J. Presper Eckert

PETER ECKSTEIN

The life experiences of any human influence the way we think and the types of activities in which we engage. This paper examines the early life of J. Presper Eckert, one of the inventors of the ENIAC, and details those experiences which obviously came to influence his contributions to the creation of the ENIAC and subsequent computers.

Introduction

Pres Eckert's father had built several large court apartment buildings in Philadelphia, but one had a troublesome intercommunication system in the lobbies. Operation required several dozen large number 6 batteries, and every month or so a tenant would accidentally leave a phone off the hook, exhausting all of their power, so new ones had to be bought and installed. Pres knew that the latest radios could run on household current because of new devices called "battery eliminators," and he devised a similar approach. He took parts out of some eliminators, worked them into a metal box, and hooked them up to replace the batteries in the intercom system. It worked—and would continue to work for the next 30 years.

John Eckert was very impressed with his son's initial success—but even more when the telephone repairman came by to check the system. John said that his son had replaced the batteries, but the repairman carefully explained that this was impossible: "I've talked to the Connecticut Telephone and Telegraph Company that made this thing, and they've tried to build such devices and can't do it." John replied gleefully: "That's a lot of baloney. My 14-year-old son just did it!" The company sent someone out to investigate, and Pres explained his system. "They were very interested," he recalled decades later. "They got me to design one for them, which they then sold." It was a major triumph.[1]

Pres with his mother, Ethel (right) and his grandmother Hallowell, who told stories of her father, Thomas Mills, who invented and manufactured equipment to make candy and ice cream.

Family Background

Franklin's Philadelphia

Pres Eckert was very much a product of early-20*th* century Philadelphia. With a population of a million-and-a-half, it was still the third-largest city in the country. It still bore the influence of its most distinguished citizen of the 18*th* century, Benjamin Franklin—scientist, statesman, inventor and entrepreneur. Few cities, a long-time resident has noted, have been so heavily "molded by the work and genius of one man." He founded its first library, its first hospital, and its first fire company, and "his exploits continue to be taught in the city's schools with reverence" [78]. Everyone knew that Broad Street had earned its name through Franklin's efforts to have it widened. The printer's trade—in which both of Pres' grandfathers had begun their careers—still retained the prestige of its most illustrious practitioner. Franklin's secularized Protestant Ethic—achievement, honesty, hard work, saving and investment—was still strong. The aphorisms of his *Poor Richard's Almanack* were common place, and the undiluted religious form of that ethic was proclaimed from church pulpits.

Mother's Family

There was inventiveness and entrepreneurship on both sides of Pres Eckert's family tree. His mother was born Ethel M. Hallowell into a old Philadelphia Quaker family. Her mother's father, however, had been Thomas Mills, an immigrant from Scotland who invented machinery to make candy and ice cream and started a company in Philadelphia. At the peak of its prosperity the Mills company had 500 employees and a product catalog as fat as a phone book, and its equipment twisted salt-water taffy on the legendary Boardwalk in Atlantic City.

Ethel's father, Clarence Hallowell, had begun working as a printer, but he eventually became chief bookkeeper in his father-in-law's company. His grandson remembered Clarence mostly as a good tenor who sang with the choirs both of his church and the local Shrine. His brother, James Hallowell, was a more notable character—a Quaker by heritage, who had seen much action as a Marine and eventually was known as the oldest living member of the Corps.

1. Unless otherwise noted, the information and quotations are from the authors' interviews with J. Presper Eckert in 1992 and 1995 and with his childhood friends in 1995. These interviews are noted in the Reference section at the end of the paper.

1058-6180/96/$5.00 © 1996 IEEE

A tall "Old Daredevil Leatherneck" who could down an entire tumbler of whiskey in one gulp, he would be displayed on the stage whenever new ships were dedicated at the Philadelphia Naval Yard.

Ethel Hallowell was raised in a four-story brownstone house on Broad Street. She received a rigorous education at Girls' High School—often ranked with the best private schools in Philadelphia—where she learned exceptional penmanship, spelling and grammar. She very much wanted to go on to college, and her father could have easily afforded it, but he had not gone beyond high school himself and thought college something foolish for a woman. Ethel instead worked for five years as a bookkeeper and office manager at a wallpaper manufacturer, where she used the Spanish she had learned in high school to conduct correspondence with customers in Latin America. After five years she left to marry John Presper Eckert.

Father's Family

John's father, David Eckert, was descended from a Swiss German family who had come to America at the time of the Revolution. He had only a high school education but had established a moderately small printing business in Philadelphia and educated himself through proofreading many books and reading many more for pleasure.

John's mother, the former Carolyn Presper, was the daughter of immigrants from Alsace-Lorraine with both German and French antecedents. They had settled in the Kensington section of Philadelphia and started a moderately successful local dairy. Her father would be remembered as "an optimistic soul" who would interrupt gripe sessions at Thanksgiving to ask whether everyone had had enough to eat and a place to sleep during the past year. When they all agreed they had, he would cut them off with a simple question, "Then what are you complaining about?"

When John Eckert was only nine, however, his mother became sick—probably with cancer. She died after five years, the illness so expensive that it forced David to sell his business. Relaxed and friendly, he was eventually able to eke out a modest living selling insurance, but the initial hardships forced John to become self-reliant from an early age. He dropped out of Central High School after his first day to earn money to help support his father and younger sister. He first worked as a meat carver for a local butcher, then as office boy and process server for a local attorney.

While still a teenager he was befriended by Edwin J. Houston, an eminent electrical engineer and somewhat reclusive bachelor. Houston—together with the even more ingenious Elihu Thomson—had patented the arc light and formed the electrical equipment company that had merged with Thomas Edison's company to become General Electric. The boy would dine every Friday at Houston's large West Philadelphia house, then one of the few fully illuminated with electric lights. Other inventions were even more dazzling. In the basement there were machines driven by coal gas to generate electricity. Along the tall staircase there was a wooden column with removable panels that held wires to bring power to every floor of the house. In the master bedroom there were switches by which Houston could lock all the windows and doors in the house at night—or in the morning could start a fire and boil coffee in the kitchen before the arrival of the servant who would bring it upstairs. John Eckert was fascinated, and he would one day pass on his wonderment to his young son.

John's attorney-employer encouraged him to become a court stenographer, so he obtained a typewriter, a dictionary, and a book on shorthand and taught himself well enough to make a living at it. Still seeking to improve himself, he took correspondence courses for the equivalent of a full high school education and studied drawing so he could become a builder.

Pres with his grandfather, David Eckert, who would read from the family encyclopedia and then discuss the articles with the boy.

He got his start through an uncle—his mother's sister's husband—a noted structural engineer named Howard Richards, who pioneered the use of concrete pilings to support large buildings on ground no firmer than quicksand. Richards' firm would eventually build bridges and the large Philadelphia Terminal for the Reading Railroad, as well as a large hotel in Atlantic City and the courthouse in Camden, New Jersey. His inventiveness would show again, when he pioneered the use of pre-stressed concrete in place of structural steel. John Eckert sought to start in the construction business by putting a $50 down payment on a lot in New Jersey, but he needed $500 more to build a house on it. Richards lent his nephew the money, and it was all the boost the young man needed.

Russell Conwell and Baptist Temple

John Eckert, though raised Presbyterian, was soon drawn to the Baptist church of one of the nation's most charismatic preachers of the Protestant Ethic, Russell H. Conwell. Like Franklin, a native of Massachusetts, Conwell was a young officer in the Civil War who decided first to become a minister and then to become a Northern Baptist. He was called to lead a struggling congregation in Philadelphia and began attracting so many followers that in 1891 he built the giant Baptist Temple. It seated 3,000 worshippers yet soon required extra halls with loudspeakers to reach the overflow crowds. A man of prodigious energies, he also founded three hospitals, and—starting with a night school in the basement of the church—Temple University as a college for working people.

Conwell delivered his famous oration, "Acres of Diamonds"—more than 6,000 times all over the country, donating the millions of dollars he earned to college scholarships. The epitome of the 19*th* Century Gospel of Wealth, it told the story of a farmer in India who sold his large and prosperous lands to spend years searching the world for diamonds, finally drowning himself in Spain when his search proved fruitless and his money ran out. Only then did the man who bought the farm discover diamonds on it and develop the richest mine in the world.

Conwell's moral—adapted to each local audience—was simple: "The opportunity to get rich, to attain unto great wealth, is here in Philadelphia now, within the reach of almost every man and woman who hears me speak tonight." Not only was it possible to prosper, but it is "your Christian and Godly duty" to get rich by finding out what your neighbors need and then supplying it. He cited many examples of new devices and argued that many more could be close at hand: "The great inventor sits next to you, or you are the person yourself."

Conwell also drew inspiration from Abraham Lincoln, whom he had once met during the war. Lincoln's greatness, he concluded, lay in his powers of concentration and determination to finish a job. "Whatsoever he had to do at all, he put his whole mind into it and held it all there until that was all done." [18, 89]

Russell Conwell had a great impact on John Eckert, who taught Sunday School at the Temple. There he met Ethel Hallowell—who, though raised a Quaker, had also been drawn to the church, a mile or so down Broad Street from her home—and married her after a five year courtship. He also followed Conwell's advice to seek more education, earning a law degree at Temple by studying after a long day's work. And—probably following some combination of his own inner lights and Conwell's teachings—he proceeded to seek his own "acres of diamonds" without leaving home.

Impetuous and endlessly energetic—he soon became known as "Johnny Rusher"—Eckert built an increasingly successful construction business in Philadelphia and nearby New Jersey. It could be rough, but he showed the grit to meet its demands. While laying out a new town and rehabilitating an old hotel on Cape May, he carried the payroll for a hundred workers in a money belt. When several would-be robbers threw knives at him, he suspected some of his own men. So he lined them all up, took out a nickel-plated pistol and displayed some imposing marksmanship shooting bottles off a fence from his hip and piercing cans thrown in midair. He carried the gun in a leather holster for years and never again had any more trouble [78].

John Eckert was soon building apartment houses—including the first garden court apartment houses in the East. He also built dozens of large, multistoried garages—public ones for the growing number of cars that Philadelphia's narrow streets could not accommodate, private ones to house the electric delivery trucks of the American Railway Express company. He even opened his own automobile dealership.

Early Years

In 1919—after a dozen years of marriage—Ethel gave birth to their only child, John Adam Presper Eckert, Jr., soon known as "Pres." For his first eight years the family lived in a small townhouse in the Mt. Airy section of Philadelphia, a part of town where the street was still paved with grass lined bricks. With increasing prosperity they moved out toward Germantown, to a much larger house on Cliveden Street with three porches and at least six bedrooms. There they employed at least two live in servants—a woman to clean and cook, a man to maintain the car and garden and to help serve dinner.

Parents' Influence

Ethel Eckert liked to sing and play the piano, though her son recalled her as "not terribly good" at either. Her most serious hobby was painting flowers and fruits onto china dishes and vases, with Pres sometimes helping and John gilding and firing the pieces for her. She often took the boy horseback riding—at one point the family owned 20 horses—and helped in his piano lessons.

During visits to the house Grandmother Hallowell told mouth watering stories that made inventiveness sound especially attractive to a young boy.

Mother and son had an affectionate relationship, but John Eckert was a more powerful influence. The boy idolized him for his energy, his success from a penniless beginning, his "down-to-earth" practicality, his ingenuity, and his personality. "He was a very likable guy, an enthusiastic guy, sort of a life-of-the-party guy." Even on vacations he would organize activities—a fishing trip or group games. "Wherever he was, he was an organizer."

During visits to the house Grandmother Hallowell told mouth watering stories that made inventiveness sound especially attractive to a young boy. She recalled how her father, Thomas Mills, would bring home new contraptions as he invented them, so she could test them out in the kitchen by making candy or cookies. As soon as Pres could read he was perusing old copies of the Mills company's fat catalog to find out which things his great grandfather had invented and which were commonplace.

From an early age Pres had many chances to see his father at work—in his little home office but especially on construction jobs. "He'd take me around and show me the stuff he was building. I watched them dynamite holes in the ground—that was exciting. All kinds of interesting things." The boy asked many questions and was impressed that his father could do any job he assigned his workers—from drawing plans to papering walls or installing wiring. He "had good mechanical sense" and "understood the principles of how roofs were supported and braced and all."

John Eckert's introduction of garden-style apartment buildings was his most dramatic innovation, but on the job he showed little touches of ingenuity that impressed his son. Long before it was conventional, he not only put up a "For Sale" sign on a building before it was sold but put up a "Sold" sign afterwards. When he was planning to build on a site, he would first erect a large billboard with a drawing of the project, giving neighbors several months to register complaints or to suggest improvements.

The boy was especially proud that his father helped his engineer uncle, Howard Richards, design wooden garage roof supports thick enough to withstand fire better than steel, which would buckle. Another builder tried to copy their design, but one of the supports broke while it was being carried into the garage, knocking down a wall, so John Eckert was hired to finish the job.

The father practiced what later became known as "management by walking around." He carried a set of thick builder's crayons, and whenever he spotted a defect he would boldly write on the plaster wall with the color that indicated the kind of workman—carpenter, electrician or plumber—who should address the problem. He also noted each defect in a little notebook to ensure follow through.

"He was sort of a perfectionist and made sure you did it right. You did it over if you didn't do it right. He was tough, but his manner wasn't tough he had a lot of charm, really. He got things done most of the time by people wanting to do the stuff."

At home, as in his work, John Eckert was "internally driven" and "very methodical." In his dresser drawers "all the socks and the shirts were *perfectly* aligned. He was just that way by nature." He was also very punctual, but it was self-taught rather than instinctive. As his son recalled his explanation, "I used to be sloppy about that, but as time went on I realized that that was a phase of my life I'd have to correct, and I have."

Pres posing on a set with silent-screen star Douglas Fairbanks.

One of the father's favorite sayings, invoked whenever the boy put off a task, was "Procrastination is the thief of time." Because both of Pres' grandfathers had originally been printers, he heard many sayings from Franklin, like "A penny saved is a penny earned," and "You may delay, but time will not."

The father was a "whiz" at mental arithmetic. He could multiply large numbers in his head and knew "all the little tricks in arithmetic and some in algebra"—and he taught them to Pres from an early age. For amusement on rainy days the father would challenge his son by calling out numbers and seeing how fast he could manipulate them—and as a result "I became very interested in mathematics." John's knowledge of formal mathematics had stopped with simple algebra, so Pres, as his schooling proceeded, "quickly outdistanced him in that kind of thing."

Sometimes even simple chores taught valuable lessons. If his mother sent him out for a half-dozen items to the small grocery store around the corner, he preferred not to make a written list. Instead, all the way to the store he would repeat the items over and over in his mind—"a bottle of ketchup, a bag of potatoes." He found, he noted, that if "you just repeat these six things often enough on the way to the store, you just won't forget them, because you're turning your short-term memory into a long-term memory."

Pres was spanked no more than once or twice, but occasionally his parents would punish him by making him sit for 15 minutes in the closet on top of a big dictionary. Sometimes when he got angry they would sit him out on the front porch and say, "We've packed your bag, and if you want to leave you can leave. If not, you can come back when you get tired of making the noise." He always came back, as they knew he would.

Russell Conwell had taught that children from rich families grew up to be inexperienced, soft and lazy, that leaving children with education and character was far better than leaving them with money [92]. Pres' parents seem to have heeded the lesson. One of the most important values they taught was that "you've got to *earn* money." They gave him a small allowance but would also pay him for doing jobs around the house.

Conwell died only a few years after christening Pres, whose only personal memory was of the minister giving him his first olive. But his parents spoke of Conwell often and sometimes played a phonograph record of passages from "Acres of Diamonds." In the process Pres derived several strong impressions. First, that the young would be churchman had joined the Northern Baptists not for their theology but because they gave "more freedom to the local parish ministers than any of the other religions he could find." He wanted to be "free to organize to do what he wanted to in his church," and great accomplishments had resulted. Second, Pres once inquired why Conwell had been so successful, and his father replied, "because he was completely sincere. You never had a reason to suspect that anything that Conwell told you wasn't straight from what he believed." Third was the message on the record as he remembered it:

> Don't go rushing around looking for—in his case, a diamond mine—but get to work where you are. You'll probably accomplish what you want to accomplish. Don't follow will-o'-the-wisps, just get to work at what you're going to do and do it.

Education

Both parents valued education and deeply regretted never having had the chance to go to college. Pres also knew how hard his father had struggled to get his legal education. "He was working making a living sometimes supervising a 100 people or more—and going to night school. That takes a lot of guts, but he was a very disciplined guy." His mother showed her thirst for knowledge by taking many adult education courses, including some in French, to supplement her high school Spanish.

As a small child Pres had a speech impediment, and his parents hired an English woman to tutor him in elocution. "She talked me out of this, literally." Her training brought his speaking from worse than average to better than average, and he eventually would go on to win speech and declamation contests in school.

The boy always grew up in the firm expectation that he would go to college. "I never gave it a second thought that I wouldn't." He spent a couple of years in local private schools. Then his parents enrolled him in the prestigious William Penn Charter School, several miles away in the Germantown section, to which the family chauffeur drove him and several other neighborhood boys. It was the country's oldest private boys' school, founded by Penn himself, and it had the reputation of being able to place any student above the bottom 10% of the class in the college of his choice.

Though the children who attended Penn Charter—about 600 in 12 grades—came from many backgrounds, it still had earmarks of its Quaker founders. Every Wednesday morning there was a Quaker-style meeting, where everyone sat silently for some time until someone felt inspired to talk—usually an outside speaker brought in for the event. The long remembered seal on the big desk in the meeting room proclaimed the school's motto, "Good instruction is better than riches." The place was indeed "devoted to good instruction," Pres' friend Alec Randall reflected later.

The long time headmaster, a noted classics scholar named Richard Mott Gummere, later left to become dean of admissions at

Harvard. His cousin, John Flagg Gummere, the head of a national society of Latin teachers, was Pres' home room teacher and counselor. One result was that the boy ended up studying "a lot of Latin I didn't particularly want." But there was a warm relationship between teacher and pupil. "I used to call him the Chief, and he called me the Professor, because he knew I had leanings in scientific areas. He was a tough teacher, but a good teacher." Gummere "would push you to do your best, to get into things, and yet he did it with a lot of humor, so you didn't resent it in any way."

From the beginning Pres was somewhat selective in his academic enthusiasms, eager and alert in mathematics and science but easily distracted in other classes. "He was incredibly sloppy in his homework papers and the way he kept his desk," his classmate Frank Davis recalled, but in math "he was always in the top of the class. That was certainly his forté." He also fondly remembered his friend's "comic side" illustrated by a classroom declamation in an immigrant dialect that kept the class in stitches" [99].

Both parents played a very active role in his education. When he had drafted a composition, his mother would help by reading it over and making suggestions for rearranging paragraphs, improving grammar or changing emphasis. Both parents would help with spelling and language studies and were "very willing to do these things, to take time out." The father had a numeric system for rating how well his son performed. Whatever marks Pres brought home from school, John would first praise him for doing so well and then "talk about what I could do to improve—in a nice way. Not in a way that got me riled, but he was a perfectionist." He would also give the boy extra money if he earned top grades or improved in subjects where he had been weak.

Both parents read books at home, and the house had a full bookcase. Ethel might read in French or Spanish, or sometimes in other languages as well. John had only studied Latin in addition to English, and he preferred reading history to fiction. Once he sat down and read all five volumes of Gibbon's *Decline and Fall of the Roman Empire.* The family also subscribed to several magazines, including *National Geographic* and one called *Travel.*

When Pres was about 10, a friend brought over a children's encyclopedia, but he recalled his parents saying, "This looks like junk. Let's buy the *Encyclopedia Britannica.* It's a little too much for the kid right now, but he's going to grow and let's put something that he has to reach for and not something he can fall over." The strategy worked: "I was always looking up stuff in there," he recalled.

An active participant in the process was Pres' self educated grandfather, David Eckert. During visits he would often sit down and read in the new encyclopedia. Typically he would also read sections to his grandson, and then they would take a long walks in the woods to discuss what they had learned. Often the topics were famous persons—sometimes that other Philadelphia printer, Benjamin Franklin. "I learned quite a lot from my grandfather," he remembered, and was deeply impressed at the old man's determination to keep on learning, which extended well into his nineties.

Cosmopolitan Upbringing

Pres Eckert's childhood was quite remarkable for the variety of people he met and the number of places he visited. The family lived only a block from Connie Mack, the legendary owner-manager of the Philadelphia Athletics, and it was common to meet stars from the team. For business purposes his father belonged to three golf clubs. At one of them one day when Pres was four, his parents coaxed him to have his picture taken in front of a man in knickers and golf cap—President Warren G. Harding. The boy was anxious—"Will the president hurt you?"—but he finally agreed to pose. From Liberty Bond drives during World War I John Eckert had befriended several of the greatest Hollywood stars of the day, and on family trips to California Pres came to know them. Douglas Fairbanks he found to be very warm, while Charlie Chaplin "blew hot and cold." They impressed him less as celebrities and more as "people who set out to do something and did it."

"Basically, they believed in God, and most of the rest of this detailed stuff didn't mean very much to them."

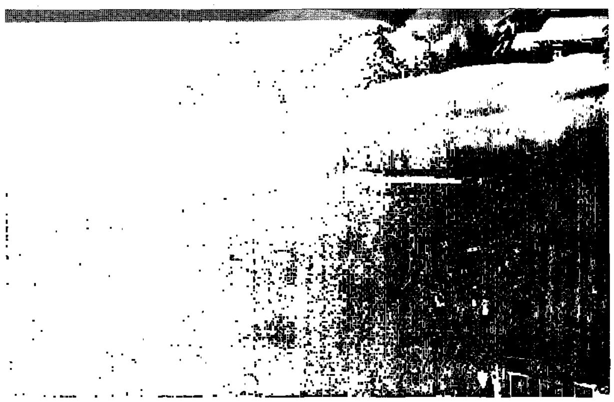
Some close friends of his parents were less famous but came from different cultures. There was a family of Moslems, with whom his parents would discuss the differences between Islam and Christianity, and a Jewish leader of the "Back to Palestine" movement. His parents came to feel that there were no important differences among the world's religions. "Basically, they believed in God, and most of the rest of this detailed stuff didn't mean very much to them." The boy came to share their view. "To me the differences between older religions are a tempest in a teapot." Most of his own playmates in the neighborhood were Jewish, and children from Connie Mack's family were Catholic. Only at school were his classmates predominantly Protestant.

John Eckert did extensive consulting on construction projects, including many in Europe for the American Railway Express company, and he liked to combine business trips with family vacations. From the time Pres was a small boy they traveled extensively, spending an average of four months abroad each year. Trips were usually during the summer, but if the boy would be missing classes, his parents would get materials from school and teach him themselves. By the time he was 12 he had gone more than 125,000 miles, not by airplane but by steamship, automobile, horse, by paddle-wheeler on the Yukon, by mule on the Grand Canyon, and by camel in Egypt and Palestine. He had visited all 48 states plus Alaska and was familiar with most of Europe's great cities and amusement parks including one in Barcelona built on the side of a cliff. For the school newspaper he had written up the adventure of a no holds barred race up the Nile in a wood burning paddle wheeler run by American Express against a coal burning paddle wheeler run by Cook's. He had also grown accustomed to seeing social practices—like interracial couples and half-dressed dancers in Paris—that were not apparent in Philadelphia.

Frequent companions on the overseas trips were John Eckert's aunt and her husband, Howard Richards. As a boy, he recalled later, "I had a funny habit of concentrating on what I was concentrating on and not paying attention to anything else." Richards would tease him by getting his attention by addressing him loudly: "PRESPER! 1, 2, 3, 4, 5, 6, 7, 8, 9, 10!"

One side-effect of all that travel was that he lived much of his childhood in an adult world—with his parents and their relatives and friends. It also broadened him and made him aware of other points of view, possibly encouraging a strong independence of judgment. "I'm not easily snowed by what other people tell me the facts are in a situation where there's any uncertainty. I have to come to my own conclusions."

The family's travels were diminished by the onset of the Great Depression, primarily because there were fewer construction projects on which John Eckert could consult. Otherwise the family did not have to curtail its lifestyle seriously. Just before the stock market crash of 1929 John Eckert, though only 45, was worth a million dollars and decided to retire. He again demonstrated his "common horse sense" by converting most of his properties into money and gold. During the Depression he was forced to repossess some of the buildings he had sold on mortgages, and the hard times eventually would cost him about half his wealth. Still, he would remain far better off than many of his friends, a few of whom lost everything, and he could even help several of them to get restarted in business.



At age 12 Pres won first prize in a Philadelphia science fair with this homemade pond underlain with mobile magnets that permitted him to control the movement of sailboats across the surface in any direction.

Earliest Tinkerings

For Pres Eckert, tinkering began while he was still a toddler. His first memory is of a minor engineering project—seizing a moment when his mother left the kitchen, removing every pot and pan from the cupboards, filling them with water and setting them around the room. When she returned she could not believe he had acted so fast, and "she was well steamed about it."

He began a lifelong fascination with photography when he was only five and his parents gave him his first good camera—made in Germany with a fast *f*-3.5 lens. He used it often, and later, when the body wore out, he saved the lens and mounted it into a Speed Graphic press camera. When he was about 12 he bought another German camera with a French lens, a bellows and a removable back for the insertion of plates or films.

His travels inspired some of his early construction projects. He thought huge ocean liners were "terrific" and with pen knives carved little pine boats and powered them with rubber bands. His father helped him make his first ones, but soon he was on his own. "There were all kinds of different ways to make them, and I made them every way you could." With each new project—and each new voyage—"I got more and more interested in boats." His scope widened when his father let him use a small tool kit from Germany, a leather case containing a single wooden handle but eight different steel inserts—chisels for gouging and blades for sawing and whittling. This general-purpose tool was eminently portable, and it enabled the boy to make things while traveling. Seven decades later he would still keep the set—all eight blades intact and polished—by his bedside.

His father had a small basement workshop with woodworking tools, and while he encouraged the boy to use them, that was not necessary: "I was interested in building things." His happiest boyhood memories of his father were of building things together.

A summer trip out West at about age nine inspired one project. John Eckert set out to demonstrate the "evil statistics" of gambling by recording in a little notebook how many nickels he had put into slot machines and how few he had won. By the end of the trip, however, he had made money, and Pres was forced to learn the lesson by watching other people lose. In the process, however, he became interested in statistics and the mechanics of slot machines. In most states the only legal ones dispensed mints or pieces of chewing gum for a nickel but provided bonuses for winning combinations. Pres played enough machines over the summer to accumulate three cigar boxes full of mints. Back home he built his own, simpler machine to dispense them—using pieces of wood, hunks of tin cans, parts of an erector set, "and anything I could get my hands on."

Pres had an elaborate Lionel standard gauge electric train set, and he soon learned how to make it do things not covered by the instruction manual. His classmate Bob Byren discovered this at Christmas time when they were about 10 and Pres came over to play with the train set in his parlor. Instead of just turning the transformer up and down to regulate the speed of the train, Pres began running wires from one part of the set to another. Soon he had "automated things" so that gates would fly open and shut and lights would flash all over the set. "Geez, what wasn't happening to that poor old train set!" The commotion got so great that the boys were ordered to play outdoors.

When Pres was 12 he undertook a project inspired by a family visit four years earlier to a large amusement area near Paris called Luna Park. There had been many rides and games, but what had really fascinated him was an indoor stall where children could compete by racing little boats on a table top pond. They would turn wheels in front of them to steer their boats through an obstacle course and into a dock. The victor of each trial won a celluloid fish. Pres figured the device worked because—unseen beneath the table—each child's wheel controlled the movement of a magnet that exerted force on a piece of metal on one of the boats. The boy had never seen anything like it—"you couldn't buy it anywhere"—and he saw it "as a challenge to make something like that."

It took him several years to acquire the needed skills. Then, with his father's help he built his own pond—about four feet wide and six feet long—with wooden sides, a bottom of skylight glass, and legs that raised it a foot or so above the basement floor. On the floor beneath he ran two parallel lengths of track from his model railroad, one running sideways at the foot of the pond, the other at the head. Each track bore an undercarriage that supported the opposite ends of a long oak floorboard that ran the length of the pond. On the board was mounted another track that carried a six-inch-high electromagnet on wheels.

Cables of picture wire on pulleys attached to a steering wheel enabled him to guide the floorboard assembly sideways; with switches, wires and a motor and gear box from a Meccano set he could guide the magnet forward and back along the length of the floorboard. Thus, he could maneuver the magnet any place under the tank and control the movement of any one of several balsa wood boats he built with little sails on top and bits of iron on their bottoms. He also took the rheostat from an old battery charger and used it to control the strength of the magnet. By turning down the power he could release his hold on one boat, then maneuver the magnet under another one and get it under control by turning the magnet back to full power.

The device in Paris had only moved boats in two dimensions across the surface of the pond, but Pres decided to do better. He got some hollow celluloid fishes, and he carved a submarine from balsa wood and then cemented iron into the bottoms of each of them. These he could manipulate in a third dimension—varying the power of the magnet to pull them down to the bottom or release them back up toward the surface. By covering the sides of the pond with "mountain paper" from his train set he could hide the mechanisms and make the container look like a little lake.

The elegant project cost him $13 to build—a full half year of allowances. Two dollars had gone to a downtown motor repair shop for winding a coil to his precise specifications. Already very much the engineer, he had it "stuffed with pieces of iron wire—not steel wire, but iron wire longitudinally—to have a core that would have not too much eddy current."

He entered his project in a citywide hobby fair, where it won first prize. For a while it was displayed in a downtown store window, and then it became the centerpiece of his train set in the basement. Six decades later he still had the prize—a rowing machine for exercise—and classmates could still recall their awe at his achievement. "He would sit at this console and make everything work," Robert Byren said, "and it was just fascinating."

Reading was another source of ideas. From the encyclopedia he figured out how to make gunpowder, then he included it in a little bomb—and blew it up remotely with an electric wire. He also got projects from *Popular Mechanics*, which he frequently bought from the newsstand.

His growing interest in tinkering was accented by the fact that he had a "fusion problem" in his eyes that made him see double after a half hour or so at any activity. He could read by alternately shutting one eye and then the other, but it prevented him from being good at baseball or tennis. He could swim well, and he rowed skulls competitively by keeping his eyes shut much of the time. In general, however, it "tended to drive me more off into doing other things," like investigating electronics.

Interest in Radio

Pres' introduction to the world of electronics was one of the most exciting events of his early years, and it came when he was only five. His father brought home a half dozen boxes containing a Freed-Eisemann Neutrodyne radio set. The instrument itself, the earphones, the B battery, the speaker horn, and the driver for the horn were all set up in the living room. Both the six volt A battery and the charger had to go to the basement, where acid spills would be easier to handle, and an antenna went onto the roof. The radio itself had three tuning dials and two rheostat dials, so "it was a real complicated deal to set up a decent radio in those days."

There was much excitement over radio in the early 1920s, perhaps more in Philadelphia than elsewhere. A history of the city recalled that as soon as broadcasting began an outcropping of antennas made city roofs into "a wire entanglement reminiscent of No Man's Land." Local radio stations scored several "firsts," including the first broadcast of a football game and the first children's program—Uncle Wip on station WIP [35]. Every day, it seemed, the newspapers had articles about building a set, improving it or adding extra equipment. Hardware stores, pharmacies, and even grocery stores had parts and equipment on display. At one point Pres even visited Uncle Wip with his father, who was considering buying a radio station. The instrument at home and the aura outside both charged the boy's imagination.

At night atmospheric conditions permitted him to pick up broadcasts from as far away as California, and on weekends his father would let him stay up late as they searched the dial for distant signals. He remembered it as "an excuse for the first time to stay up late with your father and do something. That was a big deal when you were five years old." But there was also the excitement of the phenomenon itself: "Oh, boy, we got this station and it's over a *thousand* miles away. Just think of it, a *thousand* miles away!" Radio, he concluded, "was a magic box to a kid who hadn't seen this before—and it was also magic to his father."

This general-purpose tool was eminently portable, and it enabled the boy to make things while traveling. Seven decades later he would still keep the set—all eight blades intact and polished—by his bedside.

One evidence of his excitement became a family keepsake. When he was still only five the family was dining in a fancy hotel in Atlantic City, and the boy started drawing on the back of one of the big menus. It was a detailed picture of the radio back home, with all the dials, speakers, earphones and batteries—and with musical notes coming out of the speakers. "This was a *major* thing in my life," he explained later. His mother was proud enough to save the drawing all her life.

By the age of seven, Pres undertook his own first exploration of the medium—building his own little radio around a pencil. He wound a coil of wire around the stem, replaced the eraser with a crystal of lead sulfide, and added a thin wire sliding tuner—a "cat's whisker"—and a pair of earphones. At school he wired the device to each of the metal legs of his desk—one side for the ground, the other for the antenna—and listened to it during a class that bored him. The teacher soon figured out what he was doing and made him take it home, but "the other kids thought it was pretty neat."

Each new triumph seemed to deepen his interest in radio. He received a combined Christmas and birthday present of a fancy receiver of his own and spent many hours listening to it. He subscribed to several radio magazines and used their directions to build his own full sized crystal set. Then he answered ads for more elaborate radio kits and built—with a little help from his father—some two tube portable sets.

By his early teens he was building his own phonograph amplifiers, the first ones working conventionally on alternating current. Then, one spring when he was about 13, he was preparing to go to a summer camp in the Pocono Mountains, where the only power would be direct current produced by a generator. He went to a manual and located some special low voltage tubes that could be made to work on DC, then used them to build an amplifier that he mounted on a piece of stained plywood. He took it with him to camp to provide a sound background for showings of movies, which were otherwise still silent. He would prepare for each showing by reading the plot summary that came with the films and selecting appropriate records.

Pres began buying his own radio parts or old radios to cannibalize, haggling for the best deal, first on Market Street in Philadelphia and later on Cortland Street in New York. "It was like buying stuff in the Casbah," he remembered. "You'd go in, and the guy wanted five bucks for something, and you ended up paying

40¢ for it, if you knew what you were doing." He also regularly scoured the large newspaper ads of the Pep Boys Auto Stores, eagerly seeking "super bargains" in electrical parts [47].

Encouragement of Tinkerings

John Eckert took an active role in the boy's tinkerings, helping where he could and providing encouragement. He also placed great stress on finishing projects. In his business, the son recalled, "If you started putting a building up, you *had* to make it work." One of his strongest teachings was, "You can't be a starter without being a finisher," and it impressed the boy deeply. As soon as he entered school he learned a strategy for getting through:

"My father used to say that all complicated things you come up against can be broken down into problems that can be broken down into consecutive steps. He said, 'What you want to be good at is consecutive thinking, learning how to break things down into steps and thinking it through, because the individual steps are probably easy to do. Just because there are a lot of them, you shouldn't get too bowed down by it.' That is, of course, *exactly* what a computer does. He anticipated the computer in his philosophy."

Pres' mother also "always seemed interested in what I was doing." Her one negative reaction came just after a birthday when a relative gave the boy five dollars, and he went out and bought a kit to build another crystal set. To her it seemed like a lot of money to spend, especially since he already had one. Generally, however, though she was not able to help, she encouraged his tinkerings.

In all, Pres was able to look back on a happy childhood. He had been bothered by little arguments his parents might have—over small issues, like over whether to add another porch to the house. But these were only minor disturbances in years of emotional support, economic advantage, and intellectual stimulation—and a growing chain of personal accomplishments.

High School Years

Pres continued into high school at Penn Charter, but took a while to adjust. "I didn't do so well for the first year, and I had to sort of get into it." He was also resolutely selective in the subjects that engaged him, putting far less energy into languages and biology than mathematics, chemistry and physics. His major sports interest was running on the track team, and he rowed without making varsity.

His classmates remember him as medium in height and weight, his face a little round and his body a bit "chunky." He managed his dark, thick, extra long hair with a tonic he concocted himself—once with an overdose of fragrance that "drove us all out of the classroom." He was somewhat shy, still showing the intense powers of concentration that had challenged his great uncle. "He was serious" and "on one track," Bob Byren remembered, "not one to fool around much. I think he was always thinking of other things." Pres was "always busy, going somewhere. He had a little bundle of electric stuff in a book bag," Webb Potts recalled. "He wasn't interested in small talk—just completely focused."

Teachers

The teachers at Penn Charter were generally remembered as good instructors. They were better educated than most of the high school teachers of the day, and a few even had doctorates. Many would take a special interest in talented students, helping with their projects and giving them extra things to read or to think about [102, 103].

Donald McCormick

Pres' most important teacher was Donald McCormick—"Mr. Mac"—a Scotsman who both taught math and coached soccer. Slower students would suffer from his tough, no nonsense approach. One who couldn't give the right answer in class would be quickly passed over with a firm, "Zero. Next." Still, McCormick managed to endear mathematics even to those not originally interested, as when he would take his class into the school yard to measure the height of the flagpole with a theodolite. Even if he did not always make students want to learn, Frank Davis recalled, "he made us learn." When students wrote out a one page proof of a geometry theorem and got any of it wrong, they were required to write out the correct proof five times. "You didn't have that happen very often," Dr. Alexander Randall recalled.

Pres found McCormick to be not only "a very disciplined guy" but also "a warm, caring person" with a personal interest in students, as quick to compliment a good performance as to critique a bad one. Once the boy was attending a fancy school dance, still nervous over a recent tough exam, but Mr. Mac walked over to him and reported he had scored more than 99 percent—the best in the class. He came to regard the teacher as "another father who was interested in math and was good at that sort of thing." McCormick taught not only the usual high school subjects but also a small class in college algebra, differential and integral calculus and solid trigonometry. The teacher also took students beyond the decimal system and introduced them to the binary system—as well as "the trinary system and any other system you want to talk about."

Lawrence Wight

Another favorite was the physics and chemistry teacher, Lawrence Wight, who also coached Pres in track and operated a camp in Maine that he attended for a couple of summers. Wight was down to earth, sometimes gruff, sometimes salty. His knowledge of science was not typically up to the minute, and he sometimes made mistakes in class. Still, Pres would remember him as the best teacher "from the human point of view"—as "one of the most inspirational people." He was enthusiastic about science and told fascinating stories about the history of physics or his own experiences—like trying a chemistry experiment in college and having it blow up. "Whether he remembered the molecular weight of something exactly correctly is not as important as whether he got kids interested in things."

Pres learned about Newton's law of gravity and Maxwell's four equations that described the full range of electromagnetic radiation, including electricity, magnetism, light, and radio waves. From this he drew an important conclusion:

> Most great things that happened in science and mathematics had to do when people discovered unifying principles. Not just, 'How long does it take an apple to fall so many feet' but 'How long does it take anything to fall so many feet under the influence of gravity—apple or what?' The important discoveries were things that had *broad* applicability.

Alec Randall would remember Wight's "talent at making the subject come alive"—first lecturing on it and then letting students see it work in several hours in the well equipped laboratory. He had "a way of egging us on to look into it a little further, to see what further we could figure out." One of Wight's favorite sayings was, "The only difference between a scientist and a citizen is that the citizen sees something happening, then it just goes over his head. The scientist says, 'What the heck was that?' In that sense, Pres was becoming a scientist.

Robert Byren, who had little taste for science, joked later about Pres' growing sophistication in class discussions: "After a couple of minutes of conversation between Doc Wight and Pres they lost me. Then a couple of sentences later they lost the class. And then by the time five or six minutes came around, they lost Doc Wight."

Pres continued to use the *Britannica* for school work, especially term papers. He had accompanied his mother to elegant stores in Paris when she bought perfumes and to the Casbah of Casablanca when she bought vials of essential oils to blend and combine with alcohol. When he was assigned a term paper, he used his experiences and the encyclopedia to write 10,000 words on perfumes. He wrote other papers on the history of science, including one on the light bulb before Edison.

Wight's summer camp had some memorable features—power equipment for woodworking and a two ton truck to carry campers and canoes to the untamed rivers of New Hampshire. But its most unusual activity was the "sport of kings," falconry. The boys caught birds of prey—red tail hawks, peregrine falcons, and goshawks—and trained them to catch smaller birds and ground animals and bring them back. "We were probably among the few people that did falconry in the United States," he reflected later. It was not all biology, however. The campers fashioned small silver bells to put on the birds to keep track of them, and the sport proved an excellent subject for Pres' camera.

Henry Evans

Pres also became close to the biology teacher, Henry Evans, invariably remembered by his students as "Bugs." Evans still limped from an earlier bout with polio, but he rode a motorcycle to work and coached soccer. He made biology interesting to many by drawing on a diversity of strange living creatures and by taking his students on field trips. Pres shared in the general admiration for Evans but was somewhat bored by the subject, often talking in class when he was expected to be listening. The penalty was staying after class to memorize passages from *Alice in Wonderland,* and this only strengthened their bond.

Photography

Pres' growing interest in photography became his strongest personal link to two of his teachers. Mr. Wight was the school photographer and helped Pres improve his skills as they took yearbook pictures together and developed and printed them in a big enlarger in the school darkroom. "Bugs" Evans had a home darkroom that was better designed to process 35 millimeter film, and Pres used it during his school days and even after he graduated from Penn Charter. The teacher encouraged him to do more things in photography and also demonstrated his own hobby of match making—"things that were awfully interesting" to a mechanically minded boy.

Later Pres' friend Alec Randall built a darkroom in his parents' basement, and Pres built his own enlarger. He bought the lens but put together the rest of the device from pieces of wood, tin cans mounted inside each other, and pieces of glass. He also mixed his own developers and fixing baths—with special toners for sepia colors.

Philadelphia and Electronics

Philadelphia itself played an increasing role in Pres Eckert's development, and many of the institutions that helped can be traced back to the protean figure of Benjamin Franklin. He had been the leading electrical scientist of the 18*th* century, and his inventiveness was celebrated at the Franklin Institute, founded in part with money from his estate. It began by promoting mechanical and scientific research and by presenting lectures and exhibitions. A century later its journal was still the most prestigious forum for electrical engineers like Vannevar Bush to publish new ideas, including his early electromechanical analog computers.

When Pres was in high school the Institute moved to palatial new quarters, including a modern museum with halls devoted to mechanisms, steam engines, illumination, aviation, chemistry, and electrical communications [35]. After each visit he would tell his parents "everything I saw in some detail." The things he best recalled in later years were the push button exhibits that let the visitor interact with some striking electrical phenomena. He especially remembered a working model of a wire recorder, invented by Valdemar Poulsen of Denmark nearly three decades earlier but still not in widespread use. "You recorded your voice and could play it back. That was exciting in those days. You couldn't do that anywhere else."

When he was assigned a term paper, he used his experiences and the encyclopedia to write 10,000 words on perfumes. He wrote other papers on the history of science, including one on the light bulb before Edison.

Franklin had also founded a school that eventually became the University of Pennsylvania—a place where Pres would spend nearly a decade and do the most important work of his life.

Whether by coincidence or in part by lineal descent from Franklin, Philadelphia by the 1930s had become the nation's center of research and production in the fledgling electronic industry. Well over half of the nation's radios were produced in the area. Philco (short for "Philadelphia Company") was the country's biggest manufacturer, followed by the RCA Victor Company just across the Delaware River in Camden, New Jersey. A third major producer was the Atwater Kent Manufacturing Company. Philadelphia, Eckert recalled, was then "the heart of the electronics industry."

Exposure to Innovators

In Philadelphia he came into contact with several men who set examples of innovation for the teenager. His great uncle, the pioneering structural engineer Howard Richards, was "a heroic figure of my youth." He was a leader in applying tensor mathematics to the analysis of mechanical stress, and as the boy grew more mathematically sophisticated they would often talk about that work. "It made me realize a lot of stuff that was going on in mathematics had a chance to work in electrical engineering."

The city also gave the boy a chance to meet Major Edwin Armstrong, the inventor of FM radio. In school Pres had read some of Armstrong's articles, and this drew him to a downtown meeting of the Engineer's Club, where a noted German engineer was criticizing Armstrong's mathematics. The inventor himself was sitting in the back of the room, shaking his head during the presentation and afterwards shouting, "You're a god damned liar." Pres already knew enough math to conclude that Armstrong—a pretty intuitive sort of inventor"—had misunderstood the point, and others straightened out the dispute before it escalated. When the meeting was over the head of engineering for the local phone company "dragged me over" to shake hands with the great man.

Pres also learned that innovation can come from unlikely sources. At dinner one evening with the Randalls he met Dr. Kenneth Mees, an English pioneer of color photography and now director of research at Eastman Kodak. Mees told how most unsolicited letters he received contained worthless ideas. He was initially very sceptical, then, when he received one from two professional musicians who were amateur chemists, but their ideas for making color film seemed interesting. He invited the pair to Rochester and then hired them. They stayed for several years and developed Kodachrome, the company's first film for making color slides. When Mees asked them to stay on to help develop a color print film, however, they said they had been away from their music too long and preferred to return to it.

More Tinkerings

The boy's tinkerings grew more intense during his high school years, and generally he worked at them alone. Sometimes he would diagram a circuit and save time by having it wired at an electrical shop downtown. More often he had help from Alec Randall, the other student in his class most involved in science, and the one Pres considered the brightest. Pres was always asking, "Why does this work the way it does"? Dr. Randall said later, "and then trying to do it himself." Two common forms of boyhood tinkering did not fit into the Eckert family lifestyle. Since his father owned an automobile agency, if anything ever went wrong with a family car they simply took it to the shop for repair, likewise, his father had many professional carpenters working for him, so there was little incentive to do that kind of work. Pres got involved only when his father got stuck on a problem—and that was likely to be electrical, most notably when he replaced the batteries in the intercommunication system in his father's apartment building.

Pres bought himself a ham radio receiver—a National FB 7—and built a preamplifying device to increase its sensitivity and selectivity. He also built himself a small transmitter—literally on a bread board, with porcelain insulators to hold the tubes—but he would look back at himself as "a lousy ham." He learned the code, but his real interest was "to build something to make it work," not to chat with other hams. Alec Randall recalled that Pres was much more interested in "trying something out that hadn't been tried before." Once he got a new ham set working he would give it away or sell it and then start building another, more sophisticated one. He would build the chassis in the basement, since drilling holes could make a mess. Then he would bolt and wire the parts in his little ham shack in the attic, increasingly stuffing the old bookcases with electronic parts.

Some of his tinkerings were downright prankish. During the course of a feud with one of his second cousins, who sat behind him in class, Pres filled a rubber bulb with chemicals that, when mixed together, would produce ammonia fumes. At the next sign of aggression—like putting ink on Pres' shirt—he turned around and squirted the fumes in his cousin's face. It brought on chaos in the classroom and a trip to the headmaster's office.

Another experiment almost ended in disaster. There was a chemistry assignment to make a little acetylene gas by mixing calcium carbide and water in a test tube—and then burn off the gas to prove that it had worked. Pres decided to scale the experiment up—from a test tube to a five gallon jar. Luckily the jar did not hold enough air to feed a full scale explosion, but it belched out a dense black flame, filling the entire lab with a stringy soot that clung to the walls, floor and ceiling. For several weeks the boy was forced to spend all his spare time cleaning the lab—and listening to taunts about "Eckert's Folly."

When he was about 15 the school staged a science show for the parents, and his contribution was a radio control box that was passed around the audience. Someone would push the button, and a small bomb on the stage would explode. When the upper grades put on a play, *Wings over Europe*, they staged it at the luxurious Bellevue Stratford Hotel downtown. Pres had a role—but not that of the inventor of a large bomb—and was in charge of setting up the lighting.

He built himself a crude oscilloscope from a kit, but it used "a special shaped neon device in a rotating mirror" rather than the cathode ray tubes in professional devices.

In high school his lifelong interest in music drew him to pipe organs. One of his teachers was a church organist—and Pres used his piano training to play it a little. He took some special note, then, when a few years later the Hammond company developed an electronic version—the Novachord—that contained more than a hundred vacuum tubes and was used to make eerie music in suspense films.

Sometimes Pres' technological devices especially impressed his friends. For a Halloween party at his house when he was about 15 he filled the basement recreation room with his contraptions. There was a ghost that celebrants could push in the belly, turning on a switch that would make its eyes flash and also activate a motor to gently swing a boxing glove onto the chin of the aggressor. There were literally skeletons in the closet, and they would gyrate on a string powered by a motor, while a strange green light threw shadows on them. Six decades later Bob Byren would still remember it as "the haunted house of all haunted houses."

Pres built another impressive device after reading articles about lie detectors. He learned that a full fledged polygraph would measure several reactions, including respiration and blood pressure, but he decided to make a simplified version. It would measure only a single reaction, electronic changes in the surface of the skin, but the one hardest for a subject to control. His subjects would hold in each hand an electrode connected to a circuit that would put a current of constant voltage through their bodies. Pres would have them pull a card out of a deck, return it and then watch as he went through the deck, turning up a card at a time. The machine would then measure the change in voltage that accompanied each card. Pres tried it on more than a hundred people, and for almost all it gave the right answers.

Getting Advice

When it came to electricity and electronics, Pres in his high school years was becoming a tinkerer among tinkerers, and the city offered many places a determined young man could turn for advice.

"Other kids would build radios and things, but I'd get things to work. If it didn't work I'd keep at it until it *did* work and I found out why it didn't work. If I couldn't get it to work I'd find somebody that knew why it didn't work and get him to tell me."

One was also an older ham operator who lived nearby. Once, because Pres didn't fully understand the phenomenon of bias, he messed up an amplifier, and the man was able to explain the mistakes and to recommend some reading. "In every case where this happened," he insisted later, "I went out and got books on it and ended up knowing more about it than the person who had helped me."

For other projects he might start with science teachers at school, but their expertise was limited. One place he sought help was the Franklin Institute technicians—particularly one named Jack West—who put together the fascinating push button exhibits. Eventually the boy reached the point where he was able to provide West with as much advice as he was receiving—"I was getting more educated, and he wasn't." He even helped fix the wonderful Poulsen wire recorder exhibit when it would break down under heavy use.

Sound Systems

Pres continued in earnest his work on sound systems. For himself—and sometimes for fellow students—he built amplifiers of a sort that would later be called high fidelity. Another serious science student, Norman Ball, persuaded Pres to build one for him. It "was kind of a tricky circuit," he recalled, but it worked well for several years. "He was very ingenious and original in his workings with electronics."

Students at Penn Charter were required to spend an hour a week listening to classical records and hearing explanations from the music teacher, but the phonograph gave very poor reproduction. Pres put together a high quality amplifier and speaker system, building his own circuits and buying good parts in the downtown electronics stores that he was coming to know so well. He also built a communications system for the school. He and Alec strung wires through the attic to connect the front office with a versatile amplifier that Pres built for the gymnasium at the other end of the building. During the day it might be used to transmit announcements into the gym. On weekends it could be used to play records for school dances when there was no live orchestra.

During several summers Pres installed sound systems for night clubs, dances, and political events. "It was better than cutting somebody's grass," he reflected. "I made more money, and I learned something that was fun."

His talent soon brought him a thoroughly professional job. One of his teachers knew a local minister who ran the large West Laurel Hill Cemetery in nearby Merion, and it had a problem they thought Pres could solve. The large gas burners used to cremate bodies operated with a noisy blast, disturbing people during services in the nearby chapel, and the minister wanted music to drown out the distraction. Pres built a sound system throughout the whole building and connected it to a phonograph that played records automatically. The loudspeakers were installed in niches in the walls and covered by two inch thick stone grills carved by a stonemason. Pres also created some outdoor chimes to suggest the sound of a cathedral [78].

Eventually Major Armstrong began broadcasting classical music from his original FM station in Alpine, New Jersey, and Pres saw a new opportunity. From a German engineer at General Electric he obtained a fine new double, superheterodyne tuner, and he had a telegraph pole installed behind the cemetery building. He then donned climbing cleats, shimmied up the pole, installed the tuner and pointed it toward Alpine. "It scared the hell out of me," he recalled, but "I got a very good signal." In the end he wrote an article on the project that was published in a cemetery magazine.

Transmitting Sound by Light

From his mentors at the Franklin Institute, Pres learned the idea of using light beams to communicate sound, and he was soon searching out books and articles on the subject. The tower of Penn Charter was visible a mile or so across the Wissahickon Valley from Pres' third floor ham shack at home, so he and Alec Randall set out to transmit between the two points. The idea was to speak into a microphone and use the electrical impulses to modulate a light source that would be beamed to the school. There a photoelectric cell would convert the beam back to electricity, which an amplifier would convert to sound. The scientific principles were well established, but the execution—especially the transmission—might be daunting to the average high schooler.

For a light source they obtained a crater arc tube of the sort used in early mechanical television and facsimile machines to brighten an arc of light by concentrating it into a very small space. To project the beam they got an eight inch lens used in a movie house until it had become too discolored. The system worked, but the boys also wanted to share it with a larger audience. Penn Charter periodically staged an exhibition night to display the activities of its various departments, and in the spring of their senior year Pres and Alec used the occasion to show a smaller version of their system. A neon bulb and a three inch lens were sufficient to transmit a light beam across the stage, but the audience was still impressed.

In 1933 the Eckerts had visited the Century of Progress World's Fair in Chicago. Some non technological exhibits caught the attention of a 14 year old boy—notably Sally Rand doing a fan dance.

Pres also experimented with devices to polarize the light for more efficient transmission, but he did not have sufficient equipment to take all the bugs out of his system. Still it gave him early experience with polarized light that he would put to use later.

Recognition

To Alec and Pres science was "a big factor in our lives in school," Dr. Randall recalled. They were not afraid to be different from their peers, though it limited their circle of close friends. "We weren't all that excited about the social side. The other guys were talking about dates and dances and stuff. We did go to dances, though we weren't that enthusiastic about it." Other students might tease Pres about his tinkerings. Some called him the "mad scientist" or the "absent minded professor"—without his being particularly mad or absent minded—and some followed his Latin teacher in just calling him "the professor." One of the athletes, Bob Byren, thought of Pres as something of a loner, but "a hell of a good guy" who still "got along with everybody." Though he never flaunted his talents, "everybody in the class was aware that he was just a genius" in the physical sciences.

The reactions from their parents were unambiguous. The Eckerts were "astonished to some extent" by their son's electronic wizardry, Dr. Randall remembered, but were quite supportive. Both his and Pres' parents "provided financial backing for some of the goofy things we tried to do," and Alec's physician father often expressed amazement at Pres' talents.

Television

In 1933 the Eckerts had visited the Century of Progress World's Fair in Chicago. Some non technological exhibits caught the attention of a 14 year old boy—notably Sally Rand doing a fan dance—but "my parents didn't try to hold back a child too much." He had also seen the General Electric House of Magic, in which high voltage transformers made huge sparks. Back at the school physics lab he and his friends had been inspired "just for fun" to build spark generating machines based on an old Tesla coil they dug out of the basement.

Most important, however, Pres had seen an early demonstration of a mechanical television system developed by C. Francis Jenkins. It had captured his imagination and soon he was reading avidly anything on the subject he could find in magazines, books and newspapers. In particular he had read about and come to admire Philo T. Farnsworth, who had pioneered important concepts in electronic television while still in high school. The boy was "delighted," then, to learn that on Greene Street—just few blocks away from home—Farnsworth had established a research laboratory, drawn by the city's flourishing electronics industry.

To Pres the lab became a powerful magnet, and its chronic cash shortage gave him many chances to get involved—volunteering to run errands, copy notes, solder parts together, or help in the building of devices. His only tangible reward was a steady flow of discarded parts—a chassis that didn't fit a new design, or old batteries that were not completely run down. "They would give me this junk and I would take it home and do things in my attic with it"—like building a radio receiver or a one octave electric organ.

A more important reward was the chance to work directly with some of the Farnsworth engineers—"the foremost television researchers in the world." One of the most inventive was William Eddy, then in his early thirties, who would later develop the U. S. Navy's extensive program for training electronic technicians for World War II. Eddy was largely deaf, so he built himself a tube that looked like a tobacco pipe but contained a magnetic device that enabled him to pick up sound vibrations through his teeth.

Previous experimental television systems, like the one shown in Chicago, had relied on mechanical devices. Rotating perforated disks or drums covered with mirrors were used in a studio to break down light beams so they could be picked up by a photoelectric cell and then transmitted. Then similar disks or drums were used in home receivers to reconstruct the pictures from the signal. Farnsworth, however, was developing a system using not moving parts but electronic beams—first to scan the image and then to recreate it.

By working in the lab, Pres, while still a teenager, was able to share the excitement of seeing path breaking demonstrations of electronic television. Even when the laboratory left the neighborhood and moved downtown, the boy could get there easily by trolley. He saw one of the first demonstrations of televising the voice and image of a singer—a young woman from Milwaukee later celebrated as "the Incomparable Hildegard." The boy realized even then that television "was only going to be successful without moving parts." That concept would become a major theme of his early career.

Pres did not become close to Farnsworth himself, but he came to admire him even more as "a bright guy, an energetic guy," who had nurtured a dream of practical television. Pres also began reflecting on the moral of Conwell's oration about "Acres of Diamonds." Interesting things were indeed happening right there in Philadelphia.

Entering the Moore School

But it was to the Boston area—to the legendary Massachusetts Institute of Technology—that Pres wanted to go for his next step.

By the time of his senior year at Penn Charter, his self confidence had grown substantially. His skills at tinkering were escalating, and his grades were improving to near the top of his class. His interest, aptitude and training in mathematics were particularly intense. On the math portion of the College Board exams he came in second in the country—and those who came in first and third were also students at Penn Charter. The school gave a special math exam for its own seniors, and here Pres came in first and won a trophy. By the time of graduation many of his fellow students wrote in his yearbook predicting a bright career in science.

As graduation approached, his experience at building sound systems had help define him. "I understood electronics better than I did anything else, except maybe arithmetic and math," he reported later, and he wanted to pursue its applications to entertainment. "He wanted to do something with electronics, and engineering was the natural way to go at it," Dr. Randall recalled. "He was going to go to college and really turn the world on." But as a businessman John Eckert wanted his son to attend the University of Pennsylvania's Wharton School of Business in Philadelphia. Pres himself was only torn between science and engineering, but he knew he wanted to study at MIT, and he was easily admitted.

The frustration of this desire became the most traumatic experience of Pres Eckert's youth. He was an only child, and his mother couldn't bear the thought of him leaving home that early. She persuaded her husband to cook up a story that business reverses during the Great Depression were so severe that they could no longer afford both living expenses and tuition at an expensive college. The only alternative, they explained, was to live at home and attend Penn.

Pres acquiesced, and his father enrolled him at the Wharton School, but within a few days he was thoroughly bored. "It was putting me to sleep," he complained later. "They were grinding over the same ideas about ten different ways in each setting. I thought, 'God, I can't go through four years of this.'" He tried to transfer into the physics department, and his grades were good enough, but all the entering positions were already filled. The department chairman referred him to Penn's Moore School of Electrical Engineering and—with his parents' approval—he enrolled there.

College at The Moore School

Electrical engineering had become a separate school at Penn in 1923 through a large bequest from the Moores, an old line family of Philadelphia wire manufacturers. The school's dean, Harold Pender, had been recruited from MIT and set out to build a strong faculty with an energetic research program, initially concentrating heavily on the generation and distribution of electric power.

By 1937, when Pres Eckert enrolled, Pender had developed The Moore School into a respectable center of research—though still overshadowed by MIT and Cal Tech. Its dozen faculty members were beginning to expand into the more exciting fields of communications and electronics. Its hundred or so students took many classes outside its walls during their first two years. As junior and seniors, however, they converged on its small, two story building on the edge of campus—once the home of the Pepper Musical Instrument Company and now known affectionately as "the Whistle Factory." This relative isolation tended to unify both students and faculty, creating much of the atmosphere of a small school within a large university. The Moore's substantial endowment provided an independence from the rest of the university that few engineering departments ever enjoyed [47, 78, 95]

These features would prove great advantages for the young man, but that was not the way he saw it at the time. Early in his freshman year his disappointment turned to rage when he learned from one of his father's business associates that the story of economic hardship had been a lie. "As a teenager you're trying to become independent," he recalled, "and someone's taking your independence away this way, and it made me angry." He immediately "jumped up and down and yelled" at his mother, but he left it at that, and it did not permanently cloud their relationship. His continuing resentment, however, had an "almost catastrophic effect" on his early performance, and he earned only a D average his first year.

The young man's anger slowly subsided, and he took his studies increasingly seriously. In the beginning he could afford to go easy in math, since after Donald McCormick's rigorous training—most of them were review. Some he took—"just to polish them up some more"—but used extra time in his schedule to endure a few courses in business and accounting at the Wharton School.

One of Pres' favorite professors was Cornelius Weygandt, who remembered first meeting him at an Engineers Day held to attract future students. Pres brought in a piece of test equipment from home that was better than any at the school. "That impressed me," the professor remembered. He was also impressed by a stereo system Pres had built at home and again in electrical machinery class, when Pres and his lab partner asked to do an experiment on transformers without using the unwieldy monsters in the machinery lab. The pair worked instead on a tiny radio transformer from home, which made the task harder, but they "did a good job of it." Weygandt soon came to know his student as a near genius at electronic tinkering. "Not only did he tinker but he knew why—he knew the theory." The professor also noticed a pattern Pres carried over from his earlier schooling. "If he was interested in things, he was top notch. He wasn't interested in electrical machinery," however, and "wasn't a very good student" in it [106].

Pres' most influential professor was Carl Chambers, his advisor and electronics teacher, whose background he admired. Chambers' father, a mathematician, had once been in charge of preparing and grading the very difficult national actuarial examinations. During college Chambers had trained as a statistician, and he could get summer work helping his father grade the exam—but only after he had passed it himself. In the process, Eckert noted, he became "a fine statistician" [28, 31].

Pres had begun college somewhat torn between science and engineering, but he was soon contemplating one of Chambers' sayings: "An engineer's job is to get something done, whereas a scientist's job is to find the truth." Before long his choice was clear—he would be an engineer.

His grades gradually improved. During his sophomore year he earned a C average, then a B, and finally an A in his senior year so in the end he ranked just in the middle of his class. He reserved his worst performances for the subjects in which he was least interested, like English literature. But "in fundamental things like math and physics, I knew what I was doing," and he would proudly recall earning the top mark in Chambers' electronics class. His later partner, John Mauchly, would offer another slant on Eckert's mediocre academic performance: "He didn't make top grades, but some people don't because their heads are so full of interesting things to think about and interesting things to do" [20, 28].

Personal Tinkerings

Some of those interesting things were extensions of his high school projects. To pick up FM broadcasts from Armstrong's Alpine station, he climbed the roof of his house and rigged up an antenna similar to the one he had installed at the West Laurel Hill cemetery. It was better, he reflected later, than any then available commercially. He also made money by installing loudspeakers to play recordings of bells and chimes outside other cemeteries [27].

He had friends at the E. G. Budd Company, a maker of automotive parts and diesel locomotives. They recruited him to help set up a sound system for their exhibit at the New York "World of Tomorrow" Worlds' Fair. As in Chicago there were distractions—a Salvador Dali exhibit of topless women swimming in tanks—but he diligently installed a large set of amplifiers underneath the edge of a fountain, where water would pour in front of them. The adjoining exhibit was by Bell Labs, which featured a "Vocoder," in which each key on a small keyboard would send signals through a large set of vacuum tubes to produce a different human voice sound. He got to know the Bell engineers, who let him operate the device. He learned to punch in sounds for "It's a secret," but it came out like "Eets a SEEK ret."

The Fair greatly increased his interest in electronics and convinced him that it had applications beyond his original area of interest, entertainment. It also made him appreciate the economic importance of technological progress: "If somebody makes an improvement, then somebody who remains the same is going to go down."

Sometimes his own technology played a role in his social life. One afternoon he took some junk parts that had been donated to the university and built one of his first inventions—an "osculometer," or kiss measuring machine.

Just before the outbreak of World War II, RCA built some experimental television sets, and Pres bought one. Philadelphia had the only stations in the country, including one Farnsworth operated from Chestnut Hill. When friends gathered at the Eckert house to watch, the station would sometimes report it had had run out of programming, and some members of the group might go over and act out a play or stage a spelling bee, while others would stay back to watch. "I had a background," Eckert commented later, "of seeing a lot of things beginning to happen in this area" [78].

Sometimes his own technology played a role in his social life. One afternoon he took some junk parts that had been donated to the university and built one of his first inventions—an "osculometer," or kiss measuring machine. To make it work, both partners to the act would grab separate handles, which were wired to an electronic circuit. A current was passed through the couple and amplified to light up a series of bulbs to indicate the extent of their passion. For emphasis, a loudspeaker at the top of the device hooked up with two oscillators to generate a loud sound—"WAH! WAH! WAH! WAH!" He happily tested the device himself and persuaded others to try it as well. It became a fixture at Moore School "record hops" for years [47, 100].

Pres developed considerable involvement with Leeds & Northrup, a Philadelphia maker of instruments so precise that some were built for the Bureau of Standards. A couple of friends from high school days had fathers who were sales executives there, and through them he came to know many of the company's engineers. The most interesting was Al Williams, about 20 years Pres' senior, a "very inventive sort of guy" who designed a single golf club with an adjustable head that could be used as anything from a driver to a putter. Williams and others were developing Speedomax, an extremely fast servomechanism for recording the temperatures of ingots that sped by on the conveyor belt of a steel mill. The device used fancy vacuum tubes to drive a motor that directed a pen to trace variations on a continuous strip of paper. As a result of this contact, "I was very familiar with one of the few places in the world where electronics were being used to solve problems that were not communications or entertainment."

Consulting Projects

Even more interesting things arose because of the relative independence of The Moore School. Its faculty—unlike those in other units of Penn—were able to undertake outside consulting projects. Chambers had several, and he began looking to Pres for part time help. He "really indoctrinated me with being as careful as I was in designs," Eckert recounted. "I did some circuit design for him and he always had me test it for all the variations possible" [31, 100]. From Chambers he learned "that it's worth spending a lot of time in preparation and making sure things are right, both in calculations and in tests first, and that it pays off in the long run" [30].

For Pres this approach reinforced earlier lessons in orderliness from John Eckert and Donald McCormick. Soon, he recalled, "it just fell naturally on me to think about statistical reliability problems in something I built." He began to apply this approach in summer consulting projects for local manufacturing firms.

One of his most challenging came about the time of graduation, when he was asked by the local Barrett Chemical Company to help control their camphor making process. The ingredients had to be heated within a narrow temperature range. When the process was too cool the chemicals did not combine efficiently, but when it was too hot the result was often an explosion so big it would actually blow the roof off the building. The company's engineers could measure temperatures in a test tube, but the trick was to monitor a continuous flow during the manufacturing process.

Pres proposed shining ultra violet light through the material to measure concentrations of the chemicals, but there were still many problems to solve. The material had to be contained in special glass to admit the ultra violet rays, and two layers—one with heating wires embedded—were needed to prevent condensation. The rays were measured with two photocells, which were both expensive and fragile—as Pres once proved when he dropped one after being overcome by fumes from the process. His final device included vacuum tubes, low frequency electronics, and a servomechanism to turn a disk that transmitted the measurements to a recording device built by Leeds & Northrup. In effect, he reflected later, he had built an important element of an analog computer.

A professor involved Pres in a problem for a local test machinery company, the Southwark Division of Baldwin Locomotive. Airplanes flying long distances were developing cracks—a phenomenon later known as metal fatigue—these could not always be anticipated by simple electric gauges. Pres helped design several electronic devices to measure strain on the metal, and the company soon began producing them. One used electronic oscillators that would vibrate at different frequencies to gauge metal stress, while another used photocell devices to measure any actual cracking.

To the young man there were two important lessons from these projects. The first carried over Farnsworth's approach to television—that "whatever you could do without moving parts is a lot more reliable than stuff that had moving parts." The second was "that there are a lot of things you can do with electronics aside from amuse and communicate" [27].

He had one idea that did involve amusement and communication and earned him his first patent. With the advent of talking movies, Hollywood was using expensive galvanometer devices—one from Western Electric, the other from RCA—to record sound mechanically on film. Directly inspired by Farnsworth's development of television without moving parts, Pres figured out a way to record by moving a light beam back and forth across the film—with less distortion of sound quality. Exploring his idea, he devoured all the books and magazine articles he could find on ultrasonics. When developed, this device also worked without moving parts, he recalled, "except for a quartz crystal that vibrated a few millionths of an inch—but that's not really a moving part." Despite its practicality, he could not sell the idea to RCA, and it was never used. "They liked what they were already doing better."

It was not so much his classroom performance, then, as his engineering projects that set Pres Eckert apart. Professor Irven Travis would remember him as "a very brilliant young man," notable for his creativity, his knowledge of electronics and his ability to judge whether or not a project could work [85].

Differential Analyzer at Moore

A unique advantage of The Moore School for Eckert's future work was that it was the only American campus besides MIT to house one of Vannevar Bush's Differential Analyzers. It was electromechanical—a maze of wires, gears, shafts, straps, and wheels driven by an electric motor—it covered roughly 10 by 35 feet at table height. Analyzers were then state of the art in computation, though they could only solve one kind of problem, differential equations.

The school had the machine because in the mid-1930s Pender and Travis had persuaded the Civil Works Administration—a New Deal agency created to help employ skilled workers—to finance the building of two new Analyzers. One would be housed at the Army's Ballistics Research Laboratory at the Aberdeen Proving Ground in Maryland to compute the detailed "firing tables" for artillery cannons. These showed trajectories of shells fired at a full range of angles and were used constantly in the field to aim the weapons. A different table was used for each combination of cannon, shell, and fuse, and different trajectories were needed for each change in temperature, air density, and wind. Calculating trajectory took well over a day on a desk calculator but as little as 20 minutes on the analyzer. The Moore School wanted its own Analyzer to solve problems in power machinery and distribution—but it promised to make the machine available to the Army in a national emergency.

Bush himself had given Travis his latest ideas for improvements over the original MIT machine—and lent the services of his chief draftsman. So from the start the analyzer in the basement of The Moore School—quickly dubbed "Annie"—had been larger and more reliable than the one at MIT. At the same time it was still cumbersome to use. Once operating, it could trace the path of solution to a particular differential equation rather quickly, but setting it up for a new problem could be daunting. Set screws were removed from as many as a thousand gears, the gears transferred to new positions and hammered on, and the screws reinstalled and tightened whenever they proved too loose. The work, Eckert reflected later, could take as long as four days and was more "suitable for an auto mechanic" than an engineer [12, 25, 47, 59, 78, 85, 91].

His own first contact with the Differential Analyzer was rather casual. For homework in a statistics course he would often work all night in the basement on a desk top mechanical calculator. It was laborious and frustrating because, while the machine could add, subtract, multiply and divide, it lacked an extra register to store preliminary results for further use. "I had to copy down numbers on to paper and punch them back into the machine." This seemed "a terrible waste" and "impressed me with the tediousness" of doing problems that way. In the same basement room, however, was the Analyzer, and he soon "became interested in what you could do with this machine just from watching other people use it and talking to my professors" [25, 26].

As his engineering studies progressed he also faced another frustration—the discovery "that after you'd learned all the theory, you couldn't apply most of it because of the calculation problems." It was, he reflected later, "like having a nice larder or a pantry full of canned goods, and you don't have a can opener. Here's all this good stuff up there; you can't get into it." He could describe the behavior of a transmission line with an elegant integral equation, but there was no technique for solving it. "I spent a lot of time looking in every language for solutions to that problem and never found a satisfactory solution" [30].

During his college years, however, his only actual work concerning the Differential Analyzer came because Professor Travis was consulting with General Electric on building a machine for its own use. Travis considered several alternatives to simply duplicating The Moore School analog machine. One would have been digital but still electromechanical—linking together a set of adding machines, with buttons on one machine pushed by signals from another—but a study indicated that the devices would soon fall apart under such intense use. Another would have been analog but electronic—an analyzer with electronic components, including counters of the sort being used by physicists—but it would cost far more than GE was prepared to spend. Travis also developed a third idea—an analog electronic version that would use FM waves to represent the size of variables. He asked Pres for his views on this one, and the young man did some sophisticated mathematical analysis and soon convinced his professor that it was impractical. General Electric did follow Travis' ultimate advice and planned to build its own version of the Bush Differential Analyzer. The company engineers decided, however, to make one major improvement—to replace Bush's mechanical string and band torque amplifier with one controlled by polarized light [16, 54, 85, 100].

On to Graduate School

By the time Pres graduated in 1941 he had acquired an interesting combination of knowledge. He had followed his father's bent by taking some courses in the business school, he had followed through on his own high school interest in mathematics by acquiring enough credits to be a math major, and he had mastered the elements of electrical engineering. Together, he reflected later, they had given him "the three necessary requirements" for a career in computing [25].

As graduation in 1941 approached, he received several job offers. One from the telephone company at $1,600 a year would have been office work sweetened by the prospect of later joining prestigious Bell Labs. Another was from Philco at $1,800—about 50% above the going rate, so high that he had to promise not to tell anyone. A third was doing vacuum tube research at RCA Labs near Newark [26]. None of these inspired him, however, and a recent survey of what Moore School graduates were making 15 years after their bachelor's degrees suggested to him that more education might be useful. When The Moore School offered him a graduate fellowship—tuition plus $400 a year, more than enough for carfare if he continued to live at home—he accepted.

Graduate School

Defense Training Course

One of Eckert's first assignments after graduation was to serve as a teaching assistant supervising a laboratory session in an intensive summer course that The Moore School was operating for the military. It enrolled several dozen physicists and logicians—to refresh their skills in math and physics and to orient them to electronics. One of these students was John Mauchly, the son of a physics researcher and himself a one man physics department at Ursinus College in nearby Collegeville.

Since Mauchly was already familiar with most of the experiments required in the lab, and since few of the other students needed much help, he and Eckert had lots of time to talk. Mauchly was engaged in very data intensive research—trying to relate weather patterns on earth to such phenomena as solar flares. He was convinced that only electronic counters—like those used in physics to count cosmic rays—would be fast enough to help with his problem. But thousands of vacuum tubes would be required for a full scale machine, and many engineers were skeptical that they could all last long enough to operate very long without a blowout somewhere.

Pres had begun college somewhat torn between science and engineering, but he was soon contemplating one of Chambers' sayings: "An engineer's job is to get something done, whereas a scientist's job is to find the truth." Before long his choice was clear—He would be an engineer.

Mauchly and he found, Eckert recounted later, that they had both had "the same degree of frustration" with tedious desk calculators and they "both had a passion to build some kind of computing device." Often they continued their conversations into the night at Linton's restaurant near the university—Mauchly at 34 drinking coffee, Eckert at 22 sipping ice cream sodas, both men scribbling out their ideas on paper napkins. The two "had a lot of fun doing this," Mauchly recalled.

Eckert expressed optimism that vacuum tubes could be used for counters and switches, and Mauchly was impressed: "It didn't scare him to think about something that might have a couple of thousand tubes in it. But most people were scared as hell." Eckert knew that some television sets had 30 tubes, and he had read that the Hammond company's electronic organ, the Novachord, had as many as 160 tubes. But his confidence that thousands of tubes were also possible was also based heavily on his own consulting experience, Mauchly recalled. Eckert "didn't say he knew the answer; it's just that in the kinds of work that he'd been doing, he had to attend all kinds of design problems including reliability." In the process he had developed a "rather rare" viewpoint: "that if you designed the circuits right, you could avoid reliability problems—like tube failures—people were always confronted with."

The young man's extraordinary confidence was a turning point in both their lives. Mauchly "was considerably cheered up because he thought this was a very sensible idea," he reflected later. "If it weren't for Eckert, I probably wouldn't have been encouraged to proceed" [16, 20, 22, 25, 28, 31, 54, 59, 73, 78, 91].

As professors were being called into military service, two vacancies emerged at The Moore School, and Mauchly eagerly applied for one of them. At summer's end Dean Pender appointed him an instructor—along with the only other PhD in the summer course, Arthur Burks, a logician from the Midwest. Though Mauchly had been an associate professor at Ursinus, he readily accepted the lower rank, seeing far greater opportunities and facilities for research, including the school's version of the Bush Differential Analyzer. He spent some of his early time at the Moore school watching it being set up and operated, hoping, he wrote a friend, that "I can outdo the analyzer electronically" [16, 78, 87].

Classes

Eckert continued to take courses in graduate school, and as his knowledge increased so did his self confidence. He became increasingly aware of—and impatient with—the shortcomings of some professors. He generally felt Pender was both intelligent and wise—but was perplexed when the dean required that the equations in a take home exam be solved in matrix notation rather than with the more conventional integral method. "I told him it was outlandish," Eckert recalled, but "he said it was a better way to do it." So the young man tried solving the problems both ways. "It took me 48 hours to do it his way and two hours to do it the conventional way, and he still wasn't convinced."

By contrast, he felt that John Grist Brainerd—who also served as the school's director of research—was in general "a disaster." During classroom lectures Brainerd would simply write on the blackboard all the equations in the textbook for that day's subject. He had apparently memorized the equations, because a typographical error in the book also appeared on the board. "I'd say, 'Dr. Brainerd, that can't be so.' And he'd say, 'Well, it's so and so'" [28, 31].

Beyond his classes Eckert worked as a part time research associate, and his most important education derived from the wide range of projects to which he contributed. His style, an historian wrote, was marked by "brilliance and flexibility." For each problem he "could come up with a variety of solutions" and then examine each "to determine the best one for the particular need" [87].

Magnetic Mine Devices

About the time of the attack at Pearl Harbor, the Navy hired The Moore School to help with an ambitious project—a special plane it had designed to fly near the surface of the water, generating an electromagnetic field to detonate mines and detect submarines. Several faculty members, including Mauchly, were involved in the effort over the next few months. Eckert helped by developing a sensitive amplifier that might help locate mines and subs from very weak changes in magnetic fields. The device was used in experiments at the Philadelphia Naval Yard but probably never in combat. The work, however, left him "very familiar with what intensity of magnetic fields can be produced by what means"—important expertise for his later work on computers [91, 95, 100].

Radar Work

When The Moore School took on a contract for the MIT Radiation Laboratory—the major focus of government radar research—Eckert worked part time on the project, mostly in Philadelphia but sometimes in Cambridge. One of his first tasks was to design a special amplifier to test a switching device, and this gave him his first experience building high speed circuits [31]. He also did some work on oscilloscope design.

His most intensive work was on the problem of measuring time intervals far more accurately. The time a radar signal took to strike an object and bounce back could indicate the distance to the object, and the Rad Lab sought to measure this within one yard in a 100,000 [100]. Eckert was told to improve the time measurement with analog methods, but within a few weeks of trials he decided these could never be accurate enough [26, 31]. He turned instead to the literature on electronic counters—devices that had also intrigued John Mauchly. In a couple of days he and an associate searched all the unclassified library material, including a small book, a few articles in German and French, "which I could stumble through," and a Russian article, for which they found a translator [28]. He then obtained several classified reports and "figured out what they were doing right and wrong." He liked an RCA proposal to the Aberdeen Proving Ground for counters to measure the speed of artillery shells best. "I took their circuit" modified it to get rid of its problems, got its tolerances better, and prevented it from going into false modes of operation" [100].

One timing device of interest to the Rad Lab was a fluid filled acoustical tank recently invented by at Bell Labs by William Shockley, later the coinventor of the transistor. At the same time that a radar pulse was being sent out at the speed of light to bounce off a target and return, a sound wave could be sent down the tank and bounce back from a reflector plate at the much slower speed of sound. The distance to the plate would be adjusted so that the two impulses returned at the same time. This would indicate that the target was as far away as the distance to the reflector plate multiplied by the ratio of the speed of light to the speed of sound.

Eckert was not satisfied that Shockley's device was up to the job. It was a long tank containing a thick fluid—a mixture of water and ethylene glycol, the main component of antifreeze. At the starting end a quartz crystal, comparable to a loudspeaker, converted electronic pulses into sound waves, but when these were echoed back by the reflector they were distorted and weakened.

Eckert already had a strong knowledge of ultrasonics from his work on sound recording for film. He drew on this—and a thorough search of the scientific literature—to propose using a much heavier fluid—mercury.

Then, recalling his boyhood experience of retaining shopping lists in his head by repeating them over and over, he proposed recycling the sound waves rather than echoing them. More information could be stored in the tube, he reasoned, if the sound waves were only moving in one direction. This he accomplished by replacing the reflector with another quartz crystal comparable to a microphone. It could pick up the sound wave and translate it back into electronic pulses, which could then be reinforced and transmitted by wires back to the starting end of the tank. "You feed it back and reshape the pulses and keep putting them through, just like it was when I was a kid going to the store."

The mercury delay line was also interesting to radar researchers at Harvard seeking ways to isolate a real target, like a submarine periscope, from random "noise" on the radar screen, like the movement of ocean waves. The theory was that only the images of hard objects would persist. The strategy was to store the electronic pulses that had generated earlier images and then recall them for comparison with current images. Eckert also built a model of the mercury delay line for the Harvard researchers.

Eckert had begun testing a digital device using counters and delay lines to measure time intervals when he was called to work full time on The Moore School's computer project. His experience was not wasted, however, since later versions of his mercury delay line soon became a standard memory for moving target indicators in radar. More important for our story, he had learned to build high speed electronic circuits and had mastered ways both to build counters and to store electronic pulses. He was a step closer to being able to fulfill the dream that he and Mauchly now shared—building a high speed electronic computer [5, 16, 26, 34, 51, 96, 100].

Improving the Differential Analyzer

Even before Pearl Harbor the Army had exercised its option to take over The Moore School's Differential Analyzer to compute firing tables for its Ballistics Research Laboratory in Aberdeen. New artillery pieces and new shells demanded new tables. The existing analyzer was neither accurate nor fast enough to keep up with the burgeoning work load, and its fussy mechanical parts were being strained by the wartime work load. Indeed, several hundred "computers"—mostly young women who had studied math in college—were being trained at The Moore School to use desk calculators to smooth out the trajectories generated by the two analyzers. One result, Eckert noted later, was that "we became familiar with desk calculators" [25, 78, 91, 106].

Professor Weygandt and a student assistant set out to improve The Moore School analyzer under contract from Aberdeen. Eckert's first role was that of kibitzer. "I just sort of drifted in and had ideas, and the guys in the shop would put them together," but Weygandt "kept getting me in more and more until finally I ended up doing more and he was doing less of it." Under wartime pressure "we worked on the damn thing night and day" and in a matter of a months made major alterations. Instead of having someone crank a pointer along a curve to feed its shape into the analyzer, they added photoelectric cells to track the curve electronically. They replaced the winch-like string-and-band torque amplifiers with a largely electronic device using polarized light and photoelectric cells to read the position of the integrator. The General Electric engineers had pioneered the idea as they planned to build their own analyzer. When they showed Eckert their designs, however, he saw that they were basing their amplification on a GE gas filled triode that had caused headaches for Al Williams as he built servomotors at Leeds & Northrup. Eckert turned instead to another GE product, an amplifying generator he could get from the Army because they were being used to drive gun turrets. Eckert had learned much from Williams over several years, but he recalled proudly that this time the older engineer "came down and looked at what I had done and learned some things he couldn't figure out."

In the end the team added several photocells, 400 vacuum tubes, and more than a dozen servomotors and several amplifying generators. As a result, the machine was 10 times faster and 10 times more accurate. "It was the biggest thing I had done up until then," Eckert recalled. Arthur Burks noted that the project further established Eckert's reputation as "a very able and creative engineer" and "the young expert genius type." Lieutenant Herman Goldstine, a former mathematics professor who was now Aberdeen's representative at The Moore School, had spotted Eckert as "undoubtedly the best electronic engineer" in the place. That reputation eventually extended to the craftsman who ran the school's machine shop, constantly plagued by students asking him to build new devices. He was skeptical when Pres began bringing in blueprints, but he eventually commented, "You're the only one around here who bring things in that work." Pres explained, "That's because I spend a hell of a lot of time first figuring out what it's going to do before I give you a drawing."

The Differential Analyzer was still analog, however, and largely electromechanical, with motors still turning shafts and gears. While further improvements were theoretically possible, they would involve even finer machining of parts and greater control of temperature and humidity. "We were getting close to the practical limits of the machine," Eckert concluded, and the volume of calculations demanded by the Army was still overwhelming. "Further room for improvement would have to be electronic" [26, 28, 31, 40, 54, 78, 96, 100].

Thinking Beyond the Analyzer

Meanwhile, Eckert was holding discussions with Mauchly on how to design a more electronic analyzer. Both men had now had experience with electronic counters, and they considered putting little striped pinwheels on the shafts leading to the integrator and having photocells measure their speed by sending electronic pulses to a counter. The two sketched out such ideas on blackboards at the school or on the backs of envelopes at Litton's all night restaurant. But even with an electronic integrator the machine would still have been electromechanical with many shafts and gears, and it would still only solve differential equations rather than doing general purpose arithmetic. Quickly "we decided that was crazy, if we were going to have all these pulses then we should shoot them directly" though electronic circuits "and get rid of all the gears." They considered counting long trains of pulses and soon decided that would be almost as crazy. Counting to a million would require a million pulses, while in the decimal code it would only take 60 pulses and in a binary code only 20. "So we decided we would code numbers and shoot them around that way in our machine" [26, 31].

... several hundred "computers"—mostly young women who had studied math in college—were being trained at The Moore School to use desk calculators to smooth out the trajectories generated by the two analyzers.

Starting ENIAC

In August, 1942, Mauchly dictated a memo strongly arguing the general concept that an electronic machine—based on the speed of electronic counters—could operate far faster than the Analyzer yet be as accurate as needed. He depended, he recalled later, "quite largely on information about the practicality of this which I gained from talking with Eckert." His ultimate interest was still in studying weather patterns, but he stressed the solution of differential equations used in calculating of artillery trajectories. "You can't sell them weather when what they want is firing tables." He sent the memo to Brainerd, the school's director of research, and perhaps to other faculty members, but he received no response [15, 20, 26, 59].

Mauchly kept talking about the concept, and word soon reached Goldstine, who was representing Aberdeen. He asked for a write up, but no copies of the original memo could be found. Mauchly finally asked the secretary who had typed it if she still had her shorthand notes. She did—and was able to recreate the memo perfectly [59, 91].

Goldstine soon persuaded the Aberdeen high command to ask for a full proposal. Eckert and Mauchly responded, suggesting an all electronic digital analyzer and spelling out the personnel, parts and time they thought they would need. Aberdeen then asked many technical questions and scheduled a meeting within the week. The pair worked night and day revising the proposal—and continued in the car driving to Aberdeen, and then in a back room of the laboratory, feeding new sheets to Goldstine and Brainerd as they met with the high command. By the end of the day the proposal was accepted. Eckert would be chief engineer in charge of planning the work and getting it done. Mauchly would continue teaching but serve as principal consultant, and Goldstine would serve on site as liaison from Aberdeen. Brainerd, as director of all Moore School research, would assume overall administrative responsibility but would play no technical role. It was April 9, 1943—Pres Eckert's 24th birthday [54, 91].

Even before the formal contract was signed Eckert and Mauchly got to work—hiring and training staff, building counters and oscilloscopes, setting reliability standards for components. Eckert immediately went to the RCA Laboratories near Newark, where he knew the engineers who had offered him a job after college, and asked how they would keep thousands of vacuum tubes working reliably. They suggested slightly reducing power levels and turning off the tubes as seldom and as slowly as possible. "We followed their advice," he recalled, "and found it to be substantially correct" [26, 54, 100].

Making General Purpose

When Eckert and Mauchly sold their idea to Aberdeen, the priority had been doing integration to calculate artillery trajectories. But neither man could be satisfied with doing only that. "One of the things that has always interested me very much," Eckert commented later, "is trying to get as much generality as I can in the things that I do" [29]. There was the early example of his father's wonderful set of knives—the single handle with eight attachable blades that made it a general purpose tool. More important were the examples from high school of scientific geniuses who developed very general equations—Newton on gravity and Maxwell on electromagnetic waves. "Because everything in the past that I'd ever heard of that really ended up being worth anything was something that had very general applicability," he wanted the new machine to be "very broad and universally applicable [100].

Mauchly had the same desire, because he wanted such a machine for his weather studies, which required statistical analysis, not integration. The whole logic of Mauchly's memo had been to calculate trajectories by combining a long series of arithmetic operations—addition, subtraction, multiplication and division. It would be perfectly natural, then, to build a machine that could combine these same operations in different ways to solve any sort of mathematical problem. Several of the people assigned to help by the Army were astronomers in civilian life, and they also, Mauchly remembered, wanted a machine that "could do lots more than just compute firing tables." Final ratification came when the Moore team proposed calling the machine an Electronic Numerical Integrator. Colonel Paul Gillon of Aberdeen added the words "and computer," so that no one later could complain about the extra cost of making it general purpose. Thus, the acronym went from "ENI" to "ENIAC"—and it stuck [59].

About the time the ENIAC contract was signed The Moore School awarded Eckert his master's degree, but by then it was only a minor event of an exciting summer.

Acres of Diamonds

Despite all his initial anger at not being allowed to go off to Boston, staying in Philadelphia and attending The Moore School proved to be one of the luckiest turning points in Pres Eckert's career. The presence of the Differential Analyzer made computing a centerpiece of the school's intellectual life; yet there was not the deep personal investment in analog technology that made Bush's disciples at MIT scoff at the ENIAC proposal when Aberdeen asked them to evaluate it [40, 82]. Even more important, the Analyzer brought Aberdeen to The Moore School. When wartime demands for computation exploded, it was The Moore School computing firing tables—not MIT exploring the cutting edge of radar technology—that felt the pressures. So it was at The Moore School that a desperate Lieutenant Goldstine would be handed—and would seize—a speculative new idea to break the logjam. "I don't think anybody would have given a young kid 24 years old all this money to do something if there hadn't been a war on or some emergency," Eckert reflected later. And this particular emergency was being felt far more keenly in Philadelphia than it was in Boston.

The presence of the Differential Analyzer had also helped draw John Mauchly to The Moore School. Only a quirk in timing—the departure of two professors immediately after Mauchly finished the summer course—permitted him to be hired to teach, something that would never have happened at the more competitive MIT. He was a dreamer, a scientist's son obsessed with an idea, who needed a doer—in this case a builder's son with a passion for building imaginative and reliable electronic devices—to fulfill his dream. Both recognized that the other had played an indispensable role in the project they undertook together.

"As it turned out," Eckert reflected later, his mother "did me a favor" when she conspired to keep him at home. The Moore School "at that juncture was probably the best place I could have gone to college in the world" [28, 100]. Russell Conwell had been right. ENIAC did not bring either man "great wealth," but for Pres Eckert, whose greatest joy was designing and building new things, there really were "acres of diamonds" right "here in Philadelphia." ❑

References and Bibliography

[1] F.L. Alt, "Archaeology of Computers—Reminiscences, 1945 1947," *Communications of the ACM*, vol. 15, no. 7, July, 1972, pp. 693-694.

[2] William. Aspray, *Computing Before Computers*, Ames: Iowa State University Press, 1990.

[3] William Aspray, *John von Neumann and the Origins of Modern Computing*, Cambridge: The MIT Press, 1990.

[4] Isaac L. Auerbach,"A Tribute to John William Mauchly," *Communications of the ACM*, vol. 23, no. 3, March, 1980, pp. 144-146.

[5] Isaac L. Auerbach, J. Presper Eckert, Robert F. Shaw, and C. Bradford Sheppard, "Mercury Delay Line Memory Using a Pulse Rate of Several Megacycles, " *Proceedings of the I.R.E.*, Aug. 1949, pp. 855.

[6] Stan Augarten, *Bit by Bit: An Illustrated History of Computers*, London: Unwin Paperbacks, 1984.

[7] Becky Barna, "He Was an Idea Sparker," *Datamation*, March, 1980, pp. 55.

[8] Harold Bergstein, "An Interview with Eckert & Mauchly," *Datamation*, April, 1962, pp. 25-30.

[9] Edmund Callis Berkeley, *Giant Brains: or Machines That Think*, New York: John Wiley & Sons, 1949.

[10] John G. Brainerd, "Genesis of the ENIAC," *Technology and Culture*, July, 1976, pp. 482-488.

[11] John G. Brainerd, "Comment by J. G. Brainerd," *Annals of the History of Computing*, Oct. 1981, pp. 391-392.

[12] J. G. Brainerd, and T. K. Sharpless, "The ENIAC," *Electrical Engineering*, vol. 67, Feb. 1948, pp. 163-172.

[13] Arthur W. Burks, "From ENIAC to the Stored Program Computer: Two Revolutions in Computers," in N. Metropolis, et al., eds., *A History of Computing in the Twentieth Century*, New York: Academic Press, 1980, pp. 311-344.

[14] Arthur W. Burks and Alice R. Burks, Interview with Nancy Stern, June 20, 1980, copy at Charles Babbage Institute, University of Minnesota.

[15] Arthur W. Burks and Alice R. Burks, "The ENIAC: First General Purpose Electronic Computer," *Annals of the History of Computing*, vol. 3, no. 4, Oct. 1981, pp. 310-399.

[16] Alice R. Burks and Arthur W. Burks, *The First Electronic Computer: The Atanasoff Story*, Ann Arbor: University of Michigan Press, 1988; paperback edition, 1989.

[17] Paul E. Ceruzzi, *Reckoners: The Prehistory of the Digital Computer, From Relays to the Stored Program Concept 1935 1945*, Westport, Conn.: Greenwood Press, 1983.

[18] Russell H. Conwell, *Acres of Diamonds, and Robert Shackleton, His Life and Achievements*, New York: Harper and Brothers, no date.

[19] James W. Cortada, *Historical Dictionary of Data Processing: Biographies*, "Eckert, John Presper, Jr.," pp. 77.

[20] John Costello, "The Little Known Creators of the Computer," *Nations Business*, Dec. 1971, pp. 56-62.

[21] John Costello, "He Changed the World," *The Washingtonian*, Dec. 1983, pp. 82-100.

[22] Anne Dewees, "Mauchly was his own Man," *Datamation,* March, 1980, pp. 56-58.

[23] The Office of Charles and Ray Eames, *A Computer Perspective: Background to the Computer Age*, New Edition, Cambridge: Harvard University Place, 1990.

[24] J. Presper Eckert Jr., "A Survey of Digital Computer Memory Systems," *Proceedings of the I.R.E.*, Oct. 1953, pp. 1393.

[25] J. Presper Eckert Jr., "In the Beginning and to What End," *Computers and their Future*, Richard Williams and Partners, Llandudno, Wales, 1970, pp. 3/1-3/24.

[26] J. Presper Eckert Jr., Interview with Christopher Evans, Philadelphia, 1975, copy at Charles Babbage Institute, University of Minnesota.

[27] J. Presper Eckert Jr., "Thoughts on the History of Computing," *Computer,* Dec. 1976, pp. 58-65.

[28] J. Presper Eckert Jr., Interview with Nancy Stern, October 28, 1977, copy at Charles Babbage Institute, University of Minnesota.

[29] J. Presper Eckert Jr., "The ENIAC," in N. Metropolis, et al., eds., *A History of Computing in the Twentieth Century*, New York: Academic Press, 1980,. pp. 525-539.

[30] J. Presper Eckert Jr., "Development of the ENIAC: Session One," interview with David Allison, Smithsonian Videohistory Program, Feb. 2, 1988.

[31] J. Presper Eckert Jr., "ENIAC: The Electronic and Numerical Integrator and Computer," *The Computer Museum Report*, Summer, 1986, pp. 3-6.

[32] J. Presper Eckert Jr., "In the beginning . . ," Interview with George Harrar, *Computerworld,* Special Section: Celebrating the Computer Age, Nov. 3,1986, pp. 3.-10

[33] J. Presper Eckert Jr., "What Hath He Wrought?," interview with David R. Brousell, *Datamation,* March 15, 1991, pp. 30.-31

[34] A.G. Emslie, H.B., Huntington, H. Shapiro, and A.E. Benfield, "Ultrasonic Delay Lines II," *J. Franklin Inst.*, vol. 245, Feb. 1948, pp. 101-105.

[35] Federal Writers' Project, Works Progress Administration for the Commonwealth of Pennsylvania, Philadelphia: A Guide to the Nation's Birthplace, Philadelphia: William Penn Association of Philadelphia, Inc., 1937.

[36] Editors of News Front, "Computers Come of Age," *The Fifty Great Pioneers of American Industry*, Classics edition, Maplewood, N.J.: Hammond, Inc., 1964, pp. 200.

[37] W. David Gardner, "Will the Inventor of the First Digital Computer Please Stand Up?," *Datamation,* Feb. 1974, pp. 84.

[38] W. David Gardner, "The Independent Inventor," *Datamation,* Sept. 1982, pp.12-32.

[39] Frederuc Golden, "Big Dimwits and Little Geniuses," *Time,* Jan. 3, 1983, pp. 30.

[40] Herman H. Goldstine, *The Computer: from Pascal to von Neumann*, Princeton: Princeton University Press, 1972.

[41] Laura Greene, "J. Presper Eckert," *Computer Pioneers*, New York: Franklin Watts, 1985, pp. 36-37.

[42] William H. Harris, and Judith S. Levey, eds., *The New Columbia Encyclopedia*, New York: Columbia University Press, 1975. "Franklin Institute," pp. 1001.

[43] Joseph G.E. Hopkins, ed., *Concise Dictionary of American Biography*, New York: Charles Scribners' Sons, 1964.

[44] Harry D. Huskey, "The Development of Automatic Computing," *First USA Japan Computer Conference, Proceedings*, Tokyo, 1972, pp. 698-704.

[45] T.R. Kennedy Jr., "Electronic Computer Flashes Answers, May Speed Engineering, " *The New York Times*, February 15, 1946, pp. 1, 16.

[46] Tom Lewis, *Empire of the Air: The Men Who Made Radio*, New York: Edward Burlingame Books, 1991.

[47] Herman Lukoff, *From Dits to Bits: A Personal History of the Electronic Computer*, Portland, Oregon: Robotics Press, 1979.

[48] Albert Nelson Marquis, ed., "Mauchly, Sebastian Jacob," *Who's Who in America*, vol. 15, 1928 1929, Chicago: A. N. Marquis Co, 1928.

[49] John W. Mauchly, "The Use of High Speed Vacuum Tube Devices for Calculating," typed memo, Aug. 1942; reprinted in Randell, 1975, pp. 329-332.

[50] John W. Mauchly, "Large Scale Digital Computers and the Weather," *IRE Almanack*, Philadelphia, May, 1958.

[51] John W. Mauchly, Interview with Harry Wulforst, October 26, 1961, typescript.

[52] John W. Mauchly, Deposition in Sperry Rand v. Control Data Corporation, U. S. District Court for the District of Maryland, taken in Philadelphia, Oct. 11,1967

[53] John W. Mauchly, "Resume: Education and Experience of John W. Mauchly," Special Collections, Van Pelt Library, University of Pennsylvania, Philadelphia, April, 1971, typescript.

[54] John W. Mauchly, "Mauchly on the Trials of Building ENIAC," *IEEE Spectrum*, April, 1975, pp. 70-76.

[55] John W. Mauchly, "Amending the ENIAC Story," *Datamation,* Oct. 1979, pp. 217-224.

[56] John W. Mauchly, "The ENIAC," in N. Metropolis, et al., eds., *A History of Computing in the Twentieth Century*, New York: Academic Press, 1980,. pp. 541-550.

[57] John W. Mauchly, Interview with Anne Dewees, *Datamation,* March, 1980, pp. 58-60.

[58] John W. Mauchly, "Letter to Henry Tropp, September 28, 1978," *Annals of the History of Computing*, vol. 4, no. 3, July, 1982, pp. 245-247.

[59] John W. Mauchly, "Fireside Chat, november 13, 1973, " *Annals of the History of Computing*, vol. 4, no. 3, July, 1982, pp. 248-254.

[60] John W. Mauchly, "In the beginning . . . ," interview in *Computerworld,* 5th Anniversary Edition, June 22, 1992.

[61] Kathleen R. Mauchly, "John Mauchly's Early Years," *Annals of the*

History of Computing, vol. 6, no. 2, Apr. 1984, pp. 116-138.

[62] M.M. Maynard, "Eckert, J. Presper," Ralston and Reilly, eds., 1983, pp. 581.

[63] Daniel D. McCracken, "John W. Mauchly: 1907 1980," *Communications of the ACM*, vol. 23, no. 3, March, 1980, pp.143.

[64] N. Metropolis, and J. Woriton, "A Trilogy on Errors in the History of Computing," *First USA Japan Computer Conference, Proceedings*, Tokyo, 1972, pp. 683.-691

[65] Clark R. Mollenhoff, *Atanasoff: Forgotten Father of the Computer*, Ames: Iowa State University Press, 1988.

[66] C.N. Mooers, "Atanasoff at the Naval Ordnance Laboratory," *Annals of the History of Computing*, vol. 15, no. 2, 1993, pp. 54.

[67] R. Moreau, *The Computer Comes of Age: The People, the Hardware, and the Software*, translated by J. Howlett, Cambridge: MIT Press, 1984.

[68] Ted Nelson, "John Mauchly, 1907 1980," *Creative Computing*, March, 1980.

[69] Jon Palfreman, and Doron Swade, *The Dream Machine: Exploring the Computer Age*, London: BBC Books, 1991.

[70] Angeline Pantages, "Computing's Early Years," *Datamation,* Oct. 1967, pp. 60-65.

[71] Anthony Ralston, and Edwin D. Reilly Jr., eds, *Encyclopedia of Computer Science and Engineering*, New York: Van Nostrand Reinhold Co, Second Edition, 1983.

[72] Brian Randell, *The Origins of Digital Computers: Selected Papers*, second edition, New York: Springer Verlag, 1975.

[73] David Ritchie, *The Computer Pioneers: the Making of the Modern Computer*, New York: Simon & Schuster, 1986.

[74] J.M. Rosenberg, *The Computer Prophets*, New York: Macmillan, 1969.

[75] Linda F. Runyan, "A Master of Understatement," *Datamation,* May, 1980, pp. 84-85.

[76] Linda F. Runyan, "40 Years on the Frontier," *Datamation,* March 15,1991, pp. 34-38.

[77] T.K. Sharpless, "Design of Mercury Delay Lines," *Electronics*, Nov. 1947, pp.134-138.

[78] Joel Shurkin, *Engines of the Mind: A History of the Computer*, 1984; paperback edition, New York: Washington Square Press, 1985.

[79] Robert Slater, "John V. Mauchly and J. Presper Eckert: The Men Who Built ENIAC," Chapter 7 of *Portraits in Silicon*, Cambridge: The MIT Press, 1987, pp. 65-79.

[80] Jill Smolowe, "John W. Mauchly, a Coinventor Of the First Electronic Computer," *The New York Times*, Jan. 9, 1980, pp. D 12.

[81] Nancy Stern, "John William Mauchly: 1907 1980," *Annals of the History of Computing*, vol. 2, no. 2, Apr., 1980, pp. 100-103.

[82] Nancy Stern, *From ENIAC to UNIVAC: An Appraisal of the Eckert Mauchly Computers*, Bedford, Massachusetts: Digital Press, 1981.

[83] George Winchester Stone Jr., "John W. Mauchly: A Reminiscence of youthful days with him in Chevy Chase," typescript.

[84] *Time,* "Milestones: Died, John W. Mauchly, 72," January 21, 1980.

[85] Irven Travis, Interview with Nancy Stern, Oct. 21, 1977, Paoli, PA, copyright, Charles Babbage Institute.

[86] Trial testimony, Honeywell, Inc., v. Sperry Rand Corp. et al, no. 4 67 Civ. 138. D. Minn. Filed May 26, 1967, decided Oct. 19, 1973. General Services Administration, Federal Records Center, Chicago. 1971.

[87] Henry S. Tropp, "The Effervescent Years: A Retrospective," *IEEE Spectrum*, Feb. 1974, pp. 70-79.

[88] Henry S. Tropp, "Mauchly, John William," Ralston and Reilly, eds.,1983, pp. 933.

[89] Alan M. Webber, "Acres of Diamonds," *Harvard Business Review*, May June, 1990, pp. 222.

[90] Dilys Pegler Winegrad, "ENIAC: The Age of Information Begins ...," *ENIAC: A Tribute*, University of Pennsylvania, 1986.

[91] Harry Wulforst, *Breakthrough to the Computer Age*, New York: Charles Scribner's Sons, 1982.

[92] Irvin G. Wyllie, *The Self Made Man in America: The Myth of Rags to Riches*, New Brunswick, N. J.: Rutgers University Press, 1954.

Author Interviews

[93] Kay Mauchly Antonelli, by phone from Ambler, PA, Jan. 2, Jan. 21, Feb. 5, and March 11, 1995.

[94] J. Norman Ball, by phone from Torrence, CA, Jan. 27, 1995.

[95] Arthur and Alice Burks, Ann Arbor, MI, Dec. 28, 1994.

[96] Arthur Burks, by phone from Ann Arbor, Jan. 24, 1995.

[97] Britton Chance, by phone from Philadelphia, Jan. 9, 1995.

[98] Joseph Chapline, by phone from Newbury, NH, Feb. 4, 1995.

[99] F. Davis, by phone from Vence, France, Feb. 19 and March 11, 1995.

[100] J. Presper Eckert, Gladwyne, PA, March 21, 1992; by phone from Gladwyne, Jan. 12, 1995; by phone from Bryn Mawr, PA, Feb. 19, 1995; by phone from Gladwyne, Feb. 28, 1995.

[101] Herman Goldstine, by phone from Philadelphia, Jan. 29, 1995.

[102] J. Webb Potts, by phone from Dunnellon, FL, Jan. 19, 1995.

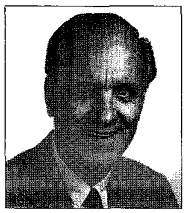
[103] Dr. Alexander Randall, by phone from Abington, PA, Feb. 6, 1995.

[104] George Winchester Stone, by phone from Bethesda, MD, Feb. 12, 1995.

[105] Mauchly Westphalen, Cocoa Beach, Florida, Feb. 27, 1995.

[106] Cornelius Weygandt, by phone from Philadelphia, Jan. 2, 1995.

[107] Augustine Winnemore, by phone from Bethesda, MD, Feb. 14, and March 12, 1995.



Peter Eckstein has a master's degree in sociology and a doctorate in economics, both from Harvard University. He is currently writing a book on the early lives of a dozen computer pioneers, of which this article is a chapter in progress.

He can be contacted at
2103 Charlton
Ann Arbor, MI
313.994.1397