I can't honestly say that things change with the presidencies as much they change with the times in which the person happens to be president. However, there were certainly some dramatic changes.

BUGÉ: You talked about how in earlier years, and going on till now, some feeling that the engineers were viewed as second-class citizens or weren't as important as the scientists, particularly the physicists. Do you think that the different presidents have had any influence on that?

CAUGHEY: No, I don't. I certainly think that of the three presidents that I have been associated with, Harold Brown had a greater perception of the place of engineers in society than either of the other two, despite the fact that he was also a physicist. Perhaps his experience as Secretary of the Air Force or as director of a national weapons laboratory placed him in closer contact with engineers.

BUGÉ: So what of the future? Do you foresee a transition in the relative importance of the various divisions?

CAUGHEY: It is always dangerous to indulge in prophesy. One usually predicts the wrong thing at the wrong time. At the present time I feel that traditional physics and engineering are entering a decade of decline. By that I mean that funding from federal agencies will be much more difficult to get. Physics is no longer "king." I believe that biology and certain areas of chemistry are going to be the kingpins in the next decade. There's a strong interplay between chemistry and biology in genetic engineering. Already human insulin is being produced commercially by genetic engineering; and there is every hope that genetic diseases such as sickle-cell anemia will be cured by genetic engineering in the next decade.

There is also serious research in the area of cognitive sciences and computing. How does the brain work as a computer? Can we build a biological computer, so to speak? Certain processes which go on in the human brain—such things as associative memory—can be mimicked by neural networks. Research in this area is being conducted in a program called Computing and Neural Networks, jointly administered by biology and engineering.

There are really two aspects to this kind of research: There is the genetic engineering aspect, where biology and chemistry will play a central role. Then there is the attempt to understand how we recognize patterns and other aspects of brain function. Here biology and computer science play the dominant role. It is interesting to note that this work is being conducted by people like biologist Christof Koch, ex-physicist John Hopfield, and engineer/computer scientist Carver Mead.

BUGÉ: Do you think that it will be possible to mimic the brain?

CAUGHEY: Yes, I believe that we will be able to mimic some aspects of brain function. Already two young Caltech engineers, Yaser Abu-Mostafa and Demetri Psaltis, have built an optical computer which can "recognize" people from a portion of a photograph, using an optical model of associative memory. This is somewhat like the way in which the human memory works. Suppose that you wish to recall a person's name, and you remember that it had something to do with a color—brown, green or white—but don't remember exactly what it was. Associative memory allows us to home in on the desired name—say Greene—using associations. A digital computer requires that you give it the precise spelling of the name, otherwise it won't recognize it. To the computer, green and Greene are infinitely far apart. If, however, you recalled that the name began with "G-R", you might ask the computer to give you a list of names beginning with "G-R" and utilize your own associative memory to home in on Greene. If your computer is smart enough that it could, if asked, give you a list of the names in your computer which are also colors, it could give you a list of names which might jog your associative memory. In all these cases the computer only serves as an adjunct to your associative memory. If digital computers had very, very large memories so that file names could contain associations as well as the basic name, then it would appear that digital computers could be equipped with associative memory. This, of course, assumes that we have a better understanding of how we use associations to store information in our brains.

For number-crunching applications, I think that the present-day computers, or their progeny, will be hard to beat; they do a superb job—so much better than the human brain can. But there are so many areas where the human brain is capable of performing pattern recognition tasks which are far beyond the capabilities of today's computers. For example, if I look around my room and close my eyes, I can visualize the whole room. Furthermore, I can tell if anything in the room has been changed. It would appear that I would have to process billions of pixels to make a comparison of the "before" and "after" views of my room, yet I appear to be able to do this in a fraction of a second—a task which our fastest serial computer would have difficulty doing in any reasonable time. As far as pattern recognition is concerned, the brain appears to act like a massively parallel computer, processing huge amounts of data simultaneously in parallel.

To give another example of pattern recognition—suppose you were to point to a telephone pole and ask a young child, "Is that a tree?" The child would immediately respond, "No, that is not a tree." Yet if I tell my computer, "A tree is an object with a vertical trunk and transverse branches coming off it," the computer would conclude that the telephone pole is a tree. And yet even a little child can tell that it is not a tree. Perhaps we store in our memory some kind of image of every object we call a tree; when we encounter a new object, we compare this new image with the stored images and decide if it is a tree.

BUGÉ: But you would have to teach the computer every single possible mutation of a tree. What if you showed it evergreens and deciduous, and then presented it with a palm tree? It might as well be a telephone pole.

CAUGHEY: Yes, I think that is true of the computer. I think that the brain makes associations between its images of trees to form a composite image of what it considers to be a tree, and what it considers to be a telephone pole. It might not recognize the palm tree as a tree; however it wouldn't mistake it for a telephone pole. At the present time we are unable to mimic many of the functions of the brain, even with the marvelous computers we have today—partly because of limitations of our computers and partly because, in many cases, we have no idea how the brain functions.

BUGÉ: What about artificial intelligence?

CAUGHEY: This is a field which is rapidly expanding and which I think will eventually justify its early promise—though so far it has failed to do so. Many of the things which we like to hold up as examples, such as expert systems, are judged not to be artificial intelligence. But the more you look at some of these problems, the more you begin to wonder what constitutes intelligence and free will. Many times a person will assert that they have made a "free will choice;" yet if you examine all the evidence, you could have predicted what the choice would be. So is it a free will choice?

Gilbert McCann and I once conceived a "hypothesis machine" which was based on Fritz Zwicky's morphological approach. The idea is that you form a large matrix and along one axis you put all the new, unexplained theoretical or experimental observations. Along the other axis you put rational explanations. You then attempt to associate a rational explanation with each observation. The association of an observation with an explanation forms a trial hypothesis. Each trial hypothesis is subjected to logical thought or experiment. If it fails to measure up, it is rejected as ridiculous and discarded; however, no association is rejected *a priori*. You can have a computer generate these associations. In addition, you can form a huge data base of theoretical and experimental facts. Each trial hypothesis the computer generates can then be checked against this database of facts. If they don't check out, they are discarded. If they pass all the tests, they become hypotheses, with which the computer tries to make predictions. The predictions are then checked against the database of facts. If the prediction proves to be false, the hypothesis is rejected. However, if the hypothesis checks out, the hypothesis becomes a theory. This is, as far as we know, the way the human mind works. The mind can and does exercise much more discrimination than we can build into a computer. The human mind can reject many of the trial hypotheses out of hand as being ridiculous, thus reducing the number of hypotheses which have to be examined. To some extent, this is offset by the speed with which computers can make comparisons.

BUGÉ: Well, the computer can't generate theories unless you supply it with the observations and the set of rational explanations.

CAUGHEY: Yes, that is true. But we also supply the same type of information to the human hypothesis machine. It's called the educational process.

BUGÉ: What ever happened to your hypothesis machine?

CAUGHEY: We never seriously considered building it. We did not have the money; and besides, the computers of the seventies had neither the speed nor the memory necessary to implement our ideas.

BUGÉ: You mentioned Fritz Zwicky a moment ago. Who was he?

CAUGHEY: Fritz Zwicky was a rather famous professor of astrophysics at Caltech. He was a very able scientist, who, amongst his many accomplishments, invented the ram-jet engine the Germans used in the V1 or buzz-bomb. Though Fritz held the Swiss patent, the Germans used the engine without his permission and did not pay royalties. More importantly, he was the scientist who coined the word "supernova." He was the first to observe the phenomenon and to give it a name. He and his group at Caltech discovered over 300 of the 600 supernovae which have been discovered to date.

One time he was complaining to me that the University of Maryland had a million dollar grant to write a computer program to find supernovae. During the period of the grant, Fritz said that the computer algorithm had found one supernova for an expenditure of a million dollars, while he had discovered over one hundred at virtually no expense to anyone. So I said to him, "Fritz, if you would tell me the process by which you find them, then I can write a computer program to do exactly the same thing." He stopped, scratched his head, and after some thought said, "Tom, I can't tell you. I don't know exactly how I do it."

I had a similar experience with Professor Richter in seismology/earthquake engineering.

BUGÉ: Charles Richter?

CAUGHEY: Yes, Professor Richter had a seismograph in his home. After a strong earthquake, he would bring the record to Dr. Housner's office to show to the earthquake engineering group. We would ask what and where and when and how big. He would look at the record and say, "A magnitude-eight earthquake in Chile, and it occurred at 8:45 a.m. Pasadena time." When asked just how he was able to extract that information from the record, he would say, "Well, look at the 'p' wave here and the 's' wave there." And I'd say, "But I have looked at the record and I can't distinguish one wave from the other." He was usually correct. The point here is that he was using clues which he had discovered, which helped him analyze the record. He could see things which the rest of us couldn't see. He was unable to explain to us what techniques he used to extract the information—to him it was intuitive. Had he been able to tell us exactly how he did this, we could have automated the process. Asking the right question is knowing half the answer; the only problem is that frequently we don't know the question to ask.

Human beings have excellent pattern recognition capabilities. From an early age we are able to read both printed and cursive writing. The letters may be small or large, thick or thin, well formed or poorly formed—yet even a child has little difficulty reading the message. It is only recently that we have been able to build machines which can read anything but the most highly structured letters. Even now, cursive writing is beyond the capabilities of most computers.

BUGÉ: It seems to me that this is something which a computer should eventually be able to do. A lot of the more profound things that you have discussed—like our cognitive and interpretive abilities—are so interwoven with our emotional network that grows and develops with us through our whole lifetime. I think it's immensely complicated. I think it's probably impossible to reproduce everything a person does.

CAUGHEY: Well, some of us feel that way. We say it's like asking a steam engine to understand thermodynamics. I don't know. It may be a poor analogy, but it seems to get the point across. I think that people in this field have selected pattern recognition as one of the first tasks that they have to solve. Clearly this is something that human beings and animals can do, yet we don't understand how it's done. And at the present time, we don't seem to have a clue as to how to do it.

BUGÉ: I have to admit that this just delights me no end. And that is why I'm biased.

CAUGHEY: Well, I think that it may take an entirely different approach, like the optical computer we mentioned earlier.

BUGÉ: I don't think that people work in the same way as the optical computer. You have an impression in your mind, which may be full of flaws, but you still know which person you're thinking of.

CAUGHEY: Yes. I think that's a good analogy. This is what is called associative memory. For example, you see a recent photograph of a balding man with a moustache and glasses. Yet there is some thing about this picture that enables you to recognize him as the clean shaven boy of eighteen—with a full head of hair—you knew and went to high school with back in the fifties. Despite that altered appearance, there are still features you associate with that eighteen-year-old, and it's this association which enables you to recognize the person.

BUGÉ: And that is reducible to things that you could teach a computer, I understand, but I don't think that's the same thing as saying that the computer could eventually recognize the young man by seeing the photograph of the older person.

CAUGHEY: That is correct. In order for the computer to recognize the young man, it would have to have stored in its memory an image of the young man with which to make the association or comparison. At the present time we don't yet know how to make that association. If we did, then the computer could also make the association. It's the old problem—asking the correct question is knowing half the answer. Unfortunately we don't know what question to ask.

BUGÉ: Yes. Well, I think that's very healthy.

CAUGHEY: Yes, I think it is also. As an engineer/scientist, I think that it would be very sad if everything had been done and if we knew all the answers, and if there were no challenges and opportunities to uncover nature's secrets. Some people regard unknowns as difficulties; we regard them as challenges and opportunities. I think it's wonderful that there are fields which are completely unexplored and which could open up huge new vistas. Many years ago, as a young assistant professor, I taught courses in geometric and physical acoustics; but for some reason there was no student interest in acoustics. So Caltech, MIT, Columbia, and other major schools dropped acoustics. There was a resurgence of interest in the seventies in connection with research in antisubmarine warfare. Getting back to the fifties, Bob Hickling—one of the students in engineering science—and I were very much interested in acoustics. We were fascinated by the work on echo location in bats that had come out of Yale. Both Bob and I had worked for the Royal Navy and were familiar with sonar and radar. Towards the end of World War II we had started to use frequency modulated sonar, where you encode a signature into your transmission so that you can discriminate against echoes from other sources. The incredible thing is that bats have been doing this since time immemorial. In addition, they use similar techniques to those used by the navy; they send out a pulse, then wait, then send out another pulse, and wait. If they get an echo back in the meantime, they immediately send out another pulse. So as they close on the target, they increase the repetition rate because this yields much more accurate information on the target, its location, and its speed.

Living in a sighted world, most of us don't appreciate how differently we would see the world if we had to rely on acoustic radar. In the first place most of the common objects we deal with are huge compared to the wavelength of visible light. We see things primarily by specular reflection, so objects appear quite clearly. In the acoustic world, objects tend to be comparable in size to the acoustic wavelengths, and so refraction and diffraction play a more dominant role than in optics. Objects scatter sound waves, and unless we go to very high frequencies, objects appear blurred and distorted. Unfortunately high frequency sound waves are rapidly attenuated in air and water and can be used only over very short distances. Very high frequencies are used in medical sonar, since distances are small and we wish high definition. Bat sonar operates at moderately high frequencies, around 80 kilohertz, with a wavelength in air of about two-tenths of an inch. In an experiment where an array of wires was placed in front of the bats' cave, the distance between the wires was such that the bats couldn't pass between them in normal flight. They had to turn sideways. The wires were about the diameter of a human hair, so that at 80 kilohertz there was virtually no specular reflection. Yet on leaving the cave in total darkness, the bats would align their wings parallel to the wires and fly straight out of the cave. Interestingly enough, the bats were unable to re-enter the cave because the strong echoes from the walls of the cave completely drowned out whatever signals the bats received from the wires. As far as I know, this interesting phenomenon has never been fully explained. Bob and I speculated at the time that the bats were somehow able to detect and use the changes in the diffraction patterns from the array as they frequency-modulated their sonar transmission. If this is indeed the explanation, it is even more remarkable considering the size of the bat's brain. It would be much easier to accept that dolphins can do similar feats because a dolphin has a large brain, and a large portion of the brain is devoted to acoustic signal-processing. But a bat is a small animal with a relatively small brain. So there are many things that we don't fully understand.

Many acoustic phenomena that we experience every day we accept without understanding. For example, we accept the fact that we can hear church bells even though the church is not in our line of sight. The sound of the bells is diffracted and refracted around the buildings which block our view of the church. If the bells were replaced by a flashing light, we would be unable to see the light because of the intervening buildings. Another common experience which many people have, but never analyze, is that the nature of a broadband sound source, such as a waterfall, changes as you approach it through a grove of trees. If you are some distance away and can't see the waterfall, the sound which reaches you is a combination of the low and intermediate frequencies which are diffracted by the trees. The high frequencies are missing; they are blocked by the trees, just like light. But as you get closer and closer, the sound increases in intensity, as one expects. But as you come out of the trees, the nature of the sound changes dramatically. It now contains a much higher frequency. The nature of the surroundings has changed and the sound is reaching you by direct transmission, and not by diffraction.

BUGÉ: Going back and looking at the long overview of Caltech, from the time you came, have the students changed? Have you noticed any trends in their qualifications or aptitude?

CAUGHEY: Well, one always thinks that the incoming students get better each year. My perception is that their information content is a lot greater and, in many ways, they are more sophisticated than students were in the fifties. However, I don't think that they're any more intelligent. I think that intelligence is something which doesn't change very much. They know a great deal more, and they have been exposed to a great deal more information. We tend to think that today's student is so smart that they should be able to absorb the standard material much faster. This is simply not the case. The human mind can develop at a certain rate, and the mathematical skills which they have to learn take time to mature.

BUGÉ: Do you think that having the student body coeducational has made a big difference?

CAUGHEY: Since I wasn't an undergraduate here, and since I have spent most of my years here in graduate school, I don't feel very well qualified to judge. But as far as I am concerned, I can't honestly say that I notice much difference. I think that the kind of girls attracted to Caltech are not all that different from the boys who come here. I think that student life could be made a lot richer if we could attract boys and girls who have a broader outlook. But that's probably impossible, given the nature of the undergraduate program here. It requires a very special kind of student, a very dedicated student. Caltech is not like most universities, where you get a much broader spectrum of student interests and abilities. I think that the number of girls at Caltech is still too small to have a major impact on student life.

BUGÉ: Evidently high school seniors feel that way also, which has made it difficult to increase the number of girls in the freshman class.

CAUGHEY: That's correct. I think that we have never gotten much above the twenty-percent level. In fact, that was in the early days; I think that it has dipped below twenty percent in recent years.

BUGÉ: Do girls come into the engineering school?

CAUGHEY: Yes, we now have an increasing number of girls in engineering. Of course the major number of girls are in biology and chemistry, two traditional science fields for girls. A few are in physics and mathematics, a few in engineering, and a few in geology and geophysics.

BUGÉ: Are there any women on the engineering faculty?

CAUGHEY: Yes, we have one woman on our faculty at present.

BUGÉ: Do you think that there will be more in the future?

CAUGHEY: I don't know. It's not that we haven't tried. We've tried on a number of occasions, but there aren't too many in engineering. And those that are, are in great demand, if only to fill a minority quota. There are some very capable women out there; there are just not enough to go around. So they tend to get lots of offers.

BUGÉ: That's a very lucrative field at the moment, too. So it must be hard to resist.

CAUGHEY: Yes, that's true.

BUGÉ: I want to go back and ask you what transitions you see for the future. In the past, the presidents have all been physicists. Do you think that engineering and the other disciplines will be taken into account in looking for a new president?

CAUGHEY: I think so. At the present time more than half of the students at Caltech are in engineering, and as I have remarked earlier, biology and chemistry dominate the research scene. So I think it's only natural not to restrict the search to physicists alone.

BUGÉ: Do you have any stories you can tell about people you have known at Caltech?

CAUGHEY: When I came to Caltech in the fall of 1951, Dr. Millikan, although he was retired, was still on campus. He was a distinguished looking elder statesman, going around dispensing peanuts. If you got into a conversation with him, pretty soon he'd pull out a handful of peanuts and offer you one. I'm told by one of my former professors in physics that one evening, as a graduate student, he was burning the midnight oil—a single desk lamp illuminating his student office in West Bridge. About one o'clock in the morning, he heard footsteps coming down the corridor. The door slowly opened and a hand reached in and turned the light off; Dr. Millikan was very cost conscious. My friend didn't have the heart to say anything, and waited in the dark until the footsteps receded down the corridor before turning the light on again.

Another elder statesman was Professor Paul Epstein. He looked very distinguished with his ulster cape and his white beard, the personification of the European professor.

I was about to lament the passing of the eccentric, but we have our own eccentrics as you probably know. You know about E. E. Simmons, our leprechaun, and Dick Gerke, our resident authority on weight and mass.

BUGÉ: Do you have any idea why our leprechaun dresses that way?

CAUGHEY: No, I don't. But my friend and colleague, Don Hudson, says apart from the publicity value, there must be some very good reason for it. He probably figured out that it's cheaper, it's warmer, and it's more comfortable. He is not irrational by any means. You know that he's the inventor of the resistance wire strain gauge, and he has done very well financially.

BUGÉ: You don't think that he's just indulging his eccentricity?

CAUGHEY: I really don't know. I'm always tempted to interject, at this point, that the NFL discovered that their players could keep warm during games back in the Midwest by wearing pantyhose or tights.

He's not offensive. However, he gets some of our seminar speakers shaken up just by his presence at a seminar. He always asks intelligent, thoughtful questions; it's clear that he's a very smart cookie.

BUGÉ: What about Gerke?

CAUGHEY: Dick is a local character who takes the technical distinction between weight and mass very much to heart, and he has taken on—as his personal crusade—educating the world on the proper use of weight and mass. He has even written to the Queen of England to have the British Parliament enact laws which would make it a criminal offence to use weight when you really mean mass.

BUGÉ: One doesn't see people like Epstein or any of the other elder statesmen on campus anymore.

CAUGHEY: We still have Willie Fowler as our elder statesman. I'm glad that we still have a few eccentrics, in the English sense of eccentric. I think that it adds a bit of character to the place.

BUGÉ: When you saw Millikan, did you ever talk to him at any length? Did you get to know him at all?

CAUGHEY: Yes, on several occasions. However I didn't get to know him at all well. He was in his eighties then and enjoyed talking to students. He was quite sharp; not at all senile.

BUGÉ: I heard somebody talk about him presenting a kind of pathetic image on campus at that time.

CAUGHEY: He appeared to me like a man who had difficulty yielding up his authority. It must have been very difficult for a person who has held a position of authority and responsibility to give up the reins to someone else.

The institute has changed quite a bit and not necessarily for the better. I suppose that change is inevitable. I remember when I first came here, we used to decry the fact that Stanford's budget was more than fifty-one percent federal. How soon we all fell into the same trap. Years ago we had more industrial support in engineering than we do now. In the intervening years, government support has increased dramatically. I suppose that industry has adopted the philosophy that if the government will fund university research there is no need for industry to do so also.

BUGÉ: Do you think that could swing the other way?

CAUGHEY: I suppose that it is possible. At the present time it takes three to four times the effort to get a fellowship from industry that it does to get the same level of funding from federal sources.

BUGÉ: And if federal sources begin to dry up?

CAUGHEY: I would certainly hope that that would be the case, but I don't know.

You asked me earlier if I had any stories about Caltech. One of my favorite stories concerns Professor Zwicky. He was a neighbor of mine, and our children were of similar ages. So I got to know him rather well. One day at the Athenaeum, he was boasting about his youngest daughter, Barbara—how smart she was and how well she talked. He would ask her, "What does the dog say?" and she'd reply, "Bow-wow." "What does the cat say?" and she'd reply, "Meow." "And what does daddy say?" and she'd reply, "goddamn."

My former research advisor and very good friend, Don Hudson, was a professor at Caltech for many years. Don has a droll sense of humor. Many years ago we had a civil engineering professor named Alfred C. Ingersoll. Al was quite a character, and the source of many humorous stories. On one occasion Al was telling Don about a serious ear infection he had, and that he had been visiting his doctor for several weeks without improvement. Don, in his usual droll way, jokingly said, "Well, Al, if you figure that your doctor probably knows as much about ears as you know about civil engineering, then it's not too surprising." Although this was said in jest, Al evidently took it to heart, and a week later walked into Don's office and said, "Well, Don, I took your advice. I quit going to my doctor and my ear infection has entirely cleared up."

BUGÉ: Can you think of anybody else?

CAUGHEY: We had on the engineering faculty for many years a dedicated bachelor, Don Clark. There is a scholarship named after him. When I first came to Caltech, he was a real martinet.

All the students, graduate and undergraduate, were afraid of him until they got to know him—his bark being much worse than his bite. I got to know him very well in his latter years when I was chapter president of AAUP [American Associtcase of University Professors], and Don was my secretary. One couldn't wish for a kinder and more generous friend than Don Clark. One day in the early sixties, a good looking male student suddenly started wearing his hair long. Don spotted this student on campus and ordered him to come to his office. The student appeared at Don's office in fear and trembling. Don said to him, "What is the meaning of this? Why are you growing your hair long?" The student replied, "Because the girls like it." Don sat back in his chair for a moment and then said, "My goodness, that's a very good reason."

BUGÉ: In the early days, there were a lot of confirmed bachelors at Caltech.

CAUGHEY: Yes, Dean Earnest Watson, George Housner and Don Hudson. Don married his secretary, Phyllis, which prompted George to remark, "Eternal vigilance is the price of freedom."

BUGÉ: Dean Watson finally married.

CAUGHEY: Yes. Interestingly enough, my wife and Mrs. Watson grew up in Fond du Lac, Wisconsin. My wife's maiden name was Jane Turner and Mrs. Watson's maiden name was Jane Werner. There was frequent confusion over the names, and they would get each other's telephone calls. So we knew Mrs. Watson long before Earnest met her. I got married in 1952, and in 1954 we went home to live in Scotland. The same year, Dean Watson and Jane met for the first time on a cruise to Europe. Shortly thereafter, they were married in Scotland.

BUGÉ: Did the two Janes know each other when they were growing up?

CAUGHEY: Yes. Not intimately, but yes, they knew each other.

BUGÉ: Dean Watson was evidently an interesting man.

CAUGHEY: Yes, he was a very interesting man. He had a very fine collection of early scientific literature and an outstanding collection of early scientific instruments.

As you know, Jane Watson was a prolific writer of children's books—the Golden Book series. Jane is the second faculty wife who is a writer of children's books. Gloria Miklowitz, the wife of my colleague Julius Miklowitz, is also a prolific writer of children's books. She also teaches a writing course at PCC [Pasadena City College].

BUGÉ: Any last thoughts?

CAUGHEY: I think that Caltech is a wonderful place. We're small and cannot do everything that major universities do. We have to be selective; and in the past the things we selected to do, we did extremely well. We have to be very careful not to rest on our laurels. We must constantly be on the lookout for promising new areas to conquer, even if it means giving up some of the older, more traditional areas in which we still excel.

During President Brown's tenure we were in a time of tight finances, a time of retrenchment rather than expansion. As a result, we didn't hire a lot of new faculty. Now we're faced with the prospect that in the next decade we will lose most of our senior faculty; and while we are now recruiting new junior faculty, there are no replacements for the senior faculty. We cannot expect the junior faculty to assume the mantle of the senior faculty, and yet we cannot afford to make too many senior appointments.