The Women of ENIAC

W. BARKLEY FRITZ

A group of young women college graduates involved with the ENIAC are identified. As a result of their education, intelligence, as well as their being at the right place and at the right time, these young women were able to perform important computer work. Many learned to use effectively "the machine that changed the world" to assist in solving some of the important scientific problems of the time. Ten of them report on their background and experiences. It is now appropriate that these women be given recognition for what they did as "pioneers" of the Age of Computing.

Introduction

Many young women college graduates were involved in various ways with ENIAC (Electronic Numerical Integrator And Computer) during the 1942–1955 period covering ENIAC's pre-development, development, and 10-year period of its operational usage. ENIAC, as is well-known, was the first general purpose electronic digital computer to be designed, built, and successfully used. After its initial use for the Manhattan Project in the fall of 1945 and its public demonstration in February 1946, it evolved during 1947–1948 to become the first operating stored-program computer. This paper relates the stories of some of the ENIAC women: their background before ENIAC, how they became involved, what they did, how they felt about what they were doing, and, briefly, what they did after their ENIAC experience.

During the time period covered by this paper, 1942–1955, women were seldom involved in the design of hardware. However, both men and women were employed as computers (in this era, a computer was a person who did computing). In my 1994 *Annals* paper [1], in a section titled *ENIAC People*, I included the names of 23 of the women who were in various ways associated with ENIAC. Many more women were employed as computers, developing the firing and bombing tables needed during World War II—the specific application that led to the contract by the Army Ordnance Department to the Moore School of Electrical Engineering of the University of Pennsylvania to design and build ENIAC. Several men originally involved as civilian computers by the Army were drafted. The job of computer was critical to the war effort, and women were regarded as capable of doing the work more rapidly and accurately than men. By 1943, and for the balance of World War II, essentially all computers were women as were their direct supervisors.

Six of these women computers became the original group of ENIAC programmers. Goldstine [2] identifies these women as the Misses Kathleen McNulty, Frances Bilas, Betty Jean Jennings (incorrectly identified by Goldstine as Elizabeth Jennings), Elizabeth Snyder, Ruth Lichterman, and Marlyn Wescoff (incorrectly listed by Goldstine as Marilyn Wescoff). Many of their personal accounts of the time during the development and early use of ENIAC are features of this paper.

As you read these recent (essentially 1995) accounts of activities of some 50 years ago, you will note some minor inconsistencies, which are to be expected. In order to preserve the candor and enthusiasm of these women for what they did and also to provide today's reader and those of future generations with their first-hand accounts, I have attempted to resolve only the more serious inconsistencies. Each of the individuals quoted, however, has been given an opportunity to see the remarks of their colleagues and to modify their own as desired.

As ENIAC evolved to become the first operating stored-program computer (or as the PBS TV series described it, "as the machine that changed the world"), additional women were hired to serve as ENIAC programmers. Several of their accounts are also included. We have little or no additional information to include on some of these women.

Computer-Assisted Problem Solving

To help set the stage for "the women of ENIAC" and what they did, it is appropriate to discuss briefly the technology of scientific problem solving at the time—the period just before the introduction and use of "high-speed" scientific electronic computers. An applied mathematician, or other applied scientist, developed a "solution" to the problem at hand in an analytic mathematical format. This mathematical model, representing the general solution, then had to be computed for individual parameters. Often the general solution included mathematical functions, already previously calculated for a wide range of parameters and published in generally large books called tables. Those readers who were educated before the general availability of hand-held calculator/computers and personal computers will remember their well-used "books of tables." To determine specific answers, the computer (at the time still a person) needed to "look up" specific values in these tables and incorporate them with other parts of the evolving "solution" to get the specific desired results. Electric calculators, the slide rule, and the differential analyzer were all used.

The evaluation of complicated expressions required the computer (still the individual person doing the computing) to perform arithmetic operations on values expressed in 8, 10, or even more significant places. Fortunately, during the years of the Depression of

1058-6180/96/$5.00 © 1996 IEEE

the 1930s, the U.S. government had funded the development of very accurate "function tables" of many of the required data in a tabular format. The resulting tables, often published under federal government auspices, proved to be extremely useful to the Army, the Manhattan Project, and other World War II activities. The availability of these tables in part contributed to the Army's success in employing the women computers to generate accurate firing and bombing tables. The Appendix to my earlier paper [1] includes examples of ENIAC's later use to create additional tables of this type.

Tabular data or analytic expressions were needed for the accurate computation of ballistic data. For example, representations of atmospheric effects (e.g., the influence of air density and temperature) on the path (i.e., the trajectory) of the shell or bomb were required. ENIAC itself was designed with hardware called function tables, capable of storing such tabular data for use in firing table generation. As ENIAC evolved to become a stored-program computer, these function tables were used to store program instructions. After 1947, the trade-off decision between the storage of data or the recomputation of an analytic expression representing the data was made by the women programmers, as part of the programming process. Such decisions continue as a part of the programming process to some extent even today

Also crucial to obtaining computer solutions was the use of numerical techniques used in obtaining numerical solutions of both ordinary and partial differential equations, interpolation, infinite series, and other such tools as contained, for example, in Scarborough [3], the first edition of which was generally available to the ENIAC women. A sidebar covers other mathematics of computing textbooks available, circa 1943.

Mathematics of Computing (textbooks generally available, circa 1943)

1. E.T. Whittaker and G.N. Watson, *A Course of Modern Analysis*. The original German edition was published in 1902. The classic fourth edition was published in English, Cambridge University Press, 1927. An introduction to the general theory of infinite processes and of analytic functions, with an account of the principal transcendental functions.
2. K. Knopp, *Theory and Application of Infinite Series*. A classic published in German in 1921 by Hafner Publishing Company and in English translation in 1928 by Blackie and Son Ltd., Glasgow.
3. J.F. Steffensen, *Interpolation*, first edition, Chelsea Publishing Company, 1927.
4. C.C. MacDuffee, *Vectors and Matrices*, Mathematical Association of America, number 7 of its Carus Mathematical Monographs, 1943.
5. A.C. Aitken, *Determinants and Matrices*, Oliver and Boyd Ltd., Edinburgh, 1939.
6. N.B. Conkwright, *Differential Equations*, first published in January 1934 by Macmillan Company with a fourth edition in May 1942. Typical of many college texts on the subject, it contained a chapter on numerical approximation covering Simpson's Rule and the Runge-Kutta method.

The ENIAC Women—Their Stories

The first women directly involved with ENIAC were those hired by the Moore School to participate in its actual construction. A few of these women had previous experience on the production line in the emerging vacuum tube-based electronics industry of World War II. They worked at the University of Pennsylvania under the direction of Solomon Rosenthal. Joseph Chedaker was "substantially responsible for the physical construction of the ENIAC" [4]. The names of these first women computer builders are not known to me at this time.

Ruth Rauschenberger (Ammlung)

I shall begin the stories with a brief account by one of the women who is typical of the many who were active during World War II doing trajectory computations but who did not get, or who chose not to take, the opportunity to become an ENIAC programmer. Ruth Rauschenberger (Ammlung) [5] reports as follows:

> I graduated from Temple University in June 1942 with a major in math and a minor in science in secondary education. I learned of the job for the Aberdeen Proving Ground (APG) at the Moore School through the Temple University placement office. I was glad of the opportunity of using my math rather than teaching it and enjoyed my work there. I also felt I was contributing to the war effort. I started at the Moore School in July 1942. After over three years involving alternating two-week periods of day and night shifts, our group was sent to Aberdeen in November 1945. I was able to get placed in the Bombing Table Section, where I worked until I retired in 1950 to raise a family.

Lila Todd (Butler)

Next, I report on the experience of Lila Todd (Butler), who is clearly one of the key early women computer/mathematicians during the period from 1942 until her retirement in 1979. She had an excellent undergraduate education in mathematics and, combined with her experience at Aberdeen, she was given a leadership role in the Army group at the Moore School. Lila Todd played an active role not only with wartime computing at the Moore School but also with the Ballistics Research Laboratory (BRL) development and use of computers during the postwar period.

Kay McNulty [6] describes Lila Todd (who was Kay's supervisor in July 1942, when Kay McNulty started at the Moore School) as "a kind, smart, tiny woman . . . who taught us with infinite patience the importance of accurate calculations to ten places."

Lila Todd (Butler) [7] reports on her career in computing as follows:

> I graduated from Temple University in the College of Arts and Science in June 1941 as the only female with a major in mathematics out of some 1,600 in the graduating class. The head of the math department didn't think women should major in math. I was employed in the Engineering Department of Dupont until March 1942 when I accepted a sub-professional appointment (SP-4) at the BRL at the APG.
>
> Shortly after arriving, Major Paul N. Gillon (assistant director of BRL) told me of the plan to use the differential analyzer at the Moore School to compute trajectories for firing tables. I was in the BRL's Firing Tables Section when he asked me to go to Philadelphia and form a section there. The analyzer was

used to produce trajectories, and desk calculators were used to generate the more complex firing tables.

Six of us were sent to Philadelphia, but after two months only Willa Wyatt Sigmund and I remained. We each supervised the differential analyzer and the computer sections. Each of us was responsible for an eight-hour shift, and together we covered 16 hours a day for six days each week. Penn students operated the analyzer. Shortly thereafter John Holberton was transferred from BRL to be our supervisor; and with the rapidly growing workload, we continued to add staff.

When our groups became too large for the available offices, we moved to a large row house on Walnut Street owned by the university. Fran Bilas and Kay McNulty were employed at this time, and they each asked to work on the analyzer. Willa and I preferred the actual final-step production of the firing tables.

Mary Mauchly (John Mauchly's first wife, who drowned several years later at the New Jersey shore) and Adele Goldstine (Herman Goldstine's wife, who died in 1964) became involved with the education of newer recruits as the qualifications of the available candidates diminished. First, when women math majors were no longer available, women college graduates with other majors and some mathematics were hired. Later, high school graduates with a good high school math knowledge were added. With the schooling in the desk calculator fundamentals given by Mary Mauchly and Adele Goldstine, this proved to be very successful.

The unit was expanded to six sections with John Holberton, Willa, and I involved in selecting the four new supervisors: Florence Gealt, Ruth Rauschenberger (Ammlung), Patricia Griffin, and Mary Gibbons (Natrella). At the same time, bombing tables and some research projects were added. Major A.A. Bennett from Brown University replaced Major P.N. Gillon. Lt. A.E. Pitcher and Lt. H.H. Goldstine were sent from BRL as liaison officers. Lt. Pitcher was shortly thereafter sent to Europe, and Lt. Goldstine was our only military representative. Dr. Leo Zippin from Queens College, N.Y., was hired as our civilian head, John Holberton was assigned to supervise the analyzer, and Lt. L. Tornheim was transferred from BRL to be our administrator.

The workload continued to grow, and we moved to another building and increased to eight sections consisting of about 80 female and three male employees. We were not aware that ENIAC was being built, even though traffic was heavy at the main building at the Moore School. The area where ENIAC was taking shape was off-limits except to authorized personnel. When we were eventually informed about the ENIAC in the spring of 1945, Lt. Tornheim held a meeting of all eight supervisors. We were asked to select one person from each section whom we could spare from our rush projects to staff the new "machine." No supervisors could be candidates, since it was important that there be no interruption in our regular output.

The supervisors were led to believe that when the war ended, we supervisors would be transferred to the ENIAC. Instead, all of the BRL group (except for Fran Bilas, who was one of those selected to work on the ENIAC) were transferred back to BRL in November 1945, long before the ENIAC was scheduled for its move, which didn't take place until early 1947. I was one of the few of our employees who opted to return to BRL. I was given a section of 15 mathematicians to supervise. The other APG employees from the Moore School were assigned to Mabel Young's section at BRL.

In 1947, I left BRL on maternity leave. Before leaving I transferred Winifred (Wink) Smith to the ENIAC and Homé McAllister (see Fig. 6) to the IBM Section. These were two of my best employees. When I returned to BRL in 1951, I was assigned to the ENIAC. At long last I was where I wanted to work.

Fig. 1. George Reitwiesner and Homé McAllister, April 1949, at ACM national meeting, Oak Ridge, Tenn.

Lila Butler continued to work at BRL for an additional 28 years, retiring in July 1979. In addition to her work on the ENIAC in the early 1950s, until ENIAC was closed down in October 1955, she served as a programmer for EDVAC, ORDVAC, and later with BRLESC I, a computer designed and built by the BRL staff, with engineering headed by John Gregory and software by

Lloyd Campbell. Lila Butler played a significant role in the development and use of the FORAST software for BRLESC I.

Kathleen McNulty Mauchly Antonelli

Among the first of the early Moore School computers and also one of the original six selected as the first ENIAC programmers was Kathleen McNulty (see Fig. 1). Kay McNulty was born in Donegal, Ireland, on Feb. 12, 1921, and came to America with her family in October 1924. At the time she spoke only Gaelic. She attended parochial grade school in Chestnut Hill (in the northwest corner of Philadelphia), Hallahan Catholic Girls High School (her math courses included two years of algebra, plane and solid geometry, and trigonometry), and Chestnut Hill College for Women. She graduated in June 1942 as one of three math majors in a class of 92 graduates. Her math courses included college algebra, math history, integral calculus, spherical trigonometry, differential calculus, and partial differential equations. Kay McNulty (Mauchly) (Antonelli) [6] reports as follows:

> By the time I reached my third year of college, I started looking around for some type of occupation that could use a math major. I didn't want teaching. Insurance companies' actuarial positions required a master's degree (and they seldom hired women, I later found out). The best bet was some business training for me. So I took as many business courses as I could squeeze in: accounting, money and banking, business law, economics, and statistics.
>
> Just after graduation, I happened to see an ad in the daily paper. The Army was looking for women with a degree in mathematics—right here in Philadelphia. I called Frances Bilas and Josephine Benson—my fellow math majors. For some now-forgotten reason, Josephine Benson couldn't meet with us. In any event Fran and I went in together for the interview and were both accepted one week later as computers, SP-4, a subprofessional civil service grade. The pay was not spectacular, but at that time, and with no work experience, it was very welcome. We received notice to report to work at the Moore School.
>
> Our new office had once been a large classroom. It now housed some 12 women and four men all busily occupied with desk calculators and large sheets of columned paper. We were introduced to the group who had recently arrived from the APG. They were busily calculating trajectories for firing tables. I recall meeting Lila Todd, Willa Wyatt, Ella May Henderson, and Mary Gibbons. The presence of the women in this men-only school caused a lot of "rubber necking" at the water fountains. Of the men in the group, I remember Joe Natrella and John Holberton, the man in charge of the unit. It was my first encounter with the Southern accent.
>
> The key to doing the job was a knowledge of numerical integration, a topic outside the math curriculum at Chestnut Hill College. When we confessed we didn't even know what the term meant, we were each given a copy of a very thick book by Scarborough [3] and told to read certain chapters. Reading the assigned material was not much help. It was not until we were given our own calculators and the huge sheets of paper and shown step by step how the integration was done that we began to realize what was expected of us. We then got to work.

The job of computer was critical to the war effort, and women were regarded as capable of doing the work more rapidly and accurately than men.

> Within a few weeks we had learned enough to be transferred to the basement of the Moore School, where we were introduced to the differential analyzer. The room housing the analyzer was the only air-conditioned room at the Moore School. Because of this Fran and I quickly learned the names of the Moore School personnel who came to cool off during the very hot summer of 1942.
>
> The differential analyzer had been loaned by the University of Pennsylvania to APG for the duration of the war. Professor Cornelius Weygandt was in charge for the Moore School and Joseph Chapline, a former student of John Mauchly at Ursinus College, was in charge of changeovers and maintenance of the analyzer. That summer of 1942, two young men from Aberdeen, Seymour Goodman and Ted Ricci, were in charge of operating the differential analyzer. Operation included setting up the boundary conditions in the integrators, repairing or replacing the strings and bands on the torque amplifiers, guiding the arbitrary functions from input tables, and punching out the results of the calculations at specified times and at summit and ground. These two men and a young woman trained Fran and me as operators for the differential analyzer, so that in a short time we were able to take over a work shift. We worked from 8 a.m. until 4:30 p.m. for two weeks, then changed over to 4 p.m. to 11:30 p.m. for two weeks.
>
> Within a month or so, the Computing Unit upstairs on the first floor of the Moore School was enlarged by the addition of some young women who had been trained in math at the college level by some aging ex-teachers from the Moore School. In this group was Betty Snyder and Marlyn Wescoff. Some of these new recruits were sent to join Fran and me in the analyzer room. By early fall 1942, a new set of classes, taught by Adele Goldstine, Mary Mauchly, and Mildred Kramer, was begun in a building at the intersection of Walnut, 34th Street, and Woodland Avenue. My understanding was that Adele Goldstine had been hired primarily to recruit math majors throughout the area, including Hunter College in New York, her alma mater. The supply was slim, so the next best alternative was to recruit some women who had some college math or four years of high school math and train them in the fundamentals of basic college math.
>
> By July 1943, Goodman and Ricci had been drafted, the analyzer room staff had been enlarged by quite a few young women coming from the newly set up classes, and Fran and I had been split up so that we were in charge of two separate shifts. We continued in this fashion until V-E Day. We

worked six days a week, everyday except Sunday, with only two holidays, Christmas and the Fourth of July. Each year we earned 10 (and later 16) days leave, for which we would be paid, or we could take as vacation days, after the war ended.

Our performance was evaluated, and we were given raises every six months. The unit that was working on the first floor of the Moore School outgrew its space and moved into a pair of three-story houses at 3436 Walnut St.—the site of the present-day University of Pennsylvania Library. At one point, there were about 100 women on two shifts, with those on the incoming shift continuing work on the incomplete trajectory computations from the previous shift until each trajectory was completed.

Additional extensive quotes from earlier private correspondence of Kay McNulty are published in my earlier paper [1].

Betty Jean Jennings (Bartik) has provided some information on another of the original six: Ruth Lichterman (Teitelbaum), who graduated from Hunter College with a BS in mathematics and was recruited by Adele Goldstine. Her father was a Hebrew scholar, and her home was in Far Rockaway Beach, N.Y. After her Moore School work and her selection as one of the six, she worked for about two years at the BRL and is pictured in Fig. 2. Ruth was the last of the original six to leave the ENIAC, leaving like the others, to get married. As the converter code was introduced in 1947 and 1948, the ENIAC programming team changed, but still included a large percentage of women. Ruth is the only one of the original six to have died as of this writing.

Frances Elizabeth (Betty) Snyder (Holberton)

Another of the original group is Frances Elizabeth (Betty) Snyder (Holberton), see Fig. 3. Betty Snyder was born on March 7, 1917, and was the oldest of the original six. Following an excellent Quaker school education at the George School in the Philadelphia area, Betty graduated in 1939 from the University of Pennsylvania with a degree in journalism, one of the few colleges at Penn open to women and providing an opportunity to take undergraduate courses in other colleges of Penn. She joined the Philadelphia Computing Unit at the Moore School on August 19, 1942. Jointly with Jean Jennings, she developed the trajectory program used to control the operation of the ENIAC during the highly successful public demonstration in February 1946.

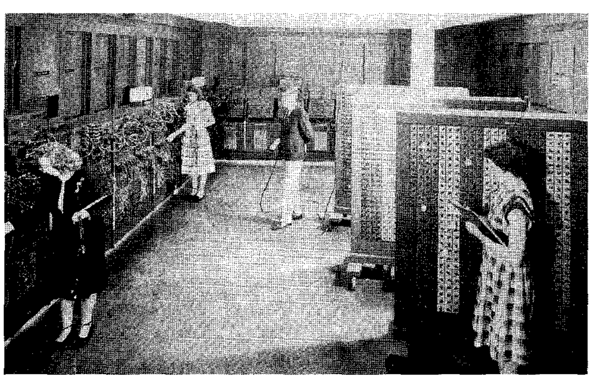


Fig. 2. ENIAC at the Ballistics Research Laboratory, Aberdeen Proving Ground. From left to right: Homé McAllister, Winifred (Wink) Smith, George Reitwiesner, and Ruth Lichterman.

(Photo courtesy of the Smithsonian Institution)

Fig. 3. Barkley Fritz, Betty Snyder, and John Holberton, April 1949.

Betty Snyder, along with Ruth Lichterman, Fran Bilas, and Kay McNulty, went to the BRL at the beginning of 1947 when the ENIAC itself was moved to Aberdeen. Later the same year, Betty left civil service and returned to Philadelphia to work as a logic design engineer for the Eckert-Mauchly "Electronic Control Company" [8]. She has been credited with much of the software for the first UNIVAC delivered to the U.S. Census Bureau. She also had a major influence on the way various parts of the UNIVAC were designed to work, especially the magnetic tape drives.

Between January and June 1952, she "devised the first sort-merge generator for UNIVAC I, from which Grace Murray Hopper claimed to have derived the first ideas about compilation" [8]. Grace Hopper in several of her talks and interviews also indicated that she regarded Betty Holberton as being the best computer programmer she had known during her long career. Betty played a significant role in the evolution of the Fortran language, helping to monitor and control its standardization.

Betty married John Holberton on July 15, 1950, remaining active in the computer field until her retirement in 1983. Her professional career spanned four decades as follows: 1945–1947, computer programmer, APG; 1947–1950, logic design engineer, Electronic Control Company; 1950–1953, programmer, Remington-Rand Corporation; 1953–1966, member, Applied Mathematics Laboratory, David Taylor Model Basin; and 1966–1983, staff member, National Bureau of Standards (NBS), currently (as of this writing) known as the Institute for Computer Science and Technology (ICST) [16]. It is interesting to note that she completed her career at NBS, since her grandfather, Monroe Benjamin Snyder, had been active during the later part of the 19th century in pointing out the need for national engineering standards and working for the creation of the NBS, which finally occurred in 1906.

Betty Jean Jennings (Bartik)

The youngest of the six, and the one who worked most closely with Betty Snyder on ENIAC, was Betty Jean Jennings (Bartik). Jean, as she prefers to be called now, was born on a farm near Stanbury, Mo., on Dec. 27, 1924. She graduated from Northwest Missouri State Teachers College (now Northwest Missouri State University) in Maryville in June 1945. Jean Jennings (Bartik) [9] reports extensively on her education and career in computing as follows:

> I began college in September of 1941. The country was very nervous. The military draft had begun. One of my brothers was already in the Navy, and another was taking civilian pilot training. Things were pretty tense that fall. Then on Dec. 7, Pearl Harbor was bombed and everything changed on campus. Almost all the men left except for a few 4-Fs and the foreign students. That spring, classes were quite small.
>
> I had started out planning to take prejournalism, but when I realized I couldn't afford to go to journalism school at the University of Missouri after college, I switched my major to mathematics with a minor in English. I had always considered mathematics as fun, like solving puzzles, thus more of a game than a subject for serious study.
>
> By my junior year, we had the Navy V-2 and V-5 programs on campus. I took analytic geometry, trigonometry, and physics with student-sailors. Often I was the only girl in the class. I also worked in the bookstore/coffeeshop, so I knew most of the students and faculty on campus. Of course, all of the student-sailors knew me. I thoroughly enjoyed myself. The courses were quite easy for me.
>
> I had been lucky in high school. I had a math teacher who bothered to teach only the bright students. It was terrible for those he didn't consider bright, but it was a boon for the rest of us. In later years, when the ENIAC was announced and the local newspaper interviewed the principal of my high school, Stanberry High School, he claimed I made the highest marks in mathematics of anybody who had ever attended the school.
>
> In college I had three teachers who had a real influence on my life. Dr. Blanche Dow was head of the foreign language department, but she also taught humanities courses: appreciation of the arts, music, drama, philosophy, and culture. The amount of reading required was mind-boggling and almost impossible for me to complete. I really learned how limited my farm and small town background had been. I had been nowhere and done nothing. Although at the time I had no basic interest in such things, I was so impressed with her obvious appreciation and joy in the arts, drama, and music of the world, I was determined to learn and enjoy them also. Everywhere I have been since, I have felt gratitude to her and joy at sharing some of the same things she enjoyed. She had an inner glow and great energy that I've always wanted to exude. Impressing on her that I was worth something was high on my list of ambitions.
>
> The second influential teacher was Dr. Horsfal. He taught biology and nearly drove me crazy, but he taught me to think. Although I didn't know it until years later when I discovered Count Alfred Korzybski and his book *Science and Sanity: An Introduction to Non-Aristotelian Systems* published in 1933. Dr. Horsfal had probably just read this book. He gave us a quiz on word definitions everyday. He would never accept a dictionary definition, any textbook definition or a contextual definition. Everyday I flunked the test. The class was in a constant turmoil of arguments over the definitions of those "blasted words." What he was trying to teach us was to define words precisely without over defining them. This was my first experience at flunking tests and not being able to do anything to correct the problem. I guess I eventually got the hang of what he was driving at, for I did pass the course.

Grace Hopper in several of her talks and interviews also indicated that she regarded Betty Holberton as being the best computer programmer she had known during her long career.

> Dr. Horsfal taught us many other things. He had worked in Arkansas on WPA projects. I'll never forget his description of the poor starving people who were helped by the federal programs. He said a year after receiving the government food, the women came to town with a baby by the hand and one under the belt. Also he allowed us to put questions on sex in a question box and he would answer them all in class. All of us in class nearly died with embarrassment, excitement, and curiosity. I had never heard such a discussion in my life. One of his more memorable statements was that one-night stands to test sexual compatibility were useless. Sex is like learning to play the piano, it takes time to learn. Also, he was a bug on tree pruning. He would carry on about the cold-blooded mutilation of trees he had seen on the way to school. When I see a tree with a large branch cut off without the gash being treated, I think of Dr. Horsfal.
>
> The third major influence was Dr. J.W. Hake, my adviser and head of the physics department. During the war he also served as head of the math department. There were only three math majors: a student from Peru, another girl in the year ahead of me, and I. Dr. Hake was a wonderful, steady, firm teacher. My relationship with him was always rather formal, however he was a major help when I really needed his support.
>
> During the summer of 1944, I had worked at Pratt-Whitney Aircraft in Kansas City on the silver plating of plates for the engines. In order to graduate, I needed 22 credits, which I had planned to complete in the single session ending in December 1944. When I came to register for the 22 credits, I was sent to Dean Jones, since I was attempting to take six credits more than the normal load. He had a fit, telling me I couldn't possibly take the 22 credits for graduation, since the courses I needed weren't even being offered. I was horrified. I had only enough money for the one semester. I went to see Dr. Hake. I cried. Dr. Hake declared he was head of the math department and since the college did offer a major in math, it must give the courses necessary to complete the degree. Furthermore since I was the only student who needed them, he would schedule them to fit in with the rest of my program.

The math department had six or seven teachers who were available to teach, two of whom should have retired long ago. My father had taken courses with Mr. Colbert over 30 years earlier. He must have been about 75 years old as was Dr. Helwig. Dr. Hake used these two to give me the courses I needed. Mr. Colbert taught me and Americo Usandivaris from Peru the theory of numbers. Dr. Helwig taught me modern geometry. Dr. Ruth Lane, who was young, vigorous, and capable, taught Americo and me advanced calculus. Dr. Helwig taught us astronomy. It was a ragtag group, but I did learn some astounding new concepts such as parallel lines meeting at infinity and about different number bases such as two, 12, and so on.

I was becoming concerned as to what I would do when I graduated. The college was constantly receiving requests for math teachers. I didn't want to teach. I wanted to get out of Missouri, see the world, and have some adventures. IBM was looking for systems service girls. I applied for that job. One girl from the college did take that job and reported that it was hard work and not very rewarding.

In talking with Dr. Lane, she reported that there were lots of jobs. She had worked at Wright-Patterson Airbase in Ohio before coming to Maryville. She also gave me a letter she had received from a Math Society publication recruiting math majors for jobs with the APG, but located at the University of Pennsylvania in Philadelphia. The job was to calculate trajectories for projectiles fired from guns tested at APG. Dr. Lane told me there were three differential analyzers in the United States: MIT, Wright-Patterson, and the University of Pennsylvania. (I learned later that APG also had an operating differential analyzer.) She urged me to apply because of the differential analyzer at Penn. When I told Dr. Hake about the job, he encouraged me to forget it and take a teaching job. He said I would be just one of many doing a repetitive task, whereas if I taught math in some small town, I would be a respected member of the community. I took Dr. Lane's advice—applying at Penn.

During January and February, I sat around home waiting to get an answer. Almost everyday, my father came home with news of another teaching job available right away. Finally toward the end of March, I received a telegram offering me the job at Penn and telling me to report as quickly as possible. I took a train out the next night. When I arrived two days later at 32nd and Walnut, they were surprised to see me.

At the time there was a severe housing shortage in Philadelphia. I was able to stay at the downtown YWCA for a week but then had to find a place to live. After much searching in what appeared to be slum housing, I checked with the university housing office, and they sent me to a room available at 22nd and Delancy in a house with students at the Curtis Institute of Music. As warned by Dr. Hake, I was just one of many doing a repetitive task (about 70 of us computing firing tables). I was using a Monroe calculator. Also, I went to a class at the Moore School given by Adele Goldstine. I remember her teaching us about inverse interpolation. I'll never forget the first time I saw Adele. She ambled into class with a cigarette dangling from the corner of her mouth, she walked over to a table, threw one leg over its corner, and began to lecture in her slightly cleaned up Brooklyn accent. I knew I was a long way from Maryville, Mo., where women had to sneak down to the greenhouse to grab a smoke.

As I looked around and saw all the people doing calculations, I realized I was way behind all of them. In the meantime, four of us who came about the same time had a good time together exploring Philadelphia. All of us were math majors: one from Ohio, one from Kansas, one from Wisconsin, and me from Missouri. When school was out for Curtis, an apartment at 2317 Delancy Place became available for the summer. Ruth Penny (from Wisconsin) and I took it.

Shortly afterward, an announcement was made that APG was recruiting what would later be known as coder/programmers for ENIAC, a new machine being completed at the Moore School. Anyone who wanted to apply could go to a meeting at the Moore School. I had no idea what the job was or what the ENIAC was. All I knew was that I might be getting in on the ground floor of something new, and I believed I could learn and do anything as well as anyone else. I went to the meeting. There must have been a dozen or so of us. We were told very little about the ENIAC because it was still classified. Each of us was called in for an interview with Herman Goldstine and Leland Cunningham. Dr. Goldstine was the BRL liaison officer with the ENIAC project, and Dr. Cunningham was an astronomer from APG. They asked a few questions, and I remember Herman asking me what I knew about electricity. I said I had had a course in physics and knew $E = I/R$. He replied what he really wanted to know was, Are you afraid of it? I replied that I wasn't. His wife, Adele, then came into the room and called me by name.

Afterward, I was notified that five programmers and two alternates had been selected. I was the second alternate. I thought that's that, close but no cigar! On the following Friday I was asked if I was prepared to go to APG on the coming Monday to be trained on the IBM punched card equipment, which was to be used with ENIAC for input/output and hard copy. I was ecstatic and immediately said yes. Four of those selected—Betty Snyder, Kay McNulty, Marlyn Wescoff, and Ruth Lichterman—had accepted. The fifth person (Greenie—Helen Greenman (Malone)) had a nice apartment in West Philadelphia and didn't want to give it up to go to APG. She turned down the offer. Later I learned that Helen Malone had gone to APG and worked on the ENIAC. The first alternative was on vacation in Missouri and didn't want to cut it short to go to APG. Thus I became the fifth ENIAC programmer trainee. Fran Bilas was apparently selected later. In any event she did not go with the original group to APG for training in June 1945.

We spent much of our time at APG learning how to wire the control boards for the various punch card machines: tabulator, sorter, reader, reproducer, and punch. As part of our training, we took apart and attempted to fully understand a fourth-order difference board that the APG people had developed for the tabulator.

We had a wonderful and exciting time at APG. It was exciting because we were involved in a new adventure. Our housing was basically a dorm. We worked together, lived together, ate together, and sat up until all hours discussing everything, including politics and religion. Ruth and Marlyn were Jewish, Betty was a Quaker, Kay was Catholic, and I was an ex-member of The Church of Christ—mainly just Protestant.

In June of 1945 when the training at APG took place, I was 20 years old and the youngest of the group. All of them were wonderful to me. Later on as we continued to work together as a group, Ruth took me to New York, Marlyn took me to Washington, and Kay and Betty both took me into their homes. In fact, Betty's family almost adopted me, since she and I worked together as a pair. Also there were men in Aberdeen, which we had not seen much of for quite a while. We did have various romances.

The extensive detailed manuals of material, authored later by Adele Goldstine, describing the ENIAC were not in existence until at least a year after our return from APG in July 1945. We did have access to the early logical block diagrams of the various units of ENIAC and some access to the engineers who were responsible for the design of specific parts of ENIAC. Harry Huskey and Arthur Burks were of particular help.

When we returned to Philadelphia, we didn't even have a place to sit. Betty and I found some space in a classroom on the second floor of the Moore School building. Marlyn and Ruth located a desk at the fraternity house at 32nd and Walnut. Fran had joined the group by this time, and she and Kay may have had a corner in the differential analyzer room where they had worked before going to APG. At the time they were adding a third floor to the Moore School building, where Betty and I had found a place to work. It was very noisy. One day a man came into the room looking up at the ceiling. He walked all around, not saying a word. Finally he said he was just checking to see if the roof was caving in. That was my introduction to John Mauchly. To that point, he was one of those faraway geniuses who had thought up and developed the ENIAC. Betty and I were studying the accumulator so we asked him all the questions we had about it. John Holberton, who was our manager, shared an office with John Mauchly and was learning ENIAC the same way we were. John Mauchly was a good teacher and also was very concerned that we learn all the ways it was possible to use ENIAC.

Occasionally, the six of us programmers all got together to discuss how we thought the machine worked. If this sounds haphazard, it was. The biggest advantage of learning the ENIAC from the diagrams was that we began to understand what it could and what it could not do. As a result we could diagnose troubles almost down to the individual vacuum tube. Since we knew both the application and the machine, we learned to diagnose troubles as well as, if not better than, the engineer.

Finally in the fall of 1945, we were given a room where the six of us could all be together, and we were assigned the job of programming the trajectory problem. We continued to work in pairs: Betty and I, Ruth and Marlyn, Kay and Fran. It was fun, but the pieces didn't appear to fit until we got the hang of using the ENIAC master programmer to tie together and reuse parts of the code. At this point in time ENIAC was not a working system, so we didn't have the advantage of fully testing our "program."

One day a man came into the room looking up at the ceiling. He walked all around, not saying a word. Finally he said he was just checking to see if the roof was caving in. That was my introduction to John Mauchly.

Betty and I were the workhorses, finishers, tying up all the loose ends. Kay was often more creative, suggesting clever ways to reuse and reduce the total size of the program. Marlyn and Ruth agreed to generate a test trajectory, calculating it exactly the way the ENIAC was to do it so we could check the detailed steps once it was on the ENIAC. We spent a lot of time working on programming notation so we could keep track of the timing of program pulses and digital operations. The ENIAC was a parallel machine, so the programmer had to keep track of everything, whether interdependent or independent.

In the meantime, Nick Metropolis and Stan Frankel came to the Moore School to run the Los Alamos nuclear problem on the ENIAC. The six of us were not directly involved with that program, except as operators setting switches and connecting cables. Nick and Stan did the programming with help from Adele and Herman Goldstine and John Mauchly. During this period we had the opportunity to begin meeting with the engineers who had designed various sections of the machine. I remember Bob Shaw explaining the function tables and Chuan Chu the divider/square-rooter. There was Johnny Davis for the accumulator, Kite Sharpless for the multiplier, Brad Shepherd, and others. Of course, there was always John Mauchly, who was pushing ENIAC as a versatile, general-purpose computer, urging us to work on programming routines other than the trajectory. I never actually talked with Pres Eckert until much later, when I worked with the group developing UNIVAC I.

About two weeks before the public announcement of ENIAC in February of 1946, Herman and Adele Goldstine invited Betty and me to their apartment in West Philadelphia. They asked us if our trajectory program was ready to go. We said it was. They asked if we could have it up and running for the demonstration at the announcement. We said we could. It still hadn't been put on ENIAC, and Betty and I were dying to put it on the machine, and we were ecstatic at being given the chance to do it. Furthermore, both of us knew we could. We had checked our program again and again, and we were convinced it was perfect. Herman said OK, they were counting on us, and we had permission to do it.

Of course, we were wildly excited, and we began immediately. We worked nights and weekends. At one point, Harold Pender, dean of the Moore School, came in to talk to us. He asked how we were doing. We said, "fine." He said, "Go to it," and left a bottle of liquor with us. Neither one of us drank liquor at the time, but the act impressed us with the importance of the upcoming demonstration to the Moore School.

On Saturday afternoon, prior to the week of the planned announcement and demonstration of ENIAC, John Mauchly came into the area where we were working with a bottle of apricot liqueur. He gave us each a little glass. I'd never had any before in my life. Neither of us was interested in drinking, but again the act impressed us with the importance of this demonstration to him. At that time, I thought John Mauchly was the most brilliant, wonderful man in the world. I still do, except a few other men have been raised into that category, including Pres Eckert and John von Neumann. Betty and I felt the tremendous pressure to make this thing work. Everybody was counting on us: the BRL, the Moore School, the ENIAC design group, the Goldstines. We both loved the attention and knew we could do it!

The night before the demonstration, the trajectory program was running perfectly, *except* it didn't stop computing when it was calculated to hit the ground. It kept going. Betty and I checked and rechecked everything until about 2 a.m.

During the night it came to Betty what was wrong. She came in the next morning and flipped one switch on the master programmer and the problem was solved. Actually, Betty could do more logical reasoning while she was asleep than most people can do awake. She was fabulous to work with. We each had great respect for the other, and we trusted each other to check the other's work so we wouldn't find additional errors while putting our programs on the machine.

The day ENIAC was introduced to the world was one of the most exciting days of my life. The demonstration was fabulous. ENIAC calculated the trajectory faster than it took the bullet to travel. We handed out copies of the calculations as they were run. ENIAC was 1,000 times faster than any machine that existed prior to that time. With its flashing lights, it also was an impressive machine illustrating graphically how fast it was actually computing.

After the announcement, many people came to see ENIAC: reporters, Movietone News, scientists, educators. The six women programmers went back to work on a variety of different applications. Kay worked with Dr. Douglas Hartree on his "laminar boundary layer flow in a compressible fluid" problem. Dr. Hartree published a paper in the British journal *Nature* that contributed to the international fame of ENIAC.

I worked next with Adele Goldstine on a "reflection of plane shock waves" problem for Dr. A.H. Taub of the University of Washington. Adele was bright, talented, and hard-working. Adele had a good technical knowledge of ENIAC and was responsible for writing the two-volume "Technical Report on ENIAC," printed in mid-1946. At the time we worked together, she had not done much real programming—in fact none of us had much experience. She did have knowledge of the shock wave problem and was the primary interface with Dr. Taub. Early on Adele and I established a good working relationship, checking each other's work, refining the code, and reasoning out what was going on. She finished running the program while I was in Missouri introducing my fiancé to my relatives. The ENIAC was to be moved to APG in early 1947. I was not going with it because I was getting married in December 1946.

I worked again with Adele when we developed, along with others, the original version of the code required to turn ENIAC into a stored-program computer using the function tables to store the coded instructions. In the early years of the development of ENIAC, it was realized that it could be programmed differently than it was for the trajectory problem for which it was primarily designed. While Dick Clippinger was at the wind tunnel group at APG, he had problems too big to run using the existing programming method and took steps to develop an alternate approach. To carry out this plan, he decided to finance a group of five people at the Moore School using me as the lead person with himself in direct control over the programs to be written. His major intention was to get this group to generate the code to convert ENIAC to a stored-program computer. When this was completed, the group would next satisfy his specific application needs using the code developed converting ENIAC to a stored-program computer. The contract called for APG to buy 12 computer programs from the group at the Moore School. He personally agreed to accept whatever I delivered, although all the programs had specific names. The first thing we were to deliver was the code to make ENIAC a stored-program computer.

When I talked this over with Dr. Irven Travis, then the Director of Research at the Moore School, he was skeptical of the whole project. His main concern seemed to be that I wouldn't stay on the job, and where would he be without anyone who knew how to program the ENIAC. I was going to hire recent college graduates and train them to program ENIAC, but this would take time. Finally, I realized what he was really afraid of was that I would get pregnant and leave. When I assured him I planned to work for several years, the contract was signed.

The group I had at the Moore School consisted of Arthur Gehring, Ed Schlain, Kathe Jacobi, and Sally Spear. I don't know what happened to Sally Spear, but all the others went on to outstanding careers in the computer field.

While I trained my group, I spent several days a week with Clippinger and his staff working on programming the instruction code for ENIAC. At that time, von Neumann and others were developing optimal sets of instructions for stored-program computers. Von Neumann had proposed a set to Clippinger for implementation. This was presumably comparable to those on EDVAC, which was being developed at the Moore School for the BRL [10], although it was much closer to the ORDVAC code than it was to the four-address EDVAC code, both of which came into use on their respective machines several years later.

Typical instructions were centered around a central accumulator: ADD acc, SUB acc, STOR acc, UNCONDITIONAL jump, CONDITIONAL jump, and so on. The ENIAC had a multiplier and a divider/square rooter that used specific accumulators for the multiplicand, multiplier, product, dividend, divisor, quotient, and square root, so the instruction set was provided to control those units with what later were known as single-address instructions.

Von Neumann was working at the Institute for Advanced Study at Princeton. Herman Goldstine worked for him, so Adele lived in Princeton. She was hired to work on the ENIAC stored-program project from Princeton. Clippinger's group and I went to Princeton about once every two weeks to consult with von Neumann and to work with Adele for a few days. Von Neumann would outline the instructions we should implement, and we would tell him of the difficulties we were having with some of them. He was a wonderful teacher and very quick to grasp our problem and to propose alternatives. It was very difficult to get all the instructions to fit on the ENIAC.

This was a great cooperative effort. Clippinger was a skilled motivator. He was enthusiastic and excited about the problems he would be able to solve. He was able to work with all sorts of people and maintain a strong unity of purpose. He was also clever and witty and therefore fun to work with.

Changing ENIAC into a stored-program computer proved to be a huge success.

Fritz [1], pp. 32-33, provides my perspective on the implementation of the "code" by which ENIAC became a stored-program computer in 1947. Two papers by Clippinger [11], [12] from that time serve to support the account above. (Note: Jean Jennings Bartik was identified as either Betty Bartik or B. Bartik in these references and my earlier paper [1].) Clippinger cites Adele Goldstine and Betty Bartik as key players in implementing "a logical coding system ... to ENIAC" with contributions by Kay McNulty, Betty Snyder, Kathe Jacobi, Fran Bilas, and Sally Spear. Homé McAllister was also cited as providing support in the 1949 ACM paper [12]. By way of clarification, the April 1949 ACM paper [12] was presented at the meeting by George Reitwiesner, since neither of the authors was at the meeting. I wrote the report on the meeting, which includes the only known publication of the register code paper.

Jean Bartik completed her assignment at the Moore School working for Clippinger and in early 1948 joined Eckert and Mauchly at their new venture known as the "Electronic Control Company" to program the guidance system for the BINAC being built for Northrop Aircraft. She moved to Washington, D.C., in 1950 with her husband and accepted a position with Remington Rand, which had taken over the Eckert–Mauchly enterprise. She retired in 1951, had a family, obtained a master's degree with a major in English and a minor in education, and didn't return to full-time employment until 1967, when she accepted a position as an editor for Auerbach Publishers.

Marlyn Wescoff (Meltzer)

Another of the original six was Marlyn Wescoff (Meltzer) [13], who reports on her career as follows:

I graduated from Temple University in June 1942 from the Secondary Education Department with a major in what was then called social studies and English and a minor in business. Teaching jobs in those fields were scarce, and I began to look around for something else to do. Late in August of that year a friend told me they were hiring at the Moore School and if I knew how to run a calculator, that would stand me in good stead. I made an appointment for an interview with John Mauchly but he quickly turned me over to his wife, Mary, who hired me when informed that I could operate an adding machine.

Actually, Betty could do more logical reasoning while she was asleep than most people can do awake. She was fabulous to work with.

On starting work, I was shown how to run a Marchant calculator and assigned to a group with eight or 10 others. Some were Moore School students who worked only a few hours, some were women anxious to help the war effort, and others were young men putting in some productive time while waiting to be called into military service. For me it was a full-time job. I was an employee of the University of Pennsylvania and my instructions came directly from one of the Mauchlys—most frequently from Mary but John kept close tabs on what was being done. No explanation was ever given as to what kind of calculations we were doing. We accepted that because it was wartime.

As I remember, in the spring of 1943 John Mauchly came to me one day and said that the unit was being disbanded and was being replaced by one that would be doing much the same sort of work for the Army Ordnance Department. He encouraged me to get federal civil service status so I could continue. I did so and the new group continued to work at the Moore School doing ballistic tables.

More and more people were added to the project. We alternated our work schedules—8:00 a.m. to 4:30 p.m. for two weeks and then 4:30 p.m. to 1:00 a.m. for two weeks. I never worked in the differential analyzer room (although it was the only air-conditioned room in the building and would have welcomed it in the summer) and didn't get to meet and know the others who were there except very casually.

The group continued to expand until eventually we took over a row house at 3436 Walnut St. There were three floors with groups on each floor. and we continued in two shifts—two weeks during the day and two weeks at night. John Holberton was the supervisor for the whole group, but my immediate supervisor was Florence Gealt on the third floor. John Mauchly was not terribly visible, but John Holberton was there and our liaison with the APG—Captain Herman Goldstine and Lt. Leonard Tornheim are the people I particularly remember.

There were others who came and stayed for short periods of time. I also recall the sign outside of our building proclaiming us to be attached to the university; we were told never to tell anyone in the area that we were working for the APG. I continued to do ballistic tables there and after we moved to a fraternity house on Walnut Street.

I really don't remember the circumstances as to when I was approached to be one of the women to work on the ENIAC, but Ruth Lichterman worked with me in the same section and she was also chosen. It seems to me that it was at this point (but it may have been earlier) that Adele Goldstine and Mildred Kramer gave some needed mathematics classes to some of us. I had not taken mathematics in college, so all of this was wonderful, strange, difficult, and exciting. I recall calculus and trigonometry. The classes went on all day for about three months. It was tiring for me to concentrate so much on what was so foreign to me. I remember having a particularly hard time after lunch to keep my attention on what was being taught.

I worked with the other five women on the various aspects of ENIAC and with the men who were sent to help keep it running and in repair until December of 1946, when I left the group. I knew we were to be sent to APG early the following year. I was planning to get married in February of 1947 so I resigned before the group was moved to APG.

Frances Bilas (Spence)

The final one of the original six ENIAC programmers was Frances Bilas (Spence). In response to several earlier requests, Fran had notified me that her husband, Homer Spence, had recently died and she was not able to prepare any input for this paper. Homer, as an enlisted man in the Army, had been assigned to the ENIAC group at the Moore School and later on as a civil servant was responsible for its maintenance as a working computer during essentially the entire period of its operation at APG. However in response to another request, Fran provided me with the following personal information [14]:

I was born in Philadelphia on Mar. 2,1922, the second of five girls. My father was a district engineer for the Philadelphia Public School System responsible for 52 school buildings. My mother was an elementary school teacher who returned to teaching after we five girls grew up. I graduated from South Philadelphia High School for Girls in January 1938 and then attended Temple University. A few months later I was awarded a full scholarship to Chestnut Hill College in Philadelphia, which of course I accepted. It was quite a trip from home to the college—an hour and a half each way—all by public transportation.

Coming from a very school-oriented family, it was only natural for me to pursue a teaching career at Chestnut Hill. The major in mathematics and the minor in physics were my idea. It was there that I met Kathleen McNulty, a fellow math major, and we became best friends. I enjoyed my practice teaching at Simon Gratz High School in Philadelphia. I graduated from Chestnut Hill College in June 1942 with the full intention of becoming a math teacher.

Just after graduation, Kathleen called me about an ad she had seen in the newspaper recruiting math majors to work for the Army at the University of Pennsylvania. As she reports, we both applied together and I was happy that we were both accepted. Even though it was hard work and I had a lot to learn, I felt great satisfaction in knowing that I was making a small contribution to the war effort.

Fig. 4. One of the rare relaxed times in Philadelphia. Top row (left to right): Willa Wyatt, Glovette Beckwith Ewell, Ella May Henderson, unknown. Botttom row: Betty Snyder and Marie Bierstein Malone.
(Photo courtesy of Marie Malone)

At the Moore School, I met Homer Spence, a soldier from the APG who had been assigned to the ENIAC as an electrical engineer—my life was changed! On Mar. 1, 1947, after the ENIAC had been moved to APG, Homer and I were married. He later became the chief of the Computer Research Branch. I resigned the following year to await the birth of the first of our three sons.

When Homer took another job in New York, the Spences left Aberdeen and moved to Syosset, N.Y. Fran became a homemaker and did not return to full-time work in the computing field.

As is now apparent to the reader, major changes occurred in the way ENIAC was programmed after it was moved to its new home. Two of the women assigned as programmers, Jean (Betty) Jennings and Marlyn Wescoff, never actually worked at APG, although Jean continued to play an important role in ENIAC's future as a result of her work developing an early version of its stored-program code. Three of the other four, although they did each work for a short time at the BRL at Aberdeen, did not stay long enough to play a significant role in its eight-year usage there.

Ruth Lichterman, from the original six, stayed on at BRL for about two years helping ENIAC adjust to its new military environment among a new group of programmers. As reported in my earlier paper [1], a large percentage of the new ENIAC group at BRL were again women. In this category were the following: Gloria Gordon (Bolotsky), Lila Todd (Butler) (her story was told earlier since her role began at the Moore School), Ester Gersten, Winifred Smith (Jonas), Marie Bierstein (Malone), Helen Greenman (Malone), and Homé McAllister (Reitwiesner).

Homé McAllister (Reitwiesner)

The stories of three of these women begin with Homé McAllister [15].

I was born on Jan. 3, 1925, in Washington, D.C., to Addams Stratton and Homé Stephens McAllister. When I was old enough to need a checking account, the bank insisted that since I was named for my mother, I was Homé Stephens McAllister, Jr. My father was assistant director of the National Bureau of Standards (now the Institute for Computer Science and Technology).

When I was a senior in high school in 1942, I was offered scholarships to both National Park Seminary (NPS) in Silver Spring, Md., a two-year junior college, and a two-year partial scholarship to Wellesley College in Massachusetts to begin in 1944, which I accepted. But the war intervened, as it did for most of us at the time, and the Army took over NPS a few days before colleges were to open that fall. There I was high and dry with no college.

I was lucky to find a space at Randolph Macon Women's College in Lynchburg, Va., albeit in the Senior Dorm. Without the benefit of summer counseling, I selected my own set of classes, knowing in my own heart that mathematics would be my major and that I could pick it up in my sophomore year, without the benefit of the usual freshman math courses. All hell broke loose when I was signing up for sophomore math courses, because "everybody knows that you can't major in math without completing your freshman-year math courses." As it happened, I had helped a number of people in my dorm who had put off til their senior year the needed freshman math course to graduate. Several of them helped me convince the powers that be that I knew the material and to let me go ahead with my plan. In the end, as a senior, I was offered the chance to take honors in math.

I worked during the summers of my first two years of college at the National Bureau of Standards in a chemistry lab (Division III, Section 8). Following my third year of college, I worked at the West Virginia Pulp and Paper Company in the Research Lab in Covington, Va., where my parents had returned to my father's home on his retirement from the National Bureau of Standards in 1945.

When asked in my senior year as to my job preferences, I admitted that I was not planning to be a teacher. "Everybody knows that only future teachers major in math," was the standard statement, and my answer was that I would not be a teacher. They finally found a position for me doing hand computing for firing tables on the second floor of the building behind the BRL at APG. Winifred (Wink) Smith (Jonas) and I reported to work at BRL on the same day in July of 1946.

...we could diagnose troubles almost down to the individual vacuum tube.

I found the work satisfying (other than the fact that we were working on guns) and was somewhat upset over a year later when it was decided that I should transfer to the IBM section in the basement of BRL. I fell in love with the IBMs and had the time of my life "wiring the boards" for the tabulator and running the sorter, reproducer, and the tabulator.

Again I was upset a bit when they wanted to move me to the ENIAC. But move I did and again I fell in love with the work. I spent long hours trying to understand the "blueprints" and wiring diagrams for the ENIAC and to try to learn direct programming—the original mode of ENIAC operation. At the beginning I had very little direct contact with the machine, beyond using the IBM machines to prepare input and print output. I spent a lot of time learning how to understand and use flow charts and checking out flow charts for other coders.

I worked on lots of projects, but since many of them were classified, I intentionally didn't try to remember specifics. I do remember one day when the program for the reduction of theodolite data for a V-2 missile suddenly became erratic. We tried to find out exactly where it went wrong and why and finally discovered that the missile had gone much higher than we were told it would go. This of course was in the days of fixed-point arithmetic, before floating-point arithmetic was easily usable on ENIAC. We added branches in the flow chart, modified the program, and went on with the calculations.

I worked on many of Clippinger's problems—often on the night shift. At the time he was building a house out in the country between Aberdeen and Havre de Grace, and those of us on the night shift would go out to the house after our shift and work on his house, then go home to the dorm and sleep only to get up and go to work on the night shift again. His wife, Dorothy, always fed us a large lunch, which was greatly appreciated by those of us who were eating most of our meals at the diner on U.S. Route 40 in "beautiful downtown" Aberdeen (see Fig. 4).

Fig. 5. Marie Bierstein Malone, circa 1990.

(Photo courtesy of Marie Malone)

Some of my happiest times were trouble-shooting either the program or the ENIAC—or perhaps both at the same time. I enjoyed the test runs we wrote out on paper to test all branches of all parts of a flow chart and helping to find out why they didn't go to the branches where we expected them to go. With respect to ENIAC operation, we were often able to point out to a technician which individual vacuum tube needed to be changed.

Each of us had a desk calculator—a Monroe, a Marchant, or a Frieden—to assist in the preparation of test runs. Naturally these too sometimes had problems, and we had to call in the calculator repairman. I especially remember returning from being off one day and being told that the repairman had been there but refused to try to fix my machine without me showing him how I could make it fail that particular time. The repairman believed my input as to how to make it fail made it easier for him to find and fix the problem. I did enjoy showing him how to make a broken calculator fail on call.

I have always considered myself lucky to have been working on the ENIAC the day in 1948 when the BRL publicity photo was taken (Fig. 2), even though many copies of the widely circulated picture were cropped to eliminate me from the left side of the photo. At the time I wasn't even dating George Reitwiesner, who was operating the control box while I was connecting cables, but we were married in September 1951, raised five wonderful children, and had over 42 years together before Parkinson's disease took him.

In spring 1950, the Institute for Advanced Study was preparing to put the first weather forecasting problem on ENIAC. The BRL crew that was to work with them went to Princeton, N.J., to learn about the project and the planned coding and also to prepare some of the test runs. It was much too big a program for ENIAC, but like other such problems at the time, ways could be found to shoe horn it on the machine. It was in one sense a very "physical" problem because we had to take the output from each run, tabulate it, and then sort the output punch cards to a new set of coordinates before we could reenter these cards via the ENIAC card reader as input for the next computer run. The application was originally planned for the Princeton version of the ORDVAC, which was behind schedule. It was being run on ENIAC only as a means of getting a test of the numerical techniques planned for the larger, faster computer to be used eventually. The joke at the time was that ENIAC could make a 24-hour weather forecast in 25 hours. Weather forecasting, some 45 years later, continues to utilize the fastest computers available. In 1950, the ENIAC was the fastest available.

Homé McAllister Reitwiesner is fond of noting that the BRL programmers in the early 1950s had to work with three different number bases: ENIAC used decimal (the usual base 10), EDVAC octal (base eight), and ORDVAC sexadecimal (as base 16 was called at the time). She continued to work at the BRL on ENIAC, EDVAC (she and her new husband, George Reitwiesner, together programmed, in less than a week, the first significant application to demonstrate that EDVAC was indeed a "working computer"), and ORDVAC (she transferred to ORDVAC in 1952 and spent the month of January 1952 at the University of Illinois at Urbana, where ORDVAC was built). She took six months' maternity leave starting in February 1954 (one month before their first son, Bill, was born) and retired in February 1955 (prior to the birth of Andy, who was born in June 1955).

Helen Greenman (Malone) was another of the BRL ENIAC programmers. Lila Butler [7] describes her as being one of the outstanding mathematicians at the BRL. She was a supervisor in Philadelphia. She returned to the BRL and was assigned to the IBM section prior to ENIAC. She transferred to White Sands. When she returned she was head of the Bell Machine and later worked as a programmer. Helen continued a long career at BRL. She and Marie Malone were sisters-in-law, having married brothers. She died in 1985.

Marie Bierstein (Malone)

Marie Bierstein (Malone) (see Fig. 5) was another of the BRL women who started at the Moore School and served as an ENIAC programmer at BRL. She reports on her career as follows [17]:

I received my degree from Duke University in 1938. My major studies were French and Spanish. However, I did get through one year of college math, so when the BRL was reduced to advertising for female college grads with "some mathematics," I saw no impediment to applying. Much to my surprise I was accepted to be trained for the computer section at the Moore School.

After I completed Mrs. Goldstine's intensive course in higher mathematics, fundamentals of the science of ballistics, and the use of the Monroe calculator, I joined the group doing trajectory calculations supervised by Willa Wyatt. Since I lived with my sister in North Philadelphia, I didn't become closely involved with many of my coworkers, and names escape me. I do remember Ella Mae Henderson, Betty Snyder, and of course Lila Butler.

Toward the end of our time at the Moore School, I did a stint on the Differential Analyzer with Fran Bilas. One incident stands out in my memory. One night I became careless and had a fingernail torn off by the mechanical gears. I bled profusely and fainted for the first time in my life! John Holberton carried me to the University of Pennsylvania Hospital for treatment. I was never careless with those gears again.

When in November 1945 the APG group was transferred to the BRL, I was put to work on the BRL Differential Analyzer with Barbara Bilsborough. However after the ENIAC was successfully moved and installed at the BRL I was transferred to the ENIAC programming group. Several of those selected to be part of the six-person staff decided to remain in Philadelphia. Eventually I do believe I became a highly competent programmer. My willingness to work on the night shift allowed me to develop skills in trouble-shooting.

Fig. 6. Four of the original six ENIAC programmers at the 50th Anniversary ENIAC Celebration Feb. 14, 1996, in Philadelphia, Pa. Top row, left to right: Betty Jean Jennings Bartik, Marlyn Wescoff Meltzer, and Kay McNulty Mauchly Antonelli. Seated: Frances Elizabeth (Betty) Snyder Holberton. Missing are Frances Bilas Spence (not attending) and Ruth Lichterman Teitelbaum (deceased).

(Photo courtesy of Kathryn A. Kleiman and First Byte Productions. © Steven M. Falk, 1996.)

I was among Dr. Clippinger's night crews when he was building his house, as related by Homé McAllister. Being unhandy with tools as well as acrophobic, I never helped much with the actual building, but I did enjoy watching the others work.

When consideration was given to upgrading the positions connected with ENIAC, a few of us with sketchy math education were urged to take courses offered by the University of Maryland at Aberdeen. I eventually earned some graduate credits in order to qualify for the job I already held. Members of the BRL staff who did the teaching included Alan Perlis, Mario Juncosa, and David Young. I don't remember specifically the texts that were used, but I was acquainted with MacDuffee's *Vectors and Matrices* and Conkwright's *Differential Equations* (see sidebar). In any event, I'm sure I remember Scarborough's *Numerical Mathematical Analysis*.

I was married to a soldier stationed at Aberdeen in 1948 and in 1951 started a long maternity leave during which our first two children were born. I returned to BRL at the beginning of 1953 and did some programs for the EDVAC and then the Bell Relay Computer. My association with BRL ended in 1954 when I resigned to join my husband, who had been transferred to Puerto Rico.

ENIAC calculated the trajectory faster than it took the bullet to travel.

In the middle 1960s I reentered the world of computers. My early programming experience transferred easily to the newer computers and the business problems of that time. My career in programming ended in 1980 when I retired from the Data Processing Division of a local hospital. I have kept in touch with Lila Butler and my sister-in-law, Helen Malone, who died in 1985 in Aberdeen.

Willa Wyatt Sigmund

Another ENIAC woman whose name has come up in several of these accounts is Willa Wyatt Sigmund. She and Lila Butler were the only two women from the BRL who transferred to Penn and stayed there during the entire ENIAC development period. In her brief account of Oct. 7, 1995, Willa Wyatt Sigmund reports as follows [18]:

I graduated from the University of New Hampshire (UNH) in 1939 with a degree in mathematics and a minor in business. I worked as a statistician for three years at UNH. Major Paul Gillon of BRL had written to the head of the UNH math department asking for the names of math majors. In 1942, after four months of service at BRL, I was transferred, along with Lila Butler, to the Moore School of Electrical Engineering at the University of Pennsylvania. Lila and several of the others have already covered what happened while we were all in Philadelphia.

Conclusion

It is difficult to sum up these stories of the women of ENIAC (see Fig. 1). Each of these women is unique. Many indicated they didn't want to teach, which was expected of college-educated women at the time. Certainly each of them was intelligent. Some of the women developed methods for solving problems that were clearly too large for ENIAC. They made trade-offs and developed clever methods for getting the job done. They were successful and performed well in their jobs as they each played a part in helping launch the Age of Computing. They certainly had the pioneering spirit. Each was enthusiastic and generally exhilarated about what they were doing.

It is hard at this point to get across to today's reader just how difficult it was to develop an accurate working program for ENIAC and then to use the computer and the program to solve the problem. In my earlier paper [1], I describe in several paragraphs the difficulties in using the initial "direct programming" (recabling method). I summarize the process as being "analogous to the design of a special-purpose computer out of ENIAC component parts for each new application." With each change of program, new components of the ENIAC system were placed in operation that may not have been used in the same way and perhaps not even tested for some time.

Several of the original six in their remarks make it clear that learning to program ENIAC required a complete understanding of how the machine was designed. They learned how ENIAC worked by talking with the original design engineers, studying their logic diagrams, and sharing ideas with the other programmers. At the very beginning they were not even able to get hands-on experience on ENIAC. When they did get access to the machine, they began to understand something of the unreliability of the vacuum tube technology of the time, and they realized the necessity of learning how to trouble-shoot the machine as well as their program. ENIAC reliability is also discussed in that paper [1].

Homé Reitwiesner [14] reminded me of some of the "help" we had from the cleaning crew, who would on occasion reconnect one or more of the cables into any convenient open position on the exposed open trays after they had happened to knock out a cable with their mops. This act provided an interesting challenge to the programmer to find, fix, and return ENIAC to reliable operation.

Only Presper Eckert, the chief engineer, seems to have had the complete design picture, but he was not accessible to the women. However, the ENIAC women quickly found out that each individual design engineer knew well the unit for which he was responsible, and each design engineer fully recognized the need to communicate that knowledge to the women.

John Mauchly understood the full potential of ENIAC and encouraged the women to use their ingenuity (should I say genius?) to fully exploit its capability to solve a broad range of applications. His sharing an office with John Holberton helped in the very important need for effective communication between the designers and the users, the hardware and the software. Up to this point little attention seems to have been given by the designers as to how the programmers were to do the job of using ENIAC to solve real problems. But these women and those who followed learned quickly.

Latter day programmers (circa the early 1950s and beyond) were presented with "Programmer Manuals" that, at the beginning, were often incorrect and incomplete in some details, but were at least a starting point. The "Report on the ENIAC, Technical Report I" (written by Adele Goldstine) was unavailable until after its June 1, 1946, official publication date. Adele Goldstine did a great job preparing this complete documentation—a requirement of the Army for ENIAC's acceptance and final payment to the Moore School—however this official material did not exist when the ENIAC women began preparing their first programs for the successful use of the new computer system in the fall of 1945.

As has been discussed here and in earlier publications, ENIAC would never have been the success it was had it continued in operation in its initial "direct programming" mode. Even with the vastly improved "converter code" method available in 1947, the ENIAC programmers' new need was to use decimal number coded instructions without an assembler or a compiler to assist in entering each program. It was still relatively difficult to change from one program to the next, making ENIAC a challenge to all but the most dedicated. However, for those who had a problem to solve in the late 1940s, it was the only high-speed computer available. If the women of ENIAC hadn't performed their job well, a half decade of important scientific computing would have waited for another day.

Nothing has been said in this paper, to this point, to indicate that some of the women trained to do the trajectory computations were members of the Women's Army Corps (WACs). This group received some eight months of training for ballistics computation—again at the Moore School. The civilian women at the Moore School apparently had no contact with the Army women and were mostly unaware of the WAC involvement. All of those selected for the ENIAC came from the civilian women. Apparently the WACs were not considered, probably because World War II was ending and, like other military personnel, the WACs were soon to be discharged.

I am reminded as I conclude that although Adele Katz Goldstine (the wife of Herman Goldstine, the Department of the Army's liaison to the ENIAC design team at Penn) has been mentioned frequently, I have not provided much in the way of biographical information. She was a math major, graduate of Hunter College, and obviously "played a key role in the story." See Goldstine [2] and numerous other references for further information on her career. Adele Goldstine died in 1964.

As is apparent from their stories, most of these women married and retired from the jobs they enjoyed, becoming full-time wives and mothers. Only two of these women, Lila Todd Butler and Betty Snyder Holberton, continued extensive, active, successful professional computer careers following the ENIAC days. Both Lila and Betty made significant contributions to the computer field, and like many women of a later generation, each did so combining marriage and children with their careers. Betty Jean Jennings Bartik, Helen Greenman Malone, and Marie Bierstein Malone also returned to work in the computer field after periods of absence raising their children.

All of those listed in this paper, and others, unknown today, contributed in their own unique ways as the women who, in the beginning, effectively used "the machine that changed the world." Each deserves greater recognition from those who followed for what they did as pioneers of the Age of Computing.

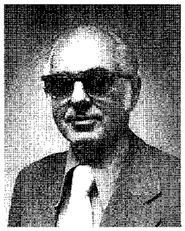
References

[1] W.B. Fritz, "ENIAC—A Problem Solver," *Annals of the History of Computing,* vol. 16, no. 1, pp. 25-45, 1994.

[2] H.H. Goldstine, *The Computer From Pascal to von Neumann.* Princeton, N.J.: Princeton Univ. Press, 1972 (paperback 1980).

[3] J.B. Scarborough, *Numerical Mathematical Analysis,* first edition of the widely used college text, appeared before World War II. Second Edition published by Johns Hopkins Press, 1950.

[4] J.G. Brainerd, "Comment," *Annals of the History of Computing,* vol. 3, no. 4, p. 391, Oct. 1981.
[5] R. Rauschenberger Ammlung, private correspondence, Feb. 12, 1995.
[6] K. McNulty Mauchly Antonelli, private correspondence, Feb. 7, 1995.
[7] L. Todd Butler, private correspondence, Mar. 18, 1995.
[8] J.A.N. Lee, *Computer Pioneers.* Los Alamitos, Calif.: IEEE CS Press, 1995.
[9] J. Jennings Bartik, private correspondence, Feb. 25, 1995.
[10] J. von Neumann, "First Draft of a Report on the EDVAC," reprinted in *Annals of the History of Computing,* vol. 15, no. 4., pp. 27-75, 1993.
[11] R.F. Clippinger, "A Logical Coding System Applied to the ENIAC," *BRL 673,* Ballistics Research Laboratory, Aberdeen Proving Ground, Md., Sept. 1948.
[12] B. Dimsdale and R.F. Clippinger, "The Register Code for the ENIAC," included in *BRL TN 30,* "Report on the Third Annual Meeting of the Association for Computing Machinery," Oak Ridge, Tenn., Apr. 18-20, 1949, published Aug. 1949.
[13] M. Wescoff Meltzer, private correspondence, July 13, 1995.
[14] F. Bilas Spence, private correspondence, Oct. 2, 1995.
[15] H. McAllister Reitwiesner, private correspondence, July 26, 1995.
[16] Betty Holberton, phone conversation, Sept. 27, 1995. This information differs in places from that found in reference 8.
[17] M. Bierstein Malone, private communication, Aug. 13, 1995.
[18] W. Wyatt Sigmund, private communication, Oct. 7, 1995.



W. Barkley Fritz retired from the Computer and Information Sciences Department at the University of Delaware in 1989. Following service in the U.S. Navy during World War II, Fritz was employed at the Ballistics Research Laboratory, Aberdeen Proving Ground, as an ENIAC programmer, numerical analyst, and ENIAC branch chief (1948–1955). His career after ENIAC and before joining the University of Delaware in 1983 included engineering and computer management positons at Westinghouse, Sun Ship, and J.J. Henry. His bachelor's degree is from Loyola College and his master's degree is from Johns Hopkins University, both with majors in mathematics. His retirement years include writing and lecturing on his career in computing.

The author can be contacted at
4 Long Point Lane
Media, PA 19063-4948
U.S.A.