# When Computers Were Women

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J. Presper Eckert and John W. Mauchly, household names in the history of computing, developed America's first electronic computer, ENIAC, to automate ballistics computations during World War II. These two talented engineers dominate the story as it is usually told, but they hardly worked alone. Nearly two hundred young women, both civilian and military, worked on the project as human "computers," performing ballistics computations during the war. Six of them were selected to program a machine that, ironically, would take their name and replace them, a machine whose technical expertise would become vastly more celebrated than their own.[1]

The omission of women from the history of computer science perpetuates misconceptions of women as uninterested or incapable in the field. This article retells the history of ENIAC's "invention" with special focus on the female technicians whom existing computer histories have rendered invisible. In particular, it examines how the job of programmer, perceived in recent years as masculine work, originated as feminized clerical labor. The story presents an apparent paradox. It suggests that women were somehow hidden during this stage of computer history while the wartime popular press trumpeted just the opposite—that women were breaking into traditionally male occupations within science, technology, and engineering.

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1. History has valued hardware over programming to such an extent that even the *IEEE Annals of the History of Computing* issue devoted to ENIAC's fiftieth anniversary barely mentioned these women's roles. See *IEEE Annals of the History of Computing* 18, no. 1 (1996). Instead, they were featured two issues later in a special issue on women in computing.

A closer look at this literature explicates the paradox by revealing widespread ambivalence about women's work. While celebrating women's presence, wartime writing minimized the complexities of their actual work. While describing the difficulty of their tasks, it classified their occupations as subprofessional. While showcasing them in formerly male occupations, it celebrated their work for its femininity. Despite the complexities—and often pathbreaking aspects—of the work women performed, they rarely received credit for innovation or invention.

The story of ENIAC's female computers supports Ruth Milkman's thesis of an "idiom of sex-typing" during World War II—that the rationale explaining why women performed certain jobs contradicted the actual sexual division of labor.[2] Following her lead, I will compare the actual contributions of these women with their media image. Prewar labor patterns in scientific and clerical occupations significantly influenced the way women with mathematical training were assigned to jobs, what kinds of work they did, and how contemporary media regarded (or failed to regard) this work. This article suggests why previous accounts of computer history did not portray women as significant and argues for a reappraisal of their contributions.[3]

## Women in Wartime

Wartime literature characterized World War II as a momentous event in the history of women's employment. In 1943 *Wartime Opportunities for Women* proclaimed, "It's a Woman's World!"[4] Such accounts hailed unprecedented employment opportunities as men were recruited for combat positions. New military and civilian women's organizations such as the Army's Women's Auxiliary Army Corps (WAAC, converted to full military status in 1943 and renamed the Women's Army Corps [WAC]), the Navy's Women Accepted for Volunteer Emergency Service (WAVES), and the American Women's Voluntary Services (AWVS) channeled women into a variety of jobs. The press emphasized the role of machines in war and urged

2. Ruth Milkman, *Gender at Work: The Dynamics of Job Segregation by Sex During World War II* (Chicago, 1987).

3. Two books currently offer some information on the participation of women in computer history: see Autumn Stanley, *Mothers and Daughters of Invention: Notes for a Revised History of Technology* (Metuchen, N.J., 1993), and Herman Goldstine, *The Computer from Pascal to Von Neumann* (Princeton, 1972). For recollections from women who worked on the ENIAC, see W. Barkley Fritz, "The Women of ENIAC," *IEEE Annals of the History of Computing* 18, no. 3 (1996): 13–28. Other histories tend to make passing references to the women and to show photographs of them without identifying them by name.

4. Evelyn Steele, *Wartime Opportunities for Women* (New York, 1943), preface. For an analysis of American mobilization propaganda directed at women, see Leila Rupp, *Mobilizing Women for War: German and American Propaganda, 1939–1945* (Princeton, 1978).

women with mechanical knowledge to "make use of it to the best possible purpose."[5] *Wartime Opportunities for Women* urged: "In this most technical of all wars, science in action is a prime necessity. Engineering is science in action. It takes what the creative mind behind pure science has to offer and builds toward a new engine, product or process."[6] According to the U.S. Department of Labor's Women's Bureau: "The need for women engineers and scientists is growing both in industry and government. . . . Women are being offered scientific and engineering jobs where formerly men were preferred. Now is the time to consider your job in science and engineering. There are no limitations on your opportunities. . . . In looking at the war job opportunities in science and engineering, you will find that the slogan there as elsewhere is 'WOMEN WANTED!'"[7]

A multiplicity of books and pamphlets published by the U.S. War Department and the Department of Labor, with such titles as *Women in War*, *American Women in Uniform*, *Back of the Fighting Front*, and *Wartime Opportunities for Women*, echoed this sentiment. Before World War II, women with college degrees in mathematics generally taught primary or secondary school. Occasionally they worked in clerical services as statistical clerks or human computers. The war changed job demands, and one women's college reported that every mathematics major had her choice of twenty-five jobs in industry or government.[8]

Yet, as Milkman suggests, more women in the labor market did not necessarily mean more equality with men. Sexual divisions of labor persisted during wartime. The geography of women's work settings changed, but the new technical positions did not extend up the job ladder. A widely held belief that female workers would be dismissed once male veterans returned from the war helps to explain the Women's Bureau acknowledgement that "except for Ph.D.'s, women trained in mathematics tend to be employed at the assistant level."[9] The War Department and the Department of Labor

5. Keith Ayling, *Calling All Women* (New York, 1942), 129.

6. Steele, 101.

7. Ibid., 99–100.

8. According to a *Women's Bureau Bulletin*, "A coeducational university, which before the war had few outlets for mathematics majors except in routine calculating jobs, found many attractive jobs available to mathematics majors during the war, mostly in Government-sponsored research. . . . There was a definite shift from the usual type of employment for mathematics majors in teaching and in clerical jobs in business firms to computing work in industry and on Government war projects." See United States Department of Labor, "The Outlook for Women in Mathematics and Statistics," *Women's Bureau Bulletin* 223–24 (1948): 3. According to this report, women comprised the majority of high-school mathematics teachers.

9. Ibid., 8. Margaret Rossiter, *Women Scientists in America: Before Affirmative Action, 1940–1972* (Baltimore, 1995), 13, confirms this practice more widely in the sciences. The few women who worked in supervisory roles generally supervised other women, a much less prestigious managerial role than supervising men. However, at the Work Project

actively promoted women's breadth of opportunity yet in some areas explicitly defined which jobs were "open to women." Classified advertisements ran separate listings for "female help wanted" and "male help wanted."

## Women's Ambiguous Entry into Computing



Women's role in the development of ENIAC offers an account of the feminization of one occupation, "ballistics computer," and both the creation of and gendering of another, "operator" (what we would now call programmer). Ballistics computation and programming lay at the intersection of scientific and clerical labor. Each required advanced mathematical training, yet each was categorized as clerical work. Such gendering of occupations had precedent. Since the late nineteenth century feminized jobs had developed in a number of sciences where women worked alongside men. Margaret Rossiter identifies several conditions that facilitated the growth of "women's work."[10] These include the rise of big science research projects,

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Administration's Mathematical Tables Project, women supervised male computers. See Denise W. Gürer, "Women's Contributions to Early Computing at the National Bureau of Standards," *IEEE Annals of the History of Computing* 18, no. 3 (1996): 29–35. The War Department in 1942 classified all military occupational specialties as either suitable or unsuitable for women; all jobs involving supervision over men were automatically declared unsuitable. Public Law 110 also made explicit that women could not command men without intervention from the secretary of war; see Bettie Morden, *The Women's Army Corps, 1945–1978* (Washington, D.C., 1990), 14.

10. See Margaret Rossiter, *Women Scientists in America: Struggles and Strategies to 1940* (Baltimore, 1982), also *Women Scientists in America: Before Affirmative Action, 1940–1972.* In the 1982 volume, p. 55, Rossiter describes the late-nineteenth-century star counters in astronomical laboratories who performed computer work for male astronomers. The famed astronomer Maria Mitchell was employed as a computer for the U.S. Coast and Geodetic Survey in the late 1860s. The term *computer,* meaning "one who computes," originally referred to the human who was assigned various mathematical calculations. Ute Hoffman dates the use of *computer* to the seventeenth century, when it was used in reference to men who tracked the course of time in their calendars. For decades the terms *computer* and *calculator* were interchangeable. In fact, early computers such as the ENIAC and Mark I were called electronic calculators. See Ute Hoffmann, "Opfer und Täterinnen: Frauen in der Computergeschichte," in *Micro Sisters: Digitalisierung des Alltags, Frauen und Computer,* ed. Ingrid Schöll and Ina Küller (Berlin, 1988). A number of other historians have documented women's work in other sciences. For example, Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago, 1997), discusses the work of women in high-energy physics laboratories, both those who counted flashes on the scintillator in Rutherford's laboratory and those who scanned the photographs from bubble-chamber experiments. Caroline Herzenberg and Ruth Howes, "Women of the Manhattan Project," *Technology Review* 8 (1993): 37, describe the work of women at Los Alamos, "some with degrees in mathematics and others with little technical background," who performed mathematical calculations for the design of the bomb. Amy Sue Bix, "Experiences and Voices of Eugenics Field-Workers: 'Women's Work' in Biology," *Social Studies of Science* 27 (1997): 625–68, reports the work of female field-

low budgets, an available pool of educated women, a lack of men, a woman who could act as an intermediary (such as a male scientist's wife), and a somewhat enlightened employer in a climate generally resistant to female employees entering traditionally male domains. Craving opportunities to use their skills, some women colluded with this sexual division of labor. Many did not aspire to professional employment at higher levels.[11]

Occupational feminization in the sciences fostered long-term invisibility. For example, beginning in the 1940s, laboratories hired women to examine the nuclear and particle tracks on photographic emulsions.[12] Until the 1950s, published copies of photographs that each woman scanned bore her name. Yet eventually the status of these women's work eroded. Later publications were subsumed under the name of the lab leader, inevitably a man, and publicity photographs rarely showcased women's contributions. Physicist Cecil Powell's request for "three more microscopes and three girls" suggests how invisibility and interchangeability went hand in hand.[13] In a number of laboratories, scientists described women not as individuals, but rather as a collective, defined by their lab leader ("Cecil's Beauty Chorus") or by their machines ("scanner girls"). Likewise in the ENIAC project, female operators are referred to as "[John] Holberton's group" or as "ENIAC girls." Technicians generally did not author papers or technical manuals. Nor did they acquire the coveted status symbols of scientists and engineers: publications, lectures, and membership in professional societies. Ultimately these women never got a public opportunity to display their technical knowledge, crucial for personal recognition and career advancement.

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workers at the Eugenics Record Office, who gathered data on individuals and families. In every case the work was subordinate to men's. See also Jane S. Wilson and Charlotte Serber, eds., *Standing By and Making Do: Women of Wartime Los Alamos* (Los Alamos, N.M., 1988).

11. See Rossiter, *Women Scientists in America* (both volumes). According to Herman Goldstine, it was the fact that women were not seeking career advancement that made them ideal workers: "In general women didn't get Ph.D.'s. You got awfully good women because they weren't breaking their backs to be smarter than the next guy." Herman Goldstine, interview by author, Philadelphia, 16 November 1994. Goldstine also noted that the few men he encountered working on programming rarely conceived of their jobs as permanent. Rather, they were steps on the way to something better. These jobs were "never careers for them, but a way of making money for a short time." Consequently, Goldstine observes, "Men in general were lousy—the brighter the man the less likely he was to be a good programmer. . . . The men we employed were almost all men who wanted Ph.D.'s in math or physics. This [hands-on work] was a bit distasteful. I think they viewed what they were doing as something they were not going to be doing for a career. If you take a woman like Hedi Selberg [a programmer at the Institute for Advanced Study Electronic Computer Project] she probably didn't want to sit around with the baby all the time."

12. Galison cites the invention and popularization of the term "scanner girl."

13. Ibid., 176.

Wartime labor shortages stimulated women's entry into new occupations, and computing was no exception.[14] Ballistics computing, a man's job during World War I, was feminized by World War II. A memorandum from the Computing Group Organization and Practices at the National Advisory Committee for Aeronautics (NACA), dated 27 April 1942, explains how the NACA conceived the role of computers: "It is felt that enough greater return is obtained by freeing the engineers from calculating detail to overcome any increased expenses in the computers' salaries. The engineers admit themselves that the girl computers do the work more rapidly and accurately than they would. This is due in large measure to the feeling among the engineers that their college and industrial experience is being wasted and thwarted by mere repetitive calculation."[15]

Patterns of occupational segregation developed in selected industries and job categories newly opened to women.[16] Women hired as computers and clerks generally assisted men. Captain Herman Goldstine, an ENIAC project leader, served as liaison from the U.S. Army's Ballistic Research Laboratory (BRL) to the Moore School of Electrical Engineering at the University of Pennsylvania, which produced ENIAC, and director of computer training for BRL. He recalls that by World War II "there were a few men [computers] but only a few. Any able-bodied man was going to get taken up into the armed forces."[17] With feminization came a loss of techni-

14. For further discussion of prewar trends in hiring practices, see Lisa Fine, *The Souls of the Skyscraper: Female Clerical Workers in Chicago, 1870–1930* (Philadelphia, 1990), and Margery Davies, *Women's Place is at the Typewriter: Office Work and Office Workers, 1870–1930* (Philadelphia, 1982). See also Milkman (n. 2 above), chaps. 1–3.

15. Paul Ceruzzi, "When Computers Were Human," *Annals of the History of Computing* 13 (1991): 242.

16. Cf. Milkman, 49: "The boundaries between 'women's' and 'men's' work changed location, rather than being eliminated. . . . Rather than hiring women workers to fill openings as vacancies occurred, managers explicitly defined some war jobs as 'suitable' for women, and others as 'unsuitable,' guided by a hastily revised idiom of sex-typing that adapted prewar traditions to the special demands of the war emergency." Both Milkman and Fine discuss how gender-specific advertisements reflect the feminization of specific occupations. Fine offers an analysis of the shifting gender imagery of some clerical occupations. On this point, however, note that focusing on the industry's language about women (in this case, the stories about the biological capacities and natural implications of womanhood—or, by extension, on the advertising techniques used to create a gendered labor force) can confuse industry ideals with women's actual practice. As Milkman's notion of the idiom of sex-typing suggests, there is indeed a disjuncture between women's prescribed place and what women actually did. This disjuncture is central to women's invisibility in technological history.

17. Goldstine interview (n. 11 above). The domain's masculinity appears in the preface of a textbook on exterior ballistics: Office of the Chief of Ordnance, *The Method of Numerical Integration in Exterior Ballistics: Ordnance Textbook* (Washington, D.C., 1921). "The names of the men who have contributed most to its [the text's] development, particularly Major Moulton and Professor Bliss, are mentioned in various places in the text, and to whom the writer might appropriately make personal acknowledgement, would

cal status, since other men doing more "important" technical and classified work remained in noncombatant positions. Thus, the meaning of "wartime labor shortage" was circumscribed even as it came into being. While college-educated engineers considered the task of computing too tedious for themselves, it was not too tedious for the college-educated women who made up the majority of computers.[18] These were not simply cases of women taking on men's tasks, but rather of the emergence of new job definitions in light of the female workforce.[19] Celebrations of women's wartime contributions thus rarely challenged gender roles. Rather, popular accounts portrayed civilian jobs for women as appropriately feminine, "domestic" work for the nation—despite the fact they were formerly done by men.[20]

The introduction of technology also facilitated women's entry into paid labor. Machines stimulated the reorganization of work processes, often leading to the creation of new occupations and the culling of older ones. In both

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amount practically to an enumeration of all the officers, civilian investigators, and computers who have been connected with the work in ballistics in Washington and at the Aberdeen Proving Ground."

18. The heads of the computing groups were all college graduates, as were the majority of computers.

19. "The title 'engineering computer' was created for these women, since such work before the war was done by young, junior engineers as part of their induction training following graduation from an engineering college." U.S. Department of Labor, "Women in Architecture and Engineering," *Women's Bureau Bulletin* 223–25 (1948): 56. See Sharon Hartmann Strom, *Beyond the Typewriter: Gender, Class, and the Origins of Modern American Office Work, 1900–1930* (Urbana, Ill., 1992), for a discussion of similar circumstances within American businesses. To call a particular job "feminized" does not restrict it to women. Certainly there were some male computers and programmers. For a review of literature on gender and technology, see Nina Lerman, Arwen Palmer Mohun, and Ruth Oldenziel, "Versatile Tools: Gender Analysis and the History of Technology," *Technology and Culture* 38 (1997): 1–30.

20. The idiom of sex-typing made the sexual division of labor seem natural; differences in work capacity were considered biologically based. Evelyn Steele, editorial director of *Vocational Guidance Research*, writes, "It is generally agreed that women do well at painstaking, tedious work requiring patience and dexterity of the hands. The actual fact that women's fingers are more slender than men's makes a difference. Also, women adapt themselves to repetitive jobs requiring constant alertness, nimble fingers and tireless wrists. They have the ability to work to precise tolerances, can detect variations of ten-thousandths of an inch, [and] can make careful adjustments at high speed with great accuracy"; Steele (n. 4 above), 46. Women's strengths thus lay in performing repetitive, detailed, unskilled tasks. Such statements were not new. Arguments made in favor of women working as telephone operators were similar: "The work of successful telephone operating demanded just that particular dexterity, patience and forbearance possessed by the average woman in a degree superior to that of the opposite sex." Brenda Maddox, "Women and the Switchboard," in *The Social Impact of the Telephone*, ed. Ithiel de Sola Pool (Cambridge, Mass., 1977), 266. See also Fine (n. 14 above), chap. 4, "The Discourse on Fitness: Science and Symbols." For a discussion of women's wartime labor as portrayed in literature and advertising, see Charles Hannon, "'The Ballad of the Sad Cafe' and Other Stories of Women's Wartime Labor," *Genders* 23 (1996): 97–119.

clerical and factory work, introducing technology changed some jobs so that women performed slightly different tasks rather than substituting directly for men. Women's entry into the workforce was greatest in new occupations where they did not displace men.[21] Once a particular job was feminized this classification gathered momentum, often broadening to include other occupations.[22] By World War II, computing was feminized across a variety of fields, including engineering, architecture, ballistics, and the aircraft industry. The new machines, capable of replacing hundreds of human computers, required human intervention to set up mathematical problems. Without a gendered precedent, the job of computer operator, like the newly created jobs of "stenographer typist" and "scanning girl," became women's work. There is, of course, a fundamental difference between the human computer and the programmer who transfers this skill to an automated process. In the 1940s, the skill of transferring this information—what we now call programming—fit easily with notions about women's work. As an extension of the job of a human computer, this clerical task offered slightly higher status and higher pay than other kinds of clerical labor.[23]

## Female Computers and ENIAC Girls

Like much of scientific research and development during World War II, the ENIAC was the offspring of a wartime alliance between a university (the University of Pennsylvania, specifically the Moore School of Electrical Engineering) and the U.S. armed forces, in this case the Army Proving

21. For a further discussion of the prewar situation and the complex interaction between new technologies and the sexual division of labor, see Fine, also Davies (n. 14 above). Jobs with a more established tradition of male employment were less likely to become feminized before World War II. For example, while "clerk" and "bookkeeper" stayed largely male, feminization was more widespread in stenography because it had not been defined as male. See Milkman (n. 2 above), chap. 4. For further discussion of how new jobs were gendered, see Heidi Hartmann, Robert Kraut, and Louise Tilly, eds., *Computer Chips and Paper Clips: Technology and Women's Employment*, 2 vols. (Washington, D.C., 1986), vol. 1, chap. 2.

22. See Rossiter, *Women Scientists in America: Struggles and Strategies to 1940* (n. 10 above), and Milkman.

23. At the time, women were concentrated in clerical roles more than in any other occupation; they comprised 54 percent of all clerical workers in 1940 and 62 percent in 1950. U.S. Department of Labor, "Changes in Women's Occupations 1940–1950," *Women's Bureau Bulletin* 253 (1954): 37. Clerical work encompasses a broad range of jobs, including office machine operators. The Employment and Training Administration and U.S. Employment Service's *Dictionary of Occupational Titles* (Washington, D.C., 1939–41) classified computing-machine operator and calculating-machine operator as entry-level clerical occupations. For further discussion of the wide range of clerical jobs, see Strom (n. 19 above) and Fine. See also David Alan Grier, "The ENIAC, the Verb 'to program' and the Emergence of Digital Computers," *IEEE Annals of the History of Computing* 18, no. 1 (1996): 51–55.

Ground (APG) in Aberdeen, Maryland. The APG housed the army's Ballistic Research Laboratory (BRL), which produced range tables for gunners. During the war, BRL recruited approximately two hundred women to work as computers, hand-calculating firing tables for rockets and artillery shells. In 1940, when President Franklin D. Roosevelt declared a national emergency, BRL commandeered the Moore School's differential analyzer and began to move some of its work to the university.[24]

One of the first women the army hired to work at the Moore School was twenty-two-year-old Kathleen McNulty. She had graduated in 1942 from Chestnut Hill College, in Philadephia, with one of the three math degrees awarded in her class. McNulty and her friend Frances Bilas answered an advertisement in a local paper that said Aberdeen was hiring mathematicians:

> I never heard of numerical integration. We had never done anything like that. Numerical integration is where you take, in this particular case . . . [the] path of a bullet from the time it leaves the muzzle of the gun until it reaches the ground. It is a very complex equation; it has about fifteen multiplications and a square root and I don't know what else. You have to find out where the bullet is every tenth of a second from the time it leaves the muzzle of the gun, and you have to take into account all the things that are going to affect the path of the bullet. The very first things that affect the path of the bullet [are] the speed at which it shoots out of the gun [the muzzle velocity], the angle at which it is shot out of the gun, and the size. That's all incorporated in a function which they give you—a [ballistic] coefficient.
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> As the bullet travels through the air, before it reaches its highest point, it is constantly being pressed down by gravity. It is also being acted upon by air pressure, even by the temperature. As the bullet reached a certain muzzle velocity—usually a declining muzzle velocity, because a typical muzzle velocity would be 2,800 feet per second [fps]—when it got down to the point of 1,110 fps, the speed of sound, then it wobbled terribly. . . . So instead of computing now at a tenth of a second, you might have broken this down to one one hundredth of a second to very carefully calculate this path as it went through there.

24. It was part of a prior agreement with the Moore School that in times of national emergency the Aberdeen Proving Ground could commandeer the school's differential analyzer. Lydia Messer, oral history, interview by Cornelius Weygandt, 22 March 1988, University of Pennsylvania Archives, Philadelphia. Joel Shurkin, *Engines of the Mind* (New York, 1984), 119. BRL had apparently organized previous cooperative projects during World War I with the University of Pennsylvania. The U.S. Army Ordnance Department's *Course in Exterior Ballistics: Ordnance Textbook* (Washington, D.C., 1921) credits H. H. Mitchell of the University of Pennsylvania as "Master Computer, who organized the range table computation work at Aberdeen." Before 1941, the Moore School also provided computers for BRL. Nancy Stern, *From ENIAC to UNIVAC: An Appraisal of the Eckert-Mauchly Computers* (Bedford, Mass., 1981), 10.

> Then what you had to do, when you finished the whole calculation, you interpolated the values to find out what was the very highest point and where it hit the ground.[25]



The work required a high level of mathematical skill, which included solving nonlinear differential equations in several variables: "Every four lines we had to check our computations by something called Simpson's rule to prove that we were performing the functions correctly. All of it was done using numbers so that you kept constantly finding differences and correcting back."[26] Depending upon their method, the computers could calculate a trajectory in somewhere between twenty minutes and several days, using the differential analyzer, slide rules, and desktop commercial calculators.[27] Despite the complexities of preparing firing tables, in this feminized job category McNulty's appointment was rated at a subprofessional grade. The BRL also categorized women like Lila Todd, a computer supervisor when McNulty started work at the Moore School, as subprofessional.[28]

Herman Goldstine recalls that BRL hired female computers almost exclusively. At first, most women were recent college graduates in the Baltimore and Philadelphia area. Adele Goldstine, his wife and a senior computer, expanded recruiting to include colleges across the Northeast, but the project still needed more personnel.[29] In a short time, recalls Goldstine, "We used up all of the civil service women we could get our hands on."[30] A memo to University of Pennsylvania provost George McClelland from Harold Pender, dean of the Moore School, explained how BRL sought to remedy the situation: "Colonel Simon, Chief of the Ballistic Research Laboratory, has had a specially selected group of WACs assigned to the

25. Shurkin, 128.

26. Shurkin, 127–28.

27. Stern, 13–14.

28. Not all women's jobs ranked lower or earned less than men's, but the history of female employment shows a persistent pattern into which the BRL's policies fit. For example, see Sharon Hartmann Strom, "'Machines Instead of Clerks': Technology and the Feminization of Bookkeeping, 1910–1950," in Hartmann, Kraut, and Tilly (n. 21 above), 2:63–97. See Fritz (n. 3 above) for women's accounts of the work they performed and H. Polachek, "Before the ENIAC," *IEEE Annals of the History of Computing* 19, no. 2 (1997): 25–30, for the complexities of computations for preparing firing tables.

29. Adele Goldstine received her bachelor's degree from Hunter College in 1941, then a master's from the University of Michigan in 1942. In 1942 she taught mathematics in the public school system in Philadelphia. From late 1943 to March 1946 she worked for the ENIAC project at the Moore School and spent part of 1944 at the Aberdeen Proving Ground. In 1948, she resumed graduate study at New York University. She became a consultant to the Atomic Energy Commission project effective 7 June 1947, working on making the ENIAC into a stored-program computer. Herman Goldstine recalls that "Los Alamos was the major user of the ENIAC so it was [John] Von Neumann [who was using it]. Adele was his assistant. I was also a consultant but she was doing the major part." Goldstine interview (n. 11 above).

30. Ibid.

Laboratory. Although these women have been individually picked they are for the most part ready for training and are not trained persons who can enter fully into the Laboratory's work. . . . By consulting appropriate persons on the campus it appears that this can be carried out without interfering with any of the University's regular work. . . . Under the above circumstances it appears that the University's regular work will not be disturbed and at the same time we will have the opportunity to do a rather important service."[31] Pender's memo embodies a more widespread ambivalence about women's wartime contributions, particularly as members of the military. While "specially selected" for a "rather important" task these women were simultaneously "not trained persons" and could not enter "fully" into the BRL's work.

Colonel Simon assigned two groups of WACs to work as computers. One used desk calculators and the differential analyzer for practical work at the BRL, while the other studied mathematics for ballistics computations at the University of Pennsylvania. These two groups alternated monthly for eight months. The first WAC course started on 9 August 1943. According to reports in the *Daily Pennsylvanian*, the university's student newspaper, these women assimilated smoothly into campus life:

> The WACs at present stationed on the University campus are members of two groups alternating in a special course at the Moore School of Electrical Engineering, and were detached from the unit at Aberdeen Proving Ground, Maryland. At Aberdeen most of them were assigned as computers. The two sections, each of which numbers approximately thirty women, are commanded by second lieutenants and corporals. They are taking courses that are equivalent to the work of a college mathematics major. The results of these studies will later be used in ballistic work at the Ballistic Research Laboratory of the Army Ordnance Department. They are stationed at the Moore School of Electrical Engineering rather than at any other University school because of the large amount of work that the Moore School has done in collaboration with the Ballistic Research Laboratory. They are quartered in the fraternity house [Phi Kappa Sigma], messed in Sergeant Hall, and receive physical training at Bennett Hall. They are required to police their own rooms and be in bed at eleven forty-five P.M., with the exception of weekends. Reveille must be answered at 7:10 A.M.[32]

31. Harold Pender to George McCelland, 23 July 1943, Information Files: World War II: WAC Training: Miscellaneous, University of Pennsylvania Archives.

32. *Daily Pennsylvanian*, 29 September 1943, untitled clipping in Information Files: World War II: WAC Training: Miscellaneous, University of Pennsylvania Archives. While women received instructions from civilians (not an unusual practice in the armed services), they were commanded by military second lieutenants and corporals. The WAC officer in charge of the detachment on campus was Lt. Mildred Fleming.

In this straightforward report, the student reporter neglects to mention the concurrent and widespread tensions surrounding WACs. Only a month earlier, on 1 July 1943, President Roosevelt had signed legislation converting the Women's Auxiliary Army Corps to full military status as the WAC. The conversion was scheduled for implementation by 1 October. According to WAC historian Mattie Treadwell, "The following ninety days of the summer of 1943, initially called The Conversion, were perhaps the busiest in the history of the Corps."[33]



While the article quoted several WACs commenting about their campus lives in a quite positive tone, Adele Goldstine, in an undated letter to a correspondent, reported, "Rumor hath it that the WACs (Sec. I) have been told that they're unloved by everybody including the ES&MWTesses. If it's true, I'm sorry to hear it because I'm afraid it will make our uphill fight steeper."[34] Her letter suggests that the women's presence on campus had become the "interference" and "disturbance" intimated by Simon's memo. Indeed, ambivalence about The Conversion had triggered slander campaigns against WACs from 1943. The cold reception of WAC volunteers was a product not only of news media but also of local gossip: "Resentment was expressed in towns where WACs were quartered, to the effect that they were spoiling the character of the town."[35] The WACs in Philadelphia may have experienced some of the more widespread hostility towards enlisted women.

Separated by skill level into two groups, the WACs at the Moore school had forty hours of classroom instruction per week. According to the syllabus, the course was designed to treat "in succinct form the mathematics which a person should have to work on physical problems such as those likely to be met in the Ballistic Research Laboratory."[36] The mathematics

33. Mattie Treadwell, *United States Army in World War Two Special Series: The Women's Army Corps* (Washington, D.C., 1954), 221.

34. Adele Goldstine to J. G. Brainerd, n.d., "Monday Night," Information Files: World War II: WAC Training: Miscellaneous, University of Pennsylvania Archives. The ES&MWTesses were the women involved in the Engineering, Science, and Management War Training courses. J. G. Brainerd was a professor at the Moore School and liaison with U.S. Army Ordnance.

35. Helen Rogan, *Mixed Company: Women in the Modern Army* (New York, 1981), 41; Treadwell, chap. 4. Building on the work of historians such as Milkman (n. 2 above) and Fine (n. 14 above), who have analyzed the need for women in men's jobs to maintain femininity, Leisa Meyer has described the sexual politics of women's entrance into military service; see "Creating G.I. Jane: The Regulation of Sexuality and Sexual Behavior in the Women's Army Corps During World War Two," *Feminist Studies* 18 (1992) 581–601, and *Creating G.I. Jane: Sexuality and Power in the Women's Army Corps during World War Two* (New York, 1996).

36. "Topics Included in the Engineering, Science, and Management War Training Courses for Members of the W.A.C. from Aberdeen Proving Ground," Information Files: World War II: WAC Training: Miscellaneous, University of Pennsylvania Archives. There was a second training course in 1945; Herman Goldstine Papers, American Philosophical Society Library, Philadelphia (hereinafter Goldstine Papers).

ranged from elementary algebra to simple differential equations. In addition, a unit on the use of calculating machines covered computation- and calculation-machine techniques, handling numerical data, organizing work for machine calculation, and using slide rules.

The instructors included three men (a Dr. Sohon, a Mr. Charp, and a Mr. Fliess) and nine women (Adele Goldstine, Mary Mauchly, Mildred Kramer, Alice Burks, a Mrs. Harris, a Miss Mott, a Miss Greene, a Mrs. Seeley, and a Mrs. Pritkin). Accounts of ENIAC that discuss the WAC course, such as Goldstine's book and the civilian women's own reflections, mention as instructors only three married women: Adele Goldstine, Mary Mauchly, wife of John Mauchly of the Moore School, and Mildred Kramer, wife of Samuel Noah Kramer, a professor of Assyriology at the University of Pennsylvania. Yet archival records show that this is not the full story.[37] Perhaps this oversight is consistent with a different trend Rossiter discusses—that more prominent women in science were often married to notable men, also often scientists. It is unclear whether Goldstine, Mauchly, and Kramer became "visible" because their husbands' visibility accorded them extra attention, because these men somehow facilitated their wives' careers, or because the women themselves campaigned for recognition.

"Thanks for the Memory," a song presumably written by several WACs, offers a playful account of their time at the Moore School:

> Of days way back when school
> Was just the daily rule
> When we just studied theories
> For fun and not as tools—thank you so much.

37. Goldstine, *The Computer from Pascal to Von Neumann* (n. 3 above), 134; Fritz (n. 2 above). The histories of other sciences, in both Britain and the United States, show scientists' wives filling a number of the more senior women's positions in science. For example, Cecil Powell's wife Isobel led the scanning girls in Powell's laboratory, and Janet Landis Alvarez, wife of Luis Alvarez, trained the women bubble-chamber scanners at Berkeley. Among the computers at NACA were a number of engineers' wives. At the Los Alamos Scientific Laboratory, John Von Neumann's second wife, Klara Dan Von Neumann, became a programmer and helped to program and code some of the largest programs of the 1950s. Also at Los Alamos were Kay Manley, wife of John Manley, and Mici Teller, wife of Edward Teller, who performed mathematical calculations for the design of the bomb. For further discussion of couples in the sciences, see Helena M. Pycior, Nancy G. Slack, and Pnina G. Abir-Am, eds., *Creative Couples in the Sciences* (New Brunswick, N.J., 1996). According to Fritz, at least four computers married engineers at the Moore School after 1946. Frances Bilas married Homer Spence, Kathleen McNulty became Mauchly's second wife, and Elizabeth Snyder married John W. Holberton. According to Goldstine, Betty Jean Jennings (Bartik) married a Moore School engineer. Also at the Moore School were Eckert's first wife, a draftsman for the ENIAC project; Alice Burks, whose husband Arthur worked with Eckert and Mauchly on the ENIAC design; and Emma Lehmer, wife of Derrick Henry Lehmer, a computer and table compiler.

Of lectures running late
Of Math that's mixed with paint
Of dainty slips that ride up hips
And hair-do-ups that ain't—thank you so much.

Many's the time that we fretted
And many's the time that we sweated
Over problems of Simpson and Weddle
But we didn't care—for c'est la guerre!

That Saturday always came
And teach ran for her train
If she didn't lam—like Mary's lamb
Her pets to Moore School came—thank you so much.

Machines that dance and dive
Of numbers that can jive
Of series that do leaps and bounds
Until you lose the five—thank you so much.

Of half-hour luncheon treks
How we waited for our checks!
Of assets, liabilities—
Till all of us were wrecks—thank you too much.

We squared and we cubed and we plotted
And many lines drew and some dotted
We've all developed a complex
Over wine, sex, and $f(x)$

Of private tete-a-tetes
And talk about our dates
And how we wish that teacher would oblige
By coming late—thank you so much.

And so on through the night.[38]

Even as the WAC courses went on, Moore School engineers were designing a machine to automate the production of the same firing and bombing tables calculated by the human computers: the ENIAC. Engineers wanted answers faster than women could supply them using available technologies. Yet ENIAC couldn't do everything itself. Programming equations into the machine required human labor.[39] The eventual transfer of computing from

38. "Thanks for the Memory," presumably written by WACs at the Moore School, ca. 1943–44, Goldstine Papers.

39. In a retrospective analysis, Goldstine framed the computers' job as a prime candidate for mechanization due to its low skill: "Computing is thus subhuman in that it calls

human to machine led to shifting job definitions. A "computer" was a human being until approximately 1945. After that date the term referred to a machine, and the former human computers became "operators."[40]

Herman Goldstine recounts selecting the operators. At BRL, one group of women used desk calculators and another the differential analyzer. Selecting a subgroup from each, Goldstine "assigned six of the best computers to learn how to program the ENIAC and report to [John] Holberton," employed by the Army Ordnance Department to supervise civilians.[41] With no precedents from either sex, the creation and gendering of "computer operator" offers insight into how sexual divisions of labor gather momentum. Computing was a female job, and other female clerical workers operated business machines. So it was not unusual that in July 1945, women would migrate to a similar but new occupation. The six women—Kathleen McNulty, Frances Bilas, Betty Jean Jennings, Ruth Lichterman, Elizabeth Snyder, and Marlyn Wescoff—reported to the Moore School to learn to program the ENIAC.

The ENIAC project made a fundamental distinction between hardware and software: designing hardware was a man's job; programming was a woman's job. Each of these gendered parts of the project had its own clear status classification. Software, a secondary, clerical task, did not match the importance of constructing the ENIAC and getting it to work.[42] The female

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on very few of man's manifold abilities and yet is fundamental to many of his other activities, as Leibnitz so clearly perceived. This then is basically why computing was chosen as a human task to be mechanized"; Goldstine, *The Computer from Pascal to Von Neumann*, 343.

40. It is unclear exactly when this shift occurred. It was at least as early as February 1945, when George Stibbitz wrote in a report on relay computers for the National Defense Research Committee: "Human agents will be referred to as 'operators' to distinguish them from 'computers' (machines)." Ceruzzi (n. 15 above), 240.

41. Goldstine interview (n. 11 above). Interestingly, Milkman (n. 2 above) has discussed how jobs perceived as feminine in some places were quintessentially masculine in others—often within the same industry. The idiom of sex-typing, while consistent in individual factories, often differed among factories manufacturing the same product. On the Mark II computer at the Navy's Dahlgren Proving Ground, for instance, operators were male. This area deserves further study.

42. The terms *hard* and *soft*, as used to describe gendered tasks, are significant. For the hard and soft sciences, hard mastery and soft mastery are binary distinctions in science and technology implying that the "hard" ways of knowing are men's domain; "soft" ways of knowing are more feminine. Goldstine, when interviewed, reported that he had resisted "there being a distinction" between hardware and software. He observed: "At the beginning, the hardware was the important thing, but as soon as you get beyond the bottleneck of making the computer," programming software became a new bottleneck. "They've automated the bejeezus out of making chips but not software." Ironically, by the time the process of making hardware was automated programming software had become a man's job and acquired higher status than it had had in the 1940s. See, for example, Phillip Kraft, "The Routinization of Computer Programming," *Sociology of Work and Occupations* 6 (1977): 139–55.

programmers carried out orders from male engineers and army officers. It was these engineers and officers, the theoreticians and managers, who received credit for invention. The U.S. Army's social caste system is historically based on European gentlemen's social codes.[43] As civil servants, the six women computers chosen to operate the ENIAC stood outside this system.

Yet if engineers originally conceived of the task of programming as merely clerical, it proved more complex. Under the direction of Herman and Adele Goldstine, the ENIAC operators studied the machine's circuitry, logic, physical structure, and operation. Kathleen McNulty described how their work overlapped with the construction of the ENIAC: "Somebody gave us a whole stack of blueprints, and these were the wiring diagrams for all the panels, and they said 'Here, figure out how the machine works and then figure out how to program it.' This was a little bit hard to do. So Dr. Burks at that time was one of the people assigned to explain to us how the various parts of the computer worked, how an accumulator worked. Well once you knew how an accumulator worked, you could pretty well be able to trace the other circuits for yourself and figure this thing out."[44]

Understanding the hardware was a process of learning by doing. By crawling around inside the massive frame, the women located burnt-out vacuum tubes, shorted connections, and other nonclerical bugs.[45] Betty Jean Jennings's description confirms the ingenuity required to program at the machine level and the kinds of tacit knowledge involved:

> We spent much of our time at APG learning how to wire the control board 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

43. Jeanne Holm, *Women in the Military: An Unfinished Revolution*, rev. ed. (Novato, Calif., 1992), 73. Social mores, as well as a variety of rules and regulations, meant that women's qualifications had to surpass men's before they could compete for higher-level jobs within academia (including government-sponsored research) and industry. The army had higher selection criteria for female officers and enlisted personnel "than those for men in the same service" (p. 50). P.L. 110, the legislation converting the WAC to full military status, specified that "its commanding officer could never be promoted above the rank of colonel and its other officers above the rank of lieutenant colonel; its officers could never command men unless specifically ordered to do so by Army superiors" (Treadwell [n. 33 above], 220). Additionally, the War Department in 1943 set the ratio of female officers to enlisted women at one to twenty. Comparable figures for men were one to ten. Using the excuse of a surplus of male officers, it capped WAC officers by limiting entrants to the WAC Officer Candidate School but did not impose a similar limitation on male officers. None of the six women ENIAC operators held high status in academia or the military. Men at the Moore School who were not affiliated with the army, such as Harry Huskey or Arthur Burks, had visible academic appointments. See Rossiter, *Women Scientists in America: Before Affirmative Action, 1940–1972* (n. 9 above), for more on hierarchies, promotions, and payment in science.

44. Shurkin (n. 24 above), 188.

45. Kraft (n. 42 above), 141.

> APG people had developed for the tabulator. . . . 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.[46]

Framing the ENIAC story as a case study of the mechanization of female labor, it would be hard to argue that de-skilling accompanied mechanization.[47] The idiom of sex-typing, which justified assigning women to software, contradicted the actual job, which required sophisticated familiarity with hardware. The six ENIAC operators understood not only the mathematics of computing but the machine itself. That project leaders and historians did not value their technical knowledge fits the scholarly perception of a contradiction between the work actually performed by women and the way others evaluate that work. In the words of Nina Lerman, "Gender plays a role in defining which activities can readily be labeled 'technological.'"[48]

Meanwhile, at the Los Alamos Scientific Laboratory in New Mexico, scientists were preparing a new thermonuclear weapon, the Super. Stanley Frankel and Nicholas Metropolis, two Los Alamos physicists, were working on a mathematical model that might help to determine the possibility of a thermonuclear explosion. John Von Neumann, a technical consultant, suggested that Los Alamos use ENIAC to calculate the Super's feasibility. Once Von Neumann told Herman Goldstine about this possible use, Herman and Adele invited Frankel and Metropolis to Philadelphia and offered them

46. Fritz (n. 2 above), 19–20.

47. A number of historians have disputed de-skilling assumptions. For example, Sharon Hartmann Strom, "'Machines Instead of Clerks'" (n. 28 above), 64, describes in the case of bookkeeping machine operators how "workers continued to apply hidden skills of judgement and to integrate a number of tasks, particularly to jobs in the middle levels of bookeeping, even though these jobs required the use of machines." Fine (n. 14 above), 84, claims that the stenographer-typist's job was more challenging than the copyist's whom she replaced. For a review of literature on gender, mechanization, and de-skilling, see Nina Lerman, Arwen Palmer Mohum, and Ruth Oldenziel, "The Shoulders We Stand On and the View from Here: Historiography and Directions for Research," *Technology and Culture* 38 (1997): 9–30. See also Kenneth Lipartito, "When Women Were Switches: Technology, Work, and Gender in the Telephone Industry, 1890–1920," *American Historical Review* 99 (1994): 1075–111.

48. Nina Lerman, "'Preparing for the Duties and Practical Business of Life': Technological Knowledge and Social Structure in Mid-19th-Century Philadelphia," *Technology and Culture* 38 (1997): 36. Judy Wajcman, *Feminism Confronts Technology* (University Park, Penn., 1991), 37, observes: "Definitions of skill can have more to do with ideological and social constructions than with technical competencies which are possessed by men and not by women."

training on the ENIAC. When the two physicists arrived in Philadelphia in the summer of 1945, Adele Goldstine and the women operators explained how to use the machine. McNulty recalled that "We had barely begun to think that we had enough knowledge of the machine to program a trajectory, when we were told that two people were coming from Los Alamos to put a problem on the machine."[49] Despite such self-effacing comments, the operators demonstrated impressive mastery of the ENIAC during the collaboration with the Los Alamos physicists. By October, the two theoretical physicists had programmed their elaborate problem on huge sheets of paper. Then, the women programmed it into the machine, which no one had formally tested. As McNulty explained, "No one knew how many bad joints there were, and how many bad tubes there were, and so on."[50] The cooperative endeavor furthered the operators' intimate understanding of ENIAC as they pushed it to a new level of performance. Programming for Frankel and Metropolis took one million IBM punch cards, and the machine's limited memory forced the women to print out intermediate results before repunching new cards and submitting them to the machine. Within a month, the Los Alamos scientists had their answer—that there were several design flaws.[51]



The "ENIAC girls" turned their attention back to shell trajectory calculations and were still engaged on that project when the war ended. The ENIAC, designed and constructed in military secrecy, was prepared for public unveiling in early 1946. A press conference on 1 February and a formal dedication on 15 February each featured demonstrations of the machine's capabilities. According to Herman Goldstine, "The actual preparation of the problems put on at the demonstration was done by Adele Goldstine and me with some help on the simpler problems from John Holberton and his girls."[52] Indeed, Elizabeth Snyder and Betty Jean Jennings developed the demonstration trajectory program.[53] Although

49. Shurkin, 188.

50. Ibid., 189.

51. C. Dianne Martin, "ENIAC: Press Conference That Shook the World," *IEEE Technology and Society Magazine* 14, no. 4 (1995): 3–10. Because the problem was classified, the equations remained concealed.

52. Goldstine, *The Computer from Pascal to Von Neumann* (n. 3 above), 229. For details of the kinds of calculations performed using ENIAC, see Arthur W. Burks and Alice R. Burks, "The ENIAC: First General-Purpose Electronic Computer," *Annals of the History of Computing* 3 (1981): 310–89. The Burks were another significant husband and wife team, publishing their story together; Alice R. Burks and Arthur W. Burks, *The First Electronic Computer: The Atanasoff Story* (Ann Arbor, Mich., 1988).

53. Fritz (n. 2 above), 20–21. Goldstine recalled bringing Douglas Hartree, a physicist who had built a differential analyzer in Britain, to the United States for a visit. "I got Kay McNulty to be his programmer and she was good and intelligent. The girls soon branched off independently and it was during that period that my wife was making ENIAC into a stored program computer"; Goldstine interview (n. 11 above).

women played a key role in preparing the demonstrations, both for the press and for visitors to the laboratory, this information does not appear in official accounts of what took place.

## Contemporary Accounts of ENIAC

Social constructionist historians and sociologists of science take the position that scientists describing their experimental work do not characterize events as they actually happened.[54] Publicity for technical demonstrations is not so different. In presenting ENIAC to the public, engineers staged a well-rehearsed event. They cooperated with the War Department, which controlled representations of the project through frequent press releases to radio and newspapers.

It is a curious paradox that while the War Department urged women into military and civil service and fed the media uplifting stories about women's achievements during the war, its press releases about a critical project like the ENIAC do not mention the women who helped to make the machine run. War Department press releases characterize ENIAC as "designed and constructed for the Ordnance Department at the Moore School of Electrical Engineering of the University of Pennsylvania by a pioneering group of Moore School experts."[55] They list three individuals as "primarily responsible for the extremely difficult technical phases of work . . . Eckert—engineering and design; Mauchly—fundamental ideas, physics; Goldstine—mathematics, technical liaison."[56] The War Department's selective press releases highlighted certain individuals involved in the ENIAC project while omitting others, specifically the women operators. Because of these omissions the operators were neither interviewed nor offered the opportunity to participate in telling the ENIAC story. Newspaper accounts characterize ENIAC's ability to perform tasks as "intelligent" but the women doing the same computing tasks did not receive similar acclaim.[57] While the media publicly hailed hardware designers as having "fathered" the machine, they

54. See, for example, Bruno Latour, *Science in Action* (Cambridge, 1987).

55. U.S. War Department, Bureau of Public Relations, "Ordnance Department Develops All-Electronic Calculating Machines," press release, February 1946, Goldstine Papers.

56. U.S. War Department, Bureau of Public Relations, "History of Development of Computing Devices," press release, 15–16 February 1946, Goldstine Papers.

57. For media characterizations of ENIAC, see C. Dianne Martin, "The Myth of the Awesome Thinking Machine," *Communications of the ACM* 36, no. 4 (1993): 125, 127; see also Martin, "ENIAC" (n. 51 above), 3–10. Like the laundry industry that made its employees invisible by publicizing the tireless machines, the ENIAC was portrayed as doing almost all of the work; Arwen Mohun, "Laundrymen Construct their World: Gender and the Transformation of a Domestic Task to an Industrial Process," *Technology and Culture* 38 (1997): 97–120.

did not mention women's contributions. The difference in status between hardware and software illustrates another chapter in the story of women in the history of science and technology. The unmentioned computer technicians are reminiscent of Robert Boyle's "host of 'laborants,' 'operators,' 'assistants' and 'chemical servants'" whom Steven Shapin described as "invisible actors." Working three centuries earlier, their fate was the same: they "made the machines work, but they could not make knowledge."[58]

The *New York Times* of 15 February 1946 described Arthur Burks's public demonstration: "The ENIAC was then told to solve a difficult problem that would have required several weeks' work by a trained man. The ENIAC did it in exactly 15 seconds."[59] The "15 seconds" claim ignores the time women spent setting up each problem on the machine. Accompanying photographs of Eckert and Mauchly, the article reported that "the Eniac was invented and perfected by two young scientists of the [Moore] school, Dr. John William Mauchly, 38, a physicist and amateur meteorologist, and his associate, J. Presper Eckert Jr., 26, chief engineer on the project. Assistance was also given by many others at the school. . . . [The machine is] doing easily what had been done laboriously by many trained men. . . . Had it not been available the job would have kept busy 100 trained men for a whole year."[60] While this account alludes to the participation of many individuals other than Eckert and Mauchly, the hypothetical hundred are described as men. Why didn't the article report that the machine easily did calculations that would have kept one hundred trained *women* busy, since BRL and the Moore School hired women almost exclusively as computers? Even in an era when language defaulted to "he" in general descriptions, this omission is surprising, since the job of computer was widely regarded as women's work.[61] Women seem to have vanished from the ENIAC story, both in text and in photographs. One photograph accompanying the *New York Times* story foregrounds a man in uniform plugging wires into a machine. While the caption describes the "attendants preparing the machine to solve a hydrodynamical problem," the figures of two women in the background can be seen only by close scrutiny (fig. 1). Thus, the press conference and follow-up coverage rendered invisible both the skilled labor required to set up the demonstration and the gender of the skilled workers who did it.

The role of the War Department and media in shaping public discourse about the machine and its meaning is significant. Several potential oppor-

58. Steven Shapin, "The House of Experiment in Seventeenth-Century England," *Isis* 79 (1988): 395.

59. T. R. Kennedy, "Electronic Computer Flashes Answers, May Speed Engineering," *New York Times*, 15 February 1946.

60. Ibid.

61. The NACA memorandum (n. 15 above) specifically used *she* to describe the computers in its service. Women played salient roles in the demonstration of many domestic and business technologies, from sewing machines to typewriters to IBM office products, making their omission here all the more pointed.

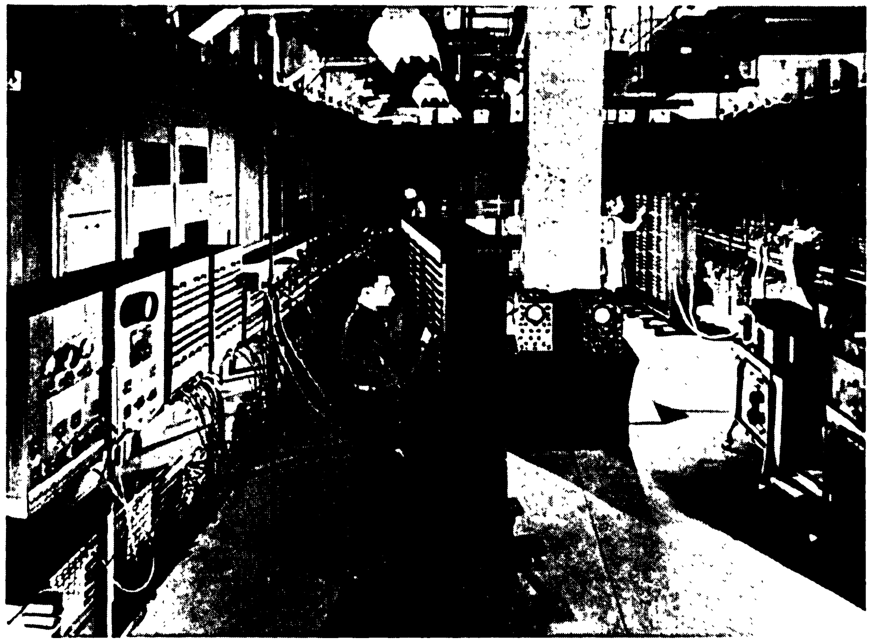

FIG. 1 One of the most widely reprinted photographs of ENIAC, from the *New York Times*, 15 February 1946. (Courtesy of New York Times Pictures.)

tunities for the women operators to get some public attention and credit for their work never materialized. For example, the publicity photograph of the ENIAC printed in the *New York Times* was among the most widely disseminated images of the machine. When it was published as an army recruitment advertisement (fig. 2), the women were cropped out.[62] This action is understandable, at one level, since the operators were all civilians. Yet given the important participation of WACs in closely related wartime work, it constituted another missed opportunity to give the women their due.

Archival records show that photographers came in to record the ENIAC and its engineers and operators at least twice. Neither visit resulted in any publicity for the women. On the first occasion, an anonymous photographer's pictures of the ENIAC group turned out poorly. Herman Goldstine wrote apologetically to Captain J. J. Power, Office of the Chief of Ordnance: "Dear John, I am returning herewith the photographs with sheets of suggested captions. As you can see from looking at these photographs, many of them are exceedingly poor, and, I think, unsuitable for publication."[63] Nonetheless, the captions for these unsuitable photographs are instructive:

62. See, for example, *Popular Science Monthly*, October 1946, 212.

63. Herman Goldstine to Captain J. J. Power, Office of the Chief of Ordnance, 17 January 1946, Goldstine Papers.

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HOW MUCH IS $\sqrt[3]{2589^{16}}$?

**The Army's ENIAC can give you the answer in a fraction of a second!**

Think that's a stumper? You should see *some* of the ENIAC's problems! Brain twisters that if put to paper would run off this page and feet beyond . . . addition, subtraction, multiplication, division—square root, cube root, any root. Solved by an incredibly complex system of circuits operating 18,000 electronic tubes and tipping the scales at 30 tons!

The ENIAC is symbolic of many amazing Army devices with a brilliant future for you! The new Regular Army needs men with aptitude for scientific work, and as one of the first trained in the post-war era, you stand to get in on the ground floor of important jobs which have never before existed. You'll find that an Army career pays off.

The most attractive fields are filling quickly. Get into the swim while the getting's good! 1½, 2 and 3 year enlistments are open in the Regular Army to ambitious young men 18 to 34 (17 with parents' consent) who are otherwise qualified. If you enlist for 3 years, you may choose your own branch of the service, of those still open. Get full details at your nearest Army Recruiting Station.

**YOUR REGULAR ARMY SERVES THE NATION AND MANKIND IN WAR AND PEACE**

212 POPULAR SCIENCE

**A GOOD JOB FOR YOU**
**U. S. Army**
**CHOOSE THIS FINE PROFESSION NOW!**

FIG. 2 This advertisement appeared in *Popular Science Monthly,* October 1946. (Army materials courtesy of the U.S. Government, as represented by the Secretary of the Army.)

> VIEW OF ONE SIDE OF THE ENIAC: Miss Frances Bilas (Philadelphia, Pa.) and Pfc. Homer W. Spence (Grand Rapids, Mich.) are setting program switches. Miss Bilas is an ENIAC operator in the employ of the Ballistic Research Laboratory, Aberdeen Proving Ground, Md., and Pfc. Spence is a maintenance engineer. . . .
>
> SETTING UP A PROBLEM ON THE ENIAC: Reading from left to right, Miss Akrevoe Kondopria (Philadelphia, Pa.) at an accumulator, Miss Betty Jennings (Stanbury, Mo.), Cpl. Irwin Goldstein (Brooklyn, NY) and Miss Ruth Lichterman (Rockaway, NY) standing at function tables. Miss Kondopria is a Moore School employee on the ENIAC project; Miss Jennings and Miss Lichterman are ENIAC operators employed by the Ballistic Research Laboratory, Aberdeen Proving Ground, Md., and Cpl. Goldstein is a maintenance engineer. . . .
>
> SETTING UP A PROBLEM ON THE ENIAC: Reading from left to right, Miss Betty Snyder (Narberth, Pa.), Miss Betty Jennings (Stanbury, Mo.), Miss Marlyn Wescoff (Philadelphia, Pa.) and Miss Ruth Lichterman (Rockaway, NY). Miss Snyder is setting program switches on an accumulator; Miss Jennings is setting up numbers to be remembered in the function table . . . Miss Wescoff and Miss Lichterman are working at the printer. . . . The function table which stores numerical data set up on its switches is seen at the right and its two control panels are behind Miss Frances Bilas (Philadelphia, Pa.) who is plugging a program cable in the master programmer. Miss Bilas is an ENIAC operator in the employ of the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland.[64]

"Setting switches," "plugging cables," and "standing at function tables"—such captions understate the complexities of women's work. While two men appear alongside the operators, they are "maintenance engineers," occupational titles suggesting technical expertise.

The second photographer was Horace K. Woodward Jr., who wrote an article about ENIAC for *Science.* He wrote to Adele Goldstine: "Dear Mrs. Goldstine and other mENIACS, You will be perturbed to hear that the color flesh shots (oops, flAsh shots) that I was taking 1 feb 46 turned out nicely. I hadn't intended them for publication but thought you folks might like them."[65] His article in *Science* carried no photographs of the women and made no reference to their existence.

More surprising still, the media reports did not highlight Adele Goldstine, despite her leadership position and her expertise in a technical

64. ENIAC file appended to Goldstine to Power, 17 January 1946.
65. Horace K. Woodward Jr. to Adele Goldstine, 23 February 1946, Goldstine Papers.

realm that had not earlier existed for either sex.[66] An affidavit Adele Goldstine submitted as testimony in *Sperry Rand v. Bell Labs* explains how she saw her own role: "I did much of the programming and the setting up of the ENIAC for the various problems performed on it while I was at the Moore School. I also assisted my husband in training Mr. Holberton and a group of girls to set up problems on the ENIAC. . . . I worked with Mr. Holberton and his group to program each problem which they put on the ENIAC up to and including the demonstration problems for the ENIAC dedication exercises."[67] Adele Goldstine and Moore School professor Harry Huskey were charged with producing an ENIAC operating manual, a complete technical report, and a maintenance manual.[68] Herman Goldstine explains: "The only persons who really had a completely detailed knowledge of how to program the ENIAC were my wife and me. Indeed, Adele Goldstine wrote the only manual on the operation of the machine. This book was the only thing available which contained all the material necessary to know how to program the ENIAC and indeed was its purpose."[69] In addition, he reports that his wife contributed heavily to a 1947 paper he coauthored with John Von Neumann, *Planning and Coding Problems for an Electronic Computing Instrument.*[70]

It is an overstatement to say that female computers and operators were never covered in any media. A few articles mention them, as in this example:

> An initial group, consisting primarily of women college graduates, especially trained for work by the Moore School, began the work in ground gunfire, bombing and related ballistics studies immediately after Pearl Harbor, when the Aberdeen Proving Ground's Ballistic Research Laboratory broadened its program at the University.
>
> Forerunners of a group eventually numbering more than 100, they made use of the Moore School's differential analyzer, which is equally useful in the realm of ballistics and the solution of peacetime mathematical problems.
>
> Two other groups were organized later, under separate contracts, one of which was devoted to analysis of experimental rocket firing at

66. While Adele Goldstine did not receive media acknowledgement, she clearly had some status among her colleagues at the Moore School as the only woman working on the machine's hardware. Initially, she oversaw Holberton. As head of the WAC course, despite her civilian status, she had frequent contact with top administrators at both the Moore School and the Aberdeen Proving Ground. In a publicity folder, biographical profiles on approximately a dozen staff members at the Moore School connected with the ENIAC include J. Presper Eckert, John W. Mauchly, Herman H. Goldstine, John G. Brainerd, Arthur Burks, Harry Huskey, Cpl. Irwin Goldstein, and Pfc. Spence. Adele Goldstine is the only woman included.

67. The affidavit is included in a letter from Harry Pugh, at Fish, Richardson, and Neave, to Herman Goldstine, 12 December 1961, Goldstine Papers.

68. Goldstine, *The Computer from Pascal to Von Neumann* (n. 3 above), 200.

69. Ibid., 330.

70. Ibid., 255 n. 4.

> Aberdeen, while the other assisted in the proving ground development of new shells and bombs.[71]

This recognition is quite different from the publicity accorded to male officers and engineers associated with the project.[72] The article cited here portrays the women as interchangeable. Even if it were too space-consuming to name each human computer, it is still notable that the article describes the women as being trained for work "by the Moore School" as opposed to "by Adele Goldstine" or by her many female colleagues.[73] That ENIAC's 1946 demonstration doubled as a vanishing act for its female participants fits neatly with postwar propaganda that as early as 1944 began redirecting women into more traditional female occupations or out of the paid labor force entirely.[74]

And what of the several years after World War II? While the Department of Labor acknowledged women's desire to stay on in paid employment, its publications were not so optimistic.[75] An avalanche of materials urged women to leave work. A 1948 *Women's Bureau Bulletin* reported on the situation for women with mathematics education who sought paid work:

> Although, during the war, production firms and Government projects were important outlets for women trained in mathematics, the emphasis, following the end of hostilities, shifted back to the more usual channels. Teaching and employment with insurance and other business firms became the principal outlets for women college graduates with mathematical training. . . . Most of the wartime research projects sponsored by the Government were dropped after V-J day. In the few that continued, the small number of mathematical jobs were filled by the staffs of the institutions at which the research was being done and by men with mathematical skills who were being released from military service. The women's military services, which utilized women with mathematical training during the war, were reduced to very small staffs. . . . As women leave, men will be hired to replace them. . . . Although many women are continuing on their

71. "Studies at Penn Aided Artillery," undated clipping from unidentified newspaper, ENIAC Publicity Folder, Goldstine Papers.

72. See, for example, Allen Rose, "Lightning Strikes Mathematics," *Popular Science Monthly*, April 1946, 85, photo caption: "T. K. Sharpless, of the Moore School of Engineering, sets a dial on the Eniac's initiating unit, which contains some of the master controls of the huge, complex mechanics. . . . Mr. Sharpless designed some Eniac equipment."

73. Bruno Latour and Steve Woolgar, in *Laboratory Life* (Beverley Hills, Calif., 1979), 219, point out that "a key feature of the hierarchy is the extent to which some people are regarded as replaceable."

74. Rupp (n. 4 above), 161.

75. Ibid., 161–62.

> wartime mathematical jobs, it is difficult to say how much of the gain will be in terms of permanent opportunities for women.[76]



The Federal Bureau of Investigation dropped many of the women it had hired as cryptographers during the war. By 1946, the National Bureau of Standards had filled most of the vacancies on its computing staff with male veterans.[77] At the Ballistics Research Laboratory, an army memorandum detailed criteria for how individuals would be let go, with separate instructions for male officers and for WAC officers.[78] With this in mind, the absence of women from an October 1946 army recruitment ad makes sense. The "propaganda machine," as Herzenberg and Howes call it, that during the war had so successfully called women out of their homes, made a 180-degree turn, pushing many women back towards full-time domesticity.[79]

In the 1950s, new opportunities developed alongside continuing ambivalences about women's occupational roles. A 1956 U.S. Department of Labor report on employment opportunities for women mathematicians and statisticians is replete with examples of women's mathematical work—and the future need for women mathematicians—in a variety of fields including programming. Four "findings" appear as an executive summary:

> 1. More women mathematicians and statisticians are currently needed, and interesting jobs await those trained at the bachelor's degree as well as graduate levels.
>
> 2. Young women in high school should be encouraged to try mathematics and if they have the qualifications for success in mathematics and statistics should be encouraged to prepare for those fields; anticipated shortages make the long-run outlook exceptionally favorable.
>
> 3. Young women who combine the qualifications for teaching with ability in mathematics should be encouraged to teach, at least part time, since in teaching they can magnify their contribution to the Nation's progress.
>
> 4. Mature college women who have majored in mathematics, possess the personal qualifications for teaching, and have time available to work, should prepare themselves through refresher courses in mathematics and education for teaching positions, if they live in one of the

76. U.S. Department of Labor, "The Outlook for Women in Mathematics and Statistics" (n. 8 above), 9–11. See also U.S. Department of Labor, "A Preview as to Women Workers in Transition from War to Peace," *Women's Bureau Special Bulletin*, 1944; Rossiter, *Women Scientists in America: Before Affirmative Action, 1940–1972* (n. 9 above), chap. 2.

77. U.S. Department of Labor, "The Outlook for Women," 11.

78. Army Service Forces Office of the Chief of Ordnance, Washington, D.C., to personnel at BRL, 29 January 1946, Goldstine Papers.

79. Herzenberg and Howes (n. 10 above).

> many communities experiencing or anticipating a shortage of mathematics teachers.[80]

The report explores a wide range of career options, including programming and actuarial work. Yet as the patriotic rhetoric of service "to the Nation's progress" makes clear, the Department of Labor prioritized teaching as a career choice. Science and engineering had won the war, and now the developing baby boom predicted a growing demand for math teachers.

Despite such exhortations, some women never left computer programming. Fran Bilas, Kay McNulty, and Betty Snyder continued briefly with ENIAC when it moved to BRL in 1947; Ruth Lichterman stayed on for two years.[81] Other women joined the ENIAC at BRL following the war. Betty Snyder Holberton went on to program UNIVAC and to write the first major software routine ever developed for automatic programming. She also collaborated on writing COBOL and FORTRAN with Grace Hopper, a key programmer of the Mark I. Hopper left active duty with the U.S. Navy as a lieutenant in 1946 but remained with the Navy reserves until 1966. From 1946 until it started running programs around 1951, the Electronic Computer Project at Princeton's Institute for Advanced Study employed mostly female programmers, who included Thelma Estrin, Hedi Selberg, Sonia Bargmann, and Margaret Lamb. Their accomplishments are future chapters for a history of computer programming.

## Conclusion

The ENIAC story highlights several issues in the history and historiography of gender, technology, and labor. Major wars have unmistakable influences on gender relations and work, and those effects can be elusive and complex. Conflicts among representations of women's work in computing ensure work for the historian in distinguishing seeming gender changes from real ones. These conflicts and sometime contradictions lie at the heart of women's historical invisibility.

First, the variance between effusive wartime recruiting literature and historians' evaluations of women's actual opportunities is striking. Disputing the claims of propaganda, historians generally agree that during wartime women may have made some progress in expanding the varieties of work they could do. Yet rather than move up the ladder of success women's work appears to have added more rungs at the bottom. The narrative histories of the ENIAC since 1946 echo this finding. With few exceptions, they make the implicit or explicit assumption that, while women

80. U.S. Department of Labor, "Employment Opportunities for Women Mathematicians and Statisticians," *Women's Bureau Bulletin* 262 (1956): vi.

81. For these women's later employment histories, see Fritz (n. 2 above), 17.

were involved, their participation was not sufficiently important to merit explication. Thus, this episode in the history and historiography of computing confirms Rossiter's "Matilda effect": individuals at the top of professional hierarchies receive repeated publicity and become part of historical records, while subordinates do not, and quickly drop from historical memory.[82]



A second conflicting representation concerns the actual work performed by women contrasted with how employers categorized this work. As this article shows, the evidence of ENIAC challenges the implicit assumption of computing historians that the low-status occupations of women meant that their work could not be innovative. Wartime propaganda proclaimed "no limitations on your opportunities," yet only certain jobs were open to women. However, it was within the confines of precisely such low-status occupational classifications that women engaged in unprecedented work. Looking behind media accounts and later narratives of the development of ENIAC to consider primary source accounts of the work women actually performed reveals how its low-status categorization clashed with the kinds of knowledge required. Finding this mismatch offers the possibility that, in their work as operators, women moving into stereotypical male domains played a subversive role, challenging the gender status quo before the war. According to this view, women's invisibility reflects deep-rooted ambivalences about the roles women professionals began to occupy in the labor force. These ambivalences permeated both power relationships in the workplace and media portrayals of women's contributions.

Third, portrayals of women's postwar fate continue the ambivalence that characterized their wartime work. Women were seen as meeting a crisis—but only a temporary one. One 1943 guide to managers explained: "Women can be trained to do any job you've got—but remember 'a woman is not a man;' A woman is a substitute—like plastic instead of metal."[83] Both postwar propaganda and historians characterize women as retreating to teaching and homemaking after the war, abandoning their gains. Yet a fair number did not leave the workforce, a fact that the Department of Labor acknowledged even as it urged women toward teaching.[84]

The revised history of ENIAC presented here reveals that many of historians' questions about the history of computing reflect the unintention-

82. Margaret Rossiter, "The Matilda Effect in Science," *Social Studies of Science* 23 (1993): 325–41.

83. U.S. War Department, *You're Going to Hire Women*, booklet produced to persuade managers and supervisors to hire women, cited in Chester Gregory, *Women in Defense Work During World War II: An Analysis of the Labor Problem and Women's Rights* (New York, 1974), 12.

84. For example, the *Women's Bureau Bulletin* 262 (1956) features several pictures of women working with computers and mentions women coding and programming.

ally "male-centered terms" of history.[85] The result is a distorted history of technological development that has rendered women's contributions invisible and promoted a diminished view of women's capabilities in this field. These incomplete stories emphasize the notion that programming and coding are, and were, masculine activities. As computers saturate daily life, it becomes critical to write women back into the history they were always a part of, in action if not in memory.

85. Gerda Lerner, "The Necessity of History," in *Why History Matters: Life and Thought* (New York, 1997), 119.