I Assistants, Housekeepers, and Interchangeable Parts: Women Scientists and Professionalization, 1880–1940

THE YEAR WAS 1921. THE PHYSICIST ROBERT MILLIKAN ANNOUNCED that the nation's expanding technostructure required better "selection and development of men of outstanding ability in science." His call for "men" was not accidental; he imagined the best candidates to be masculine, rugged types and likened them to "explorers" in search of "nature's gold." Thomas Alva Edison, holder of more than one thousand American patents and the most widely recognized scientist in the country, embodied this enterprising pioneer as he attempted to recruit young men in his mold to develop technologies in his research facility in West Orange, New Jersey. Edison wouldn't settle for small-time thinkers; his team of "A-class men" would be drawn from applicants who passed a rigorous test he had devised. But his recruitment efforts proved disappointing: of the five hundred men who applied for positions, only 6 percent passed his exam. His own son failed to earn a place in his ranks of A-Class men.[1]

Test takers grew defensive; they were not common street folk, but graduates of science programs in the most prestigious universities in the country. The problem lay not with them, they claimed, but rather with Edison's arbitrary criteria for gauging scientific competence in the modern age. Some of the questions on his exam were what they were used to: "What pinch pressure at the driving wheels does a 23-ton locomotive require when drawing a load of 100 tons on level track?" Others, however, seemed highly irregular for testing scientific competence: "Who was Leonides?" "What is the name of a famous violin maker?" "What is felt?" One stumped job applicant wondered, "How many $10,000 per annum men . . . could have answered 50 percent of those tomfooleryisms." Another dismissed the test as "vulgar," an insult to his educated sensibility. "Who cares who wrote 'Home Sweet Home,'" a college graduate lashed out. "We are in an age of specialization, and men are being trained to do things in certain lines of work that do not allow them to waste time and gray matter on general knowledge that can be had by referring to an encyclopedia."[2]

Not all reactions to Edison's questions were defensive; some thought that the test proved just how "amazingly ignorant" college men had become. "I think that any man who cannot give a prompt answer to 75 percent of the questions at least is lacking in education, and, if a college man, had wasted his time in college," asserted an anonymous reader of the *New York Times*. Another reader thought the questions answerable "by any well-read and average intelligent man or woman," regardless of college credentials. Some thought it refreshing that Edison looked for men who didn't have "one-track minds," who sought to expand their mental storerooms rather than let them atrophy. A doctor from New York believed that more test takers would have passed had they devoted time to book reading rather than ball games, moving pictures, the sporting news, and other preoccupations of American males. Readers who followed the story flexed their cerebral muscles by taking the exam themselves. Men congregated in subways, clubrooms, college dorms, and hotel lobbies, jotting down answers to questions they speculated had been on the exam. People were wholly invested in establishing whether or not the exam tested scientific competence, and those with and without college training were curious about how they would perform on it if it did.[3]

As erudite as Edison appeared through all this, people seemed to forget that he had become who he was without the assistance of professional degrees of any kind. He never went to college; as a boy he was homeschooled and thrown quickly into business ventures to fend for himself. He observed the world around him and learned through reading and hands-on experimentation. As an established inventor he still boasted a subscription list of sixty-two periodicals, most of them scientific but also economic and legal and others oddly eclectic. Science and technology fascinated him, but so did geography, literature, and music—realms of knowledge that academic specialists considered "generalized trivia" in the technological age.[4]

Edison's hands-on experience of science reinforced his opinion that academic specialization, the hallmark of the modern university, had stifled human curiosity and compartmentalized men's thoughts until they knew lots about minutiae and nothing about anything else. He doubted that a modern college man could come close to filing a patent portfolio as large and varied as his, for it was unlikely that he was as inquisitive about the natural world. He put college men on the defensive at a time when they had sought authoritative status as experts. His exam had burst open a pregnant debate about college versus practical industrial training, but it also brought to the surface questions about the intellectual equipment of educated American men. In determining that his applicants were ill equipped to handle modern-day problems, Edison had essentially emasculated them.

Women observed these debates from the periphery and had their own opinions. "It is the men to whom we are accustomed to look for intellectual guidance who say the test could only be met by an 'encyclopedic mind,'" reflected Ellen Lynch of New York. She thought it "a matter of unsentimental fact" that there was "not a question in the list that could not be answered correctly by any well-trained boy or girl of 16." Who are the real best and brightest, another woman posited: masters of some atomized niche or broad thinkers with the capacity to draw knowledge from many parts of the social and natural world? Female readers of the *Times* seemed to relish the opportunity to respond sanctimoniously to these questions. Edison's test may have been of deeper significance to them than their husbands and fathers supposed, for it challenged the assumption that academic channels open almost only to men were requisites to a scientific mind. Perhaps women's hands-on study of nature—unpaid, without title, without resources, and outside the university—was of value after all. For a long time women had been told otherwise.[5]

The notion that women and science didn't mix had deep roots, traceable to Aristotelian and Platonic ideas about nature and knowing and Enlightenment views that supposed men and women's inherent traits to be complementary and oppositional. The Greeks linked femaleness with passive, indeterminate matter (and maleness with active, determinate forms), and in later generations the observation of fertilization under microscopes (interpreted as a motile sperm penetrating a passive egg) seemed affirmation. Eventually Kant, Rousseau, and other liberal philosophers (male by definition in this tradition) insisted that women were anti-intellectual by anatomy and default. They were lovers and feelers; men, thinkers and doers. Early positivists such as Newton, Descartes, and Locke also conceptualized links between external disinterestedness and male knowing and internal subjectivity and female knowing. They grew confident that Nature was knowable through the senses or experiment; but only men, not women, were equipped to unlock its mysteries. Philosophers from Bacon to Goethe to Nietzsche all assumed that the prerogative of Rational Man was dominance over female nature; the mastery of nature and woman was essentially one and the same.[6]

As the ideas of the scientific revolution took hold, they fostered the rise of industrial capitalism, which in turn privatized family households. Poor and working-class women and men went to work in factories, though among the burgeoning industrial middle class the divisions of labor and spheres of influence were more clearly distinguishable between the sexes. Ideal men occupied the public realms of learning, politics, paid work, and eventually professional science, while ideal women occupied the supposedly subjective and sentimental domestic sphere. Women were said to excel in such activities as cooking, cleaning, nurturing, and soothing daily quarrels; good science, as mirrored in the male professional, however, required unemotional and empirical thinking in abstract and universal terms. Whether or not individual women—or men—possessed traits to support such binary views was irrelevant, for cultural stereotypes possessed logic of their own.[7]

In the eighteenth century, a knowledge of "natural history" had become part of the intellectual equipment of well-to-do women, and it continued to be a popular subject of the lyceum circuit through the nineteenth century. Botany in particular had long been cast as an avocation of women with leisure and means sufficient to cultivate herb gardens and collect specimens for men to analyze. Editors of such domestic periodicals as *Godey's* and *The Ladies Repository* encouraged women to attend public lectures that would help them to nurture their children's love of plants, assuming that women readers were sentimentally drawn to the care of living things. Mrs. C. M. Badger illustrated lithographs of flowers and shrubs, requiring painstaking classification of genus and species. In the taxonomy of professional men, however, her books were classified as nonscience; they were creative endeavors inspired by a female love of beauty rather than by a penchant for scientific truth.

Jane Marcet was among the women who wrote best-selling science books in the nineteenth century—astonishingly, in the field of chemistry, not botany. Her success can be ascribed to the appropriately pedagogical tone and style of her work, often organized as conversations between mother and child. Her timing, too, was critical to her success, since she published before she could become associated with the concepts of amateurism that stigmatized women later in the century. By the end of the nineteenth century, the woman scientist had become the ultimate oxymoron; one science editor likened a woman's fondness for experiment to a perversion that needed to be concealed. Normal women were nurturing and noncompetitive, but modern science was imagined as the opposite. Women like Marcet were acceptable because they wrote watered-down science for children, busying themselves with the common work of popularization to free men to conduct prestigious research.[8]

Professional men accepted women curators and collectors, textbook writers, and illustrators, since such work dovetailed neatly into the work of women custodians, pedagogues, and helpmeets. Anna Botsford Comstock drew flora and fauna for the textbooks of her husband and eventually became one of the most recognizable science writers for children and lay people in the United States. American schoolteachers referred to her *Handbook of Nature Study* as the "Nature Bible," and she became so influential a lecturer and writer that the League of Women Voters chose her as one of the twelve greatest women in the United States. But her greatness was rarely couched in terms of science. In the minds of men, the pedagogue, popularizer, editor, and engraver of natural history was literary and sentimental, at best an amateur.[9]

The associations between amateur science and womanhood rigidified as men enjoyed more government funding in public universities to which women had little access. The American Association for the Advancement of Science divided itself into specialized societies of men, each of which established specialized journals and agendas. And yet discussion about women's scientific abilities in popular journals such as *Scientific American* and *Popular Science Monthly* indicated that there was no total consensus on the issue. After the Civil War, women's colleges, among them Mount Holyoke, Wellesley, and Barnard, offered science courses in particular fields that aspired to the rigorous standards of male institutions. By the 1890s some of the nation's most prestigious universities—Cornell, Chicago, Berkeley, and others—accepted women students, several of whom aspired to be scientists. Harvard medical professor Edward Clarke insisted that women engaged in such pursuits to the detriment of their reproductive health, but social scientists, many of them women, made a more compelling argument for the environmental underpinnings of gender difference than biological rationales.[10]

With degrees in hand, modest numbers of women began to enter scientific institutions that were originally bastions of men—albeit in marginalized capacities as librarians, computers, secretaries, and assistants. They had the academic credentials but not the titles and salaries of scientists. They were segregated within fields but also across fields—horizontally as well as vertically. Women were ejected from fields deemed "hard" in the name of higher standards—essentially a strategy of containment. Professionalization continued to be a gendered and gendering process, one designed to ameliorate *softening* by reinstating masculine status in some fields over others.[11]

Several meanings are implicit in the metaphorical use of "hard" and "soft": Hard science came to be understood as intellectually and physically rigorous, fortified by airtight, indestructible positivist methodology. Subjects of "hard" research were physically inanimate, not squishy, oozing, or alive; results of "hard" research were consequently "hard and fast," versus the ambiguous findings of social scientists or other increasingly female investigators. Hardness and softness had long been assigned gendered connotations (the penetrating mind and hard muscles of men and the sentimental thinking and soft curves of women), and now through associative logic men funneled women into "softer" fields of lesser prestige. At some universities, including Yale, New York University (NYU), Cornell, MIT, and the University of Chicago, women instructors filled niches of expertise in hygiene; nutrition; and "social," "physiological," and "domestic" science.[12]

One of the pioneers of female science in the late nineteenth century was Ellen Swallow Richards, a woman who had worked with astronomer Maria Mitchell as an undergraduate at Vassar. When she couldn't find a job after college she decided to study chemistry at MIT, where she was admitted as a "special student" so that her name wouldn't appear on the university roster. She sewed buttons and swept floors to gain men's acceptance in the lab. For decades the university used her services as an instructor of chemistry and engineering, most of the time without compensation or title. As much as her story sounds like a victimology, one can also see her as an agent of her own destiny, a woman who used domesticity as camouflage to become master of an uncontested domain: the “Woman’s Laboratory,” where she quietly innovated in the fields of ecology and sanitary engineering. Rather than rue the day she was relegated to domestic science, Richards established organizations and scholarships in her separate and distinctly female expertise. Her investigations into ventilation, nutrition, and clean water were of great social significance, even if their importance wasn’t reflected in her promotion or pay.[13]

Richards’s strategy made sense, given the climate of institutional science, but it begged the question: In separateness, had she achieved professional equality? Younger women thought not. In earlier years they could rely on husbands and fathers to get them access to labs, but after 1910 women scientists, who were largely relegated to women’s colleges and women’s fields, felt more removed from the scientific establishment then ever before. In politics young women increasingly rejected the separatist tactics of their mothers, who wanted to win suffrage on the basis of their special moral authority as women; in the lab these daughters wanted to compete and interact directly with men, not as women, but as scientists. They were heartened when the U.S. Civil Service Commission decided to administer its qualifying examinations on a sex-blind basis in 1921. For the first time they could be hired, in theory, as researchers for agencies such as the Federal Bureau of Standards. In practice the hiring for government jobs was hardly sex blind, however, and at colleges and universities, where science departments made similar claims, the results were equally ambiguous. Although women experienced a slight increase in hiring at coed college campuses after 1920, when they were 20 percent of all employed women scientists, the promise for more equitable hiring practices brought about a reverse trend: the women’s colleges that women once relied on for employment sought out more men to lend prestige to their programs. Earlier in the century 58 percent of women scientists worked at women’s colleges; by 1920 the total had decreased to 37 percent. The percentages were not balanced by increased numbers of women hired by coed institutions.[14]

Some women looked outside the university to industry, for World War I had expanded photographic, communication, and ballistic technologies, among others. Marie Curie, the most acclaimed woman scientist in the world, left her lab for the battlefront during the war; her vehicle, “the little Curie,” carried X-ray equipment to makeshift medical facilities on the frontlines, proving that women, too, could provide significant resources to the allegedly masculine realms of science and war. In the United States, women who would have been shunted into home economics were producing gas and projectile weapons, explosives, instrumentation, and other war materials. A select few, such as Wellesley graduate Louise McDowell and Vassar graduate Frances Wick, worked on radar at the National Bureau of Standards and on airplane radios for the U.S. Army's Signal Corp, but their access to research was short lived. After 1918 women were laid off and men reinstated.[15]

By 1921 women's advances in science were still modest, especially since they enjoyed more access to science degrees than employment opportunities in science fields. Yet even with their small numbers, men feared a crisis of impending feminization in fields they had taken pains to infuse with power and prestige. Edison unwittingly proved that the crisis had come to a head. By doubting the qualifications of college-educated men, he was also doubting the dominant portraits of American manhood and men's innate scientific talent, bringing these issues to the surface, where men and women could weigh in.

The very day the *Times* first reported on Edison's exam, it also ran a story on Marie Curie's arrival in New York, the beginning of a six-week tour of the country. She was coming to collect a gram of radium donated by American women and would soon find herself at the center of tensions between the old and the new science, between feminists and the male establishment, and between Americans who differed on men's and women's proper spheres of influence. Men used her tour to showcase American science and industry, while educated women made it their coming out of sorts—a chance to make the case for their place in science and professional life. Curie was their living proof of success.

Notes

1. Robert Kargon, *The Maturing of American Science* (Washington, DC: American Association for the Advancement of Science, 1974), 2–3, 33; "Edison Asserts He Wants College Men If He Can Get Them," *New York Times*, May 16, 1921, 1. Hereafter, *New York Times* cited as *NYT*.

2. "Controversy Rages over Edison Test," *NYT*, May 15, 1921, 14; "Edison Questions Stir up a Storm," *NYT*, May 11, 1921, 6; "Edison Dashes Off New Questionnaire," *NYT*, May 14, 1921, 9.

3. "Edison's Questions Still Puzzle City," *NYT*, May 12, 1921, 17; "Here is Edison's 4-Column Sheaf of Knowledge," *NYT*, May 13, 1921, 10; "Edison Is Upheld by Many Writers," *NYT*, May 19, 1921, 20; "Edison Brainmeter Divides the Critics," *NYT*, May 17, 1921, 8.

4. See details of Edison's early years, in Randall Stross, *The Wizard of Menlo Park: How Thomas Alva Edison Invented the Modern World* (New York: Crown, 2007); Gene Adair, *Thomas Alva Edison: Inventing the Electric Age* (New York: Oxford University Press, 1996); Paul Israel, *Edison: A Life of Invention* (New York: John Wiley and Sons, 1998); "Edison Dashes Off New Questionnaire."

5. "Edison Brainmeter Divides the Critics."

6. Elizabeth Fee, "Women's Nature and Scientific Objectivity," in *Woman's Nature: Rationalizations of Inequality*, ed. M. Lowe and R. Hubbard (New York: Pergamon Press, 1981), 9–22; Genevieve Lloyd, "Reason, Science, and the Domination of Matter," in *Feminism and Science*, ed. Evelyn Fox Keller and Helen E. Longino (New York: Oxford University Press, 1996), 41–52; Carolyn Merchant, "Isis' Consciousness Raised," in *History of Women in the Sciences: Readings from Isis*, ed. Sally Gregory Kohlstedt (Chicago: University of Chicago Press, 1999), 11–15; Lisbet Koerner, "Goethe's Botany: Lessons of a Feminine Science," *Isis* 84 (1993), 470–95; Margaret Wertheim, *Pythagoras' Trousers: God, Physics, and the Gender Wars* (New York: W. W. Norton, 1997), 148–54; Evelyn Fox Keller, *Reflections on Gender and Science* (New Haven, CT: Yale University Press, 1995), 19, 31–44.

7. Sandra Harding, *The Science Question in Feminism* (Ithaca: Cornell University Press, 1986), 60–64, 123–25; Londa Schiebinger, *Has Feminism Changed Science?* (Cambridge, MA: Harvard University Press, 1999), 70–71.

8. Sally Gregory Kohlstedt, "In from the Periphery: American Women in Science, 1830–1880," *Signs* 4 (Autumn 1978), 81–96; Deborah Jane Warner, "Science Education for Women in Antebellum America," in *History of Women in the Sciences*, 193; M. Susan Lindee, "The American Career of Jane Marcet's *Conversations on Chemistry, 1806–1953*," *Isis* 84 (1993), 470–95; Barbara T. Gates and Ann B. Shteir, eds., *Natural Eloquence: Women Reinscribe Science* (Madison, WI: University of Wisconsin Press, 1997), 3, 11–17.

9. Comstock was in fact an "academic," who taught at Cornell University for decades before being tenured at the age of sixty-five. Pamela M. Henson, "'Through Books to Nature:' Anna Botsford Comstock and the Nature Study Movement," in *Natural Eloquence*, 116–39; Marcia Myers Bonta, *Women in the Field: America's Pioneering Women Naturalists* (College Station, TX: Texas A&M University Press, 1991), 152–64.

10. Sally Gregory Kohlstedt, "Parlors, Primers, and Public Schooling: Education for Science in Nineteenth-Century America," *Isis* 81 (1990), 425–45; Kohlstedt, "In from the Periphery," 90–91; Rosalind Rosenberg, *Beyond Separate Spheres: Intellectual Roots of Modern Feminism* (New Haven, CT: Yale University Press, 1982), xv, 1–27. Studies of women social scientists include Helen Thompson Woolley, *The Mental Traits of Sex: An Experimental Investigation of the Normal Mind in Men and Women* (Chicago: University of Chicago Press, 1903); Leta Stetter Hollingworth, "Comparison of the Sexes in Mental Traits," *Psychological Bulletin* 25 (December 1918), 427–32; Elsie Clews Parsons, *The Old-Fashioned Woman: Primitive Fancies About the Sex* (New York: Putnam, 1913).

11. Margaret Rossiter, *Women Scientists in America: Struggles and Strategies to 1940* (Baltimore: Johns Hopkins University Press, 1982), xvi, 29–72, 98–99, 107; Harding, *Science Question in Feminism*, 62.

12. Schiebinger, *Has Feminism Changed Science?*, 160–64.

13. Sarah Stage, "Ellen Richards and the Social Significance of the Home Economics Movement," in *Rethinking Home Economics: Women and the History of a Profession*, ed. Sarah Stage and Virginia B. Vicenti (Ithaca, NY: Cornell University Press, 1997), 21–22.

14. Daniel Kevles, *The Physicists: The History of a Scientific Community in Modern America* (Cambridge,MA: Harvard University Press, 1987), 202–3.

15. Rossiter, *Women Scientists in America*, 116–18.

1 Madame Curie's American Tours: Women and Science in the 1920s

IT WAS AN INTERVIEW TO RELISH: THE RECLUSIVE MADAME CURIE agreed to sit with American editor Marie Mattingly Meloney for a profile to be published in Meloney's magazine, the *Delineator*. Stéphane Lauzanne, editor-in-chief of *Le Matin*, had been following the Nobel laureate's story for years. "She will see no one," he warned Meloney. "She cannot understand why scientists, rather than science, should be discussed in the press." For all her attempts to prevent it, Curie's had become a household name. She had not made a public appearance in fifteen years, and yet she agreed to meet this American journalist in 1920.

Meloney had met famous scientists before. She had grown up near the estate of the illustrious Alexander Graham Bell, a breeder of horses that she yearned to ride. And only weeks before arriving in Paris she had stood in the laboratories of Thomas Alva Edison; eyeing the newfangled equipment at his command, she decided that one's scientific prowess brought not only admiration, but also great financial reward. In Pittsburgh she had seen the smokestacks of the greatest radium-reduction plants in the world. And yet when she reached the physics building at the rue Pierre Curie, the originator of this technology was a pale, timid woman, surrounded by nothing that would suggest material gain for her efforts. Her office was sparse; even to an untrained eye, the facilities looked inadequate. Curie rubbed the tips of her fingers over and over the pad of her thumb, a habit she had developed while trying to regain feeling lost in her hands. For her, scientific discovery had not led to riches but physical and material sacrifice.[1]

That the two women would hit it off famously could not have been predicted, for Meloney was in many ways Curie's younger antithesis. An important person in the U.S. editing world and in New York society, she had started out as a reporter for the *Washington Post* but had become one of the most influential women of American media. She exuded social grace, money, and a penchant for publicity. Curie, a Pole who had emigrated to France to pursue science, was not interested in appearances, including her own. She dressed plainly, typically in black, and preferred to be undisturbed by anyone, at home or in the lab. Male colleagues she met at professional meetings thought her terse and disagreeable; small talk was not her métier. Her closest confidant since her husband's death in 1906 was her daughter Irene, a young physicist who was like her mother in interest and temperament. Despite their differences, however, Curie and Meloney were also working mothers who understood each other's struggle to balance professional and family obligations. The interview at the Sorbonne lengthened into informal talks during Curie's personal time. Meloney became "Missy" and Curie "Marie"; a mutual affection took root that lasted the rest of their lives.

Meloney felt confident that her readers wanted to hear from the reclusive scientist, for Americans had been following her story for years. In 1904, *Vanity Fair* had presented Marie and Pierre as a couple, months after they had together won the Nobel Prize for radioactivity. Marie appeared to be a puzzling contradiction: a brilliant scientist who was, nevertheless, also the "woman behind the man" in the Curie partnership. Although she was the codiscoverer of radium, she was also the person responsible for family domesticity, an image confirmed by another woman journalist who covered "The Curies at Home" for *The World To-Day* the same year.[2] The domestic image may have seemed to diminish her as a scientist; yet young women with career aspirations saw her differently, as a model of grace and competence outside the home. When Curie won her second Nobel Prize in 1911, science editor James McKeen Cattell cast her in *Science* and *Popular Science Monthly* in an overtly feminist light, calling her rejection from the *Académie des Sciences* a tragedy for women scientists and science alike.[3]

The journalistic treatment of Curie was startling, given the paucity of coverage on women scientists generally in the American press. Taking into account scientists both as authors and biographical subjects, male scientists were fifteen times more visible than their female counterparts in mainstream magazines. Journalists described science as an endeavor requiring culturally virile attributes—emotional detachment, intellectual objectivity, even physical strength at times. In 1920 a Columbia scientist described the "Eminent Chemists" of his day as the "the Dickenses," "the Thackerays," and the "Wells" of the field; then he heralded Curie as "the Columbus who discovered another continent in science," feigning amnesia about her gender to write about her in grandiose terms.[4]

Still, even as Meloney talked with Curie, American women stood on the brink of winning suffrage. It was the increasing reality that domestic women were making inroads into political, professional, and public endeavors. Meloney thought that writing of Curie's achievements might allow other science-minded women to gain social acceptance. And who better than Curie to inspire an educated readership? She held a doctorate degree, had won Nobel Prizes, and had proved that, despite the odds, a woman could reach the highest echelons of her chosen professional field—even while rearing two fatherless daughters. She was a single mother and a world-class scientist—an everyday woman who made greatness look reachable. Meloney thought American women would see her as an icon for achieving it all: marriage, family, and career.

But as she told her story, Curie's frustrations became apparent. French science was impoverished after World War I, making it impossible to procure radium, the very element she had discovered, and as a result, her research had been curtailed. She could account for the locations of some fifty grams of radium in the United States; four were in Baltimore, six in Denver, seven in New York.

"And in France?" Meloney queried.

"My laboratory has hardly more than a gram," Curie replied, and that bit was available only for extracting emanations for cancer treatment in hospitals.

Meloney begged for clarification: "*You* have only a gram?"

"I? Oh, I have none. It belongs to my laboratory."

"But surely revenues from the patent of radium can pay for more," Meloney suggested.

"There were no patents," Curie corrected. "We were working in the interest of science. Radium is an element. It belongs to all people."[5]

Curie thought it wrong to profit from her discovery, and yet the discovery had most assuredly lined the pockets of chemical producers back in the United States. American companies had mastered her processes to become the foremost producers of her coveted radium. Standard Chemical Company of Pittsburgh was responsible for more than half the 140 grams in existence worldwide, but it wasn't cheap. Medical researchers bought it in milligram increments for $120 apiece, and Curie needed more—at least a gram if she could get it. Meloney listened intently, the wheels turning in her mind. She prided herself on making things happen; she was going to get Curie her radium.[6]

A public relations strategy developed in her imagination in the form of a story that would play out on the pages of the *Delineator* and major publications throughout the United States. It had all the elements of an American legend in the making: a tale of travesty about a woman and mother, who had sacrificed for the world but had received nothing in return. This woman had endured abject poverty to discover the element that was the leading cure for cancer, but had refused to patent its production so that the researchers of the world could study it readily. She should have been heralded as a saint, and yet the price of her altruism was a debilitating lack of funds, not for her own creature comforts but for humanity, who continued to suffer without her life-saving research. “I had been prepared to meet a woman of the world, enriched by her own efforts and established in one of the white palaces of the Champs d’Elysées or some other beautiful boulevard of Paris,” Meloney wrote. “But Madame Curie was a simple woman, working in an inadequate laboratory and living in an inexpensive apartment, on the meager pay of a French professor.”[7]

The synopsis seemed extreme to Curie, who insisted that French scientists worked under modest conditions all the time, but Meloney wouldn’t hear it. In the United States, she told Curie, many women had money, and when she returned from Paris she would write letters to the wives of physicians in major medical societies. Meloney planned a broad campaign that would bring together an odd mix: cancer researchers, academic scientists, chemical companies, and women with money and social connections. American science had grown quickly after World War I so that government funding was no longer enough to maintain it, and the age of fund-raising in the name of “science as social cause” had emerged. Meloney hoped to exploit Curie’s image just as chemical companies were exploiting Albert Einstein’s to raise funds for themselves and his educational initiatives overseas.[8]

But the campaign could only succeed if donors perceived the scientist and her work as forces of benevolence. When Alice Hamilton and Ellen Swallow Richards were praised in the press for the healing applications of their work, American women who wanted to emulate them entered nursing and medical fields in larger numbers than ever before. But they studied organic material rather than the lifeless stuff of physical science. Meloney's promotional strategy necessarily had to reinvent Curie's physics, turning inanimate radium into a regenerative force for healing—and reenvision Curie's life, turning her into a benevolent lady. The press coverage on medical radium strengthened Meloney's view of how to proceed. The *New York Times* reported more than 150 deaths directly linked to cancer and radium research, its victims including men who had once worked under the Curies themselves. As more of the world's radium experts succumbed to mysterious symptoms, Curie's commitment to research seemed all the more heroic in Meloney's hands. The burns on her fingers, the jaundice, and worsening cataracts made Curie a martyr to behold; the findings of her research would be her gift to the world.[9]

Curie had other compelling reasons to team up with American sponsors. During World War I she had been charmed by the simple demeanor of the young American soldiers who came to Paris to study radioactivity. She was also grateful to Andrew Carnegie, who had established a fund to keep her lab staffed after the death of Pierre. Over the years American women had expressed their admiration for her work, but she still couldn't imagine what would compel them to write checks—or in most cases, to have their husbands write checks—so that a French scientist could pursue her research. Meloney explained that they would see a mutually beneficial arrangement before them: as they raised money for her radium, they would exploit her image for their humanitarian and professional ends. This was false advertising, Curie told her. She had abstained from ideological movements her whole life to work in the spirit of "pure science" and wanted nothing to do with developing medical applications for radium or advancing the cause of women. Don't taint my radium with agendas, she implored; it absolutely "must belong to science."[10]

A perfect strategy in the eyes of a privileged career woman like Meloney was apparently not acceptable to a scientist like Curie. To base a campaign on her maternal motivations was to make her look emotional, subjective, and hence defective to male scientists. The maternalism that women evoked to win access to college and the vote was antithetical to the idea of science that Curie had internalized and come to revere. But for the sake of obtaining her radium she deferred to Meloney—it was all about the science in the end.

Against her better judgment Curie began writing a biographical piece to be distributed in the United States. Meanwhile, Meloney called on her connections in the world of publishing to get dozens of articles into print during the coming months. *Current History Magazine* printed "The Story of Radium in America." Dr. William Mayo asked *Delineator* readers, "Do You Fear Cancer?" drawing out anxieties that supporting Curie's work would presumably allay.[11] Although these pieces were not explicitly about Curie, they set the stage for solicitations on her behalf by dramatizing the dangers of cancer and its study. Articles that followed emphasized Curie's importance to the field and shaped images of her that were appealing enough to make Americans open their hearts and checkbooks for the medical breakthroughs she ostensibly represented. Editors for *Century Magazine* and *Current Opinion* were hardly subtle, calling Curie a Jeanne D'Arc of the laboratory and "the most famous woman in the world." Meloney praised her in print for "minister[ing] to an agonized people." The front page of her magazine declared Curie's raison d'être: "That Millions Shall Not Die!" Her face, Meloney wrote, was "softer, fuller, more human" than most. "It had suffering and patience in it," as did "every line of her slender body." In its totality, hers was "the mother look" epitomized.[12]

Meloney's publicity campaign was designed to appeal to a wide swath of people. Modern career women would admire Curie's professional competence, ambitious young people her self-making; she had achieved the American dream, even if not on American soil, pulling herself up by the proverbial bootstraps to work tirelessly for success. Unlike the aristocratic scientists of Europe, she apparently never forgot her modest Polish roots. It was not beneath her, Meloney told readers, to launder her own undergarments, even when she was hosted in homes that had servants. She was the embodiment of the Puritan ethic, much as Americans fancied themselves.[13] Too poor to pursue science formally, she had borrowed books from the factory library and earned money as a governess to purchase a fourth-class ticket from Poland to Paris. With almost nothing but the clothes on her back, the twenty-four-year-old had arrived in the Latin Quarter, where she continued to exercise the frugality of legend. Journalists and biographers sensationalized her student years in a sixth-floor walk-up. Allegedly she hauled her own wood for a furnace that didn't work and resorted to piling clothes on the bedcovers and anchoring furniture on top to create a shield from drafts. Some maintained that she treated herself to an occasional boiled egg or piece of chocolate; others insisted she lived on tea and crusts of bread. All, including Curie herself, described a young woman so fixated on her studies that she didn't think to eat until her body collapsed. Her notebooks were obsessively neat. She graduated first in physics at the Sorbonne in 1893 and second in mathematics a year later.[14]

Curie had many professional and social acquaintances, yet biographers insisted that the only person who caught her attention in those monastic years was Pierre, a man of equal intensity. A Polish professor introduced her to the thirty-five-year-old physics professor at L'Ècole Municipale in 1894. In addition to working on crystals and magnetism, he and his brother had inauspiciously discovered piezoelectricity and were using their findings to design instruments, including the electrometer Curie used to confirm the existence of radium. The first gift Pierre offered his future wife was a paper on the symmetry of electric and magnetic fields. He must have sensed their unique connection, for there was no better gesture of affection in her eyes. They were kindred spirits; neither ate, slept, or remembered social niceties when in the throes of some scientific question. Pierre loved Marie's commitment to science. Women of her intellect and drive were so rare, he thought, that he had to have her for himself. Their single-minded devotion to science should be their gift to humanity, he told her, and she eventually agreed. The path they walked together they described as an "anti-natural" one: they renounced "the pleasures in life" and pared down all distractions outside their immediate family to live and breathe their research. This meant renting a modest home, eating and dressing plainly, and rarely entertaining guests. "All preoccupations with worldly life were excluded from our existence," Marie recalled fondly. In a scientific man such reclusiveness was expected, but Marie loved Pierre because he accepted the same in her.[15]

Their wedding in 1895 was simple; there was no exchange of rings or festivities to follow. Marie chose a navy blue dress versatile enough to wear at the wedding and in the lab afterward. She and Pierre enjoyed a bicycling honeymoon in the French countryside, but they didn't stay away from the lab for long. Pierre resumed his formal position at L'École

Municipale, while Marie continued her studies and served as his assistant gratis. Marie agreed to be the homemaker so long as the work was confined to rudimentary tasks. Aside from used furniture relatives had given them, she had little to keep clean. She was not talented as a cook, but Pierre seemed not to notice what she was feeding him anyway. Their three-room apartment was on the rue de la Glacière, in close proximity to the school of physics so they could spend more time in the lab.[16]

Marie had been investigating the magnetization of tempered steel when recent findings caught her attention. On the heels of Wilhelm Röntgen's discovery of the X-ray, Henri Becquerel, who had been studying uranium salts, had noticed that they emitted special rays. Marie made it her mission to measure them and discern the conditions under which they existed. She confirmed that they were in fact an atomic property of uranium and that samples of thorium behaved similarly, but the rays emitted in her samples of minerals were not commensurate with the amounts of uranium and thorium she knew to be in them. Her observations led her to a theory: the ores contained trace amounts of another substance, one more radioactive than any known element. After grueling experiments Marie discovered that in fact two new substances were involved. She identified one in 1898 and named it polonium, after her homeland. Five months later, she identified the second element, which came to be known as radium.

The problem then became isolating the elements. Pierre was studying crystals but found himself increasingly swept up into his wife's doctoral research. While he studied the properties of radium, Marie extracted pure radium salts. The Austrian government had disposed of tons of pitchblende, a uranium ore, which Marie had obtained cheaply in order to begin the painstaking process of purification. She had to dissolve the dusty substance in acid before chemically separating its elements, which meant transferring vast vessels of liquid and precipitate and, with an iron bar, stirring cauldron after cauldron of the substance. The tasks were laborious; they left her exhausted and she fell ill with pneumonia. She extracted thousands of gallons of distilled liquid from her mounds of pitchblende, ultimately yielding amounts of radium solution that barely filled a thimble.[17]

The work wasn't glamorous, but it had been romanticized in the American press. Readers were transfixed by the image of Pierre and

Marie conducting experiments side by side in their dilapidated shed. Inside they performed the bench work; in the adjoining yard, the bulkier transport of pitchblende. The building's windows were broken and its heating unit didn't work; at the height of their experiments Marie logged an indoor temperature of just above freezing. They worked for hours in silence, stopping only to put on sweaters or warm themselves with cups of tea made at a rickety stove. There was one detail publicists made more of than Curie herself: amid the hauling, stirring, measuring, and recording she had in fact given birth to a child. Taking none of the standard precautions of modern nuclear labs, Marie fed Pierre lunch probably laced with radioactive material. She took in harmful fumes herself, which contributed to her chronic illnesses and her frustrations with nursing.[18]

Still, without qualification Curie recalled the years in the shed as the happiest of her life—not because of newfound motherhood, but rather because of her unfettered access to scientific work. The bliss only ended when her discovery of radium brought unwanted celebrity, making the "anti-natural" ideal impossible to maintain. She was entirely in charge of her baby's care and she was also in the midst of doctoral research. Desperate for domestic help, she searched for wet nurses, housekeepers, and nannies, which also took her away from the lab, as did the additional teaching hours she had to take on to cover the cost of her helpers. She secured a position at a girls' school in Sèvres, well outside Paris; the commute was yet another diversion from the experiments she was desperate to run.[19]

Curie's father-in-law, a widower, came to her aid and helped to care for baby Irene, as his own. The balancing act became easier, but even then, Marie thought the baby a distraction—a perspective that American biographers then treated ambivalently, as others have since. Some have insisted that she doted on her daughter—recording the baby's first teeth, steps, and words and making her clothes by hand. Indeed some personal notebooks verify these details, but they also read like lab notes, clinical and joyless, for what could not be measured or quantified precisely she simply left unrecorded.[20] Curie admitted privately that the responsibilities of motherhood kept her from the work she loved the most. The night she isolated her pure radium chloride, she and Pierre left Irene sleeping in her crib to return rain-soaked to the lab. Like doting parents they checked in on their other sleeping baby—a test tube of radium that filled them with pride when it started to glow. Unambiguously, Curie described radioactivity to one of her students as "the child to whom she had given birth"; she would nurture it and devote to it "the whole of her working life."[21]

Physicist George Sagnac expressed concern that Marie's unbalanced family life bordered on obsession and neglect; he worried about her health and her daughter's: "Don't you love Irene? It seems to me that I wouldn't prefer the idea of reading a paper by Rutherford to getting what my body needs and looking after such an agreeable little girl." Pierre refused to be critical; ultimately the baby was his wife's unexpected burden more than his. He was given a full appointment at the Sorbonne, as Marie struggled to balance research, teaching, domestic duties, and child care. This was not the dream he had promised her. Marie resented her obligations, but never Pierre: "He used to say that he had got a wife made expressly for him to share all his preoccupations. Neither of us would contemplate abandoning what was so precious to both."[22]

The world knew 1903 as the year the Curies won their Nobel Prize. For Marie, it was the year she lost her privacy and a second child. In August she prematurely delivered a baby girl who died hours later. Letters to her sister revealed how angry she was at herself for thinking her body up to the rigor she had put it through leading up to the birth. She had continued the taxing purification of pitchblende, stopping only to take the bicycle holiday that had induced her early labor. She felt more optimistic the following year when she gave birth to a healthy daughter named Eve. She recalled the added burden lightheartedly in the biographical piece she wrote for Meloney: "It was not easy to reconcile these household duties with my scientific work, yet, with good will, I managed it."[23]

If she sounded like the model of contented motherhood, the reality was more complicated. It was Grand Pé who took Irene to see the sites of Paris and the nanny who taught the girls her native Polish. For whole summers the girls stayed with hired help in Brittany so that Curie could work uninterrupted back in Paris. Irene wrote letters to her dear "Mé," imploring her to see them, and felt devastated when she received in return only one letter of apology. Eve, too, felt cheated, that she could never compete with her mother's science. While Irene worked harder to become the lab partner with whom her mother wanted to engage, Eve turned elsewhere, becoming a musician on the international stage. Marie and Irene avoided publicity, but Eve loved to be seen. She had a penchant for makeup and heels and contemplated becoming a journalist; her mother thought she might just as well become the devil himself. Only in later years did the bond between them strengthen, especially when Eve nursed her mother through her last illness. After Curie's death, Eve became committed to political and social causes—taking the antithesis of her parents' anti-natural path.[24]

In emphasizing the early years of Marie's marriage and career, Americans sentimentalized her as a mother and whitewashed the chauvinism that pervaded her career before and after she had children. No one mentioned the stares of male students and faculty, who thought her an interloper on their sacred ground. Pregnancy and motherhood had divided her energies in ways male colleagues couldn't appreciate. Even in the most liberal of French circles, her return to work so soon after birthing seemed to border on neglect. Men wanted to believe that her extracurricular activities (read: domestic) gave them cause not to take her seriously, but they had to; she performed better than any of them on the Concours d'Agrégation, and the dissertation that followed stunned her evaluators, future Nobel winners themselves. She was the first woman in Europe to complete a doctorate in her field, and she did it with force and style. Not only had she discovered radium, but she had isolated it and determined its atomic weight. The phenomenon of radioactivity was no longer a mystery—and yet a formal academic appointment for her remained elusive.[25]

The scientific community looked on in disbelief when she and Pierre won the Nobel in physics with Becquerel in 1903. The distinction didn't come easily; the French Académie quietly lobbied for the prize to be split between Becquerel and Pierre only, a ploy a Swedish physicist made known to Pierre. No prize for radioactivity could possibly exclude his wife, he implored. *She* first suspected the existence of the elements they discovered, and *she* had already run experiments when he entered the fray. Upon conferring the prize, the president of the Swedish Academy of Sciences cited the old proverb "Union is strength," acknowledging the Curies as a team. He also thought it apropos to cite a biblical passage: "It is not good that man should be alone; I will make a helpmeet for him." His assumption that Marie served the team as helpmeet was pervasive in the science community. Most believed she was an assistant rather than a partner, a doer of deeds that Pierre brilliantly conceived. For now Pierre's assertions shielded her, but they did not change what men thought in the back of their minds.[26]

British physicist Hertha Ayrton, Curie's trusted confidant, suffered similar suspicious stares from men who assumed her successes to be her husband's. "Errors are notoriously hard to kill," she asserted, "but an error that ascribes to a man what was actually the work of a woman has more lives than a cat." Curie stayed close to Pierre to enjoy the refuge from scrutiny, but she also created strategic distance, publishing her own papers that demonstrated her ability to conceptualize and perform original research.[27]

She found her reputation harder to defend after Pierre was tragically killed in a traffic accident in the rue de Dauphine in 1906. American publicists insisted that devotion to her children saved her from deep despair, but she said it was the promise she and Pierre had made to each other that kept her focused and gave her purpose. She refused a widow's pension, taking over Pierre's academic appointment at the Sorbonne instead. University officials went along—even if they appointed her as an assistant rather than give her Pierre's full professorship.[28]

The following November, reporters, dignitaries, and such legendary figures as Lord Kelvin himself sat among the advanced students in the amphitheater in which Curie gave her dead husband's lectures. She walked in to booming applause that she tried to suppress with gestures for quiet. People wondered if she'd react with displays of emotion and odes to Pierre. Instead she proceeded in a steady monotone: "When we consider the progress made by the theories of radioactivity since the beginning of the Nineteenth Century . . ." Students were amazed; she had picked up on Pierre's last explication of polonium almost to the sentence. Even in the wake of Pierre's death, she refused to give colleagues reason to think her anything but the consummate professional. She had to convince the audience that she could act the part of the disinterested scientist as well as any man with whom she now competed.[29]

But when the period of mourning was over, reaction to her university appointment changed; invariably colleagues and the press began to look critically at the widow propelled by her husband's death. Pierre had been elected into the Académie des Sciences in 1905, but his colleagues took less kindly to his widow's submission as a candidate five years later.

A war of the sexes played out in the press, for the Académie had a long, prestigious history of being open only to men. Her detractors found it easier to build their case against her when they seized on allegations from the wife of physicist Paul Langevin that he and Curie were lovers. Langevin had been a former student of Pierre's and a close family friend, making the alleged affair all the more scandalous. Langevin's wife released supposed love letters to the tabloids, creating a publicity nightmare from which Curie never recovered.

If it all seemed unrelated to her science, members of the Académie refused to see it that way. Feminists defended her, but right-wing detractors scrutinized her fitness for membership on every score. In the illustrated daily *L'Excelsior*, a physiognomist and handwriting expert examined the published love letters to determine her qualifications. Nationalist publications used her foreign origins against her; she became the object of anti-Semitic slander, though she was not a Jew. A prominent French editor wrote of her in scathing terms: she was no longer the "Vestal Virgin of Radium" but a Polish interloper with inappropriate ambitions; first she rode the coattails of Pierre, and now she looked to his unsuspecting students.[30] Albert Einstein committed adultery and left his wife without ill effects in the press, but Curie was different. Although no longer bound in matrimony, she had mistakenly revealed herself as a sexual woman, and thus the fiction of her saintly science was impossible to maintain. In the midst of scandal, Curie also made headlines for winning her second Nobel Prize. It should have shored up her unquestioned status in science, but it only led to greater scrutiny. The Nobel Committee seemed to be splitting hairs, some suggested, awarding a prize for her chemical study of radium when the first one she won was for radioactivity in general. Curie accepted her prize reticently; Irene, now a fourteen-year-old, sensed the tension surrounding her mother in Stockholm. Marie credited Pierre but also with indignation referred to "*my* hypothesis about radioactivity," "*my* chemical work to isolate radium." Without Pierre there to defend her, it is unlikely she was convincing.[31]

The allegedly adulterous Langevin went back to work unscathed, but for Curie the sex scandal seemed to flick a switch; her trespass into the masculine realm of science could no longer be excused. The scientific establishment decided that she couldn't win individual accolades with her reputation intact. Already reclusive, Curie tried to evade the public eye at all costs. For the following decade she refused almost all requests for interviews, no matter the context, making it all the more curious that she agreed to talk with Meloney in 1920. Perhaps Curie hoped that the staunchly independent American would provide both a sympathetic ear and the power to advance her scientific work. The way to do it, Meloney insisted, was to reinstate her maternal image among Americans more willing to forgive her frailties. She had the word of every leading newspaper editor in New York that he would make no mention of the love affair during her Radium Campaign. Arthur Brisbane, managing editor of the *Evening Journal*, even handed over his file on the scandal to let Meloney do with it as she pleased.[32]

The Curie who was introduced to Americans appeared as the Virgin Mary in black—maternal, saintlike, in no way sexual. Her refusal to patent her method for extracting radium was presented as an absolute sign of her altruism, and her tragic circumstances as a widow only added to the image. Curie was to be the "common woman" in a country where the common man was beyond reproach. In press releases the title "devoted wife and collaborator of Pierre" preceded her name; stories in the press focused on her monastic years in the shed, when she and Pierre gave themselves up for their life-saving science. Curie knew that her American self was largely a figment of Meloney's imagination, but other than wielding an editorial hand when stories got "too personal," she was complicit in the end.[33]

The Tour of 1921

Meloney wove the web of publicity meticulously, each strand of Curie's life story braided to create an extraordinary American design. Her marriage provided the romance, her Spartan ways a sacrifice for nobler good. That her radium could be linked to medical research made it possible to see her as maternally benevolent. While the nation's chemical and physical societies embraced her as their own, some of the most conspicuous displays of gratitude took place at medical research facilities and medical colleges, where her discovery of radium was seen as a humanitarian act. During the course of Meloney's campaign the National Association of Medical Women made Curie an honorary member, seeing her as a saintly foremother. Heartwarming human interest stories followed. A horticulturalist, for example, named his prized strain of red roses for the woman he saw as responsible for the medical breakthrough that had saved his life.[34]

Meloney was gratified to see that within months the Radium Fund was oversubscribed. The call to raise a hundred thousand dollars had attracted more than one hundred thousand women and an impressive group of medical men who believed, as Meloney had hoped, that Curie's cause was their own. Carrie Chapman Catt, the popularly recognized pacifist and suffrage organizer, wrote a piece in *Woman Citizen* called "Helping Madame Curie to Help the World." Curie had become the expedient face of her maternalist politics. Men, too, had written checks in support of scientific innovation, medical advance, or other causes Curie ostensibly represented. Arthur Brisbane's one-hundred-dollar check to the Radium Fund did not honor a scientific mind but the best in womanhood, for he gave it in the name of Julia Ward Howe, famed writer of the "Battle Hymn of the Republic."[35]

Curie had hoped to accept the donations quietly, but Meloney wanted to satisfy the American thirst for celebrity, pull the drama from print, and parade it in the flesh. She had turned into public spectacle the taking of sealed bids from chemical manufacturers to produce the gifted radium. Now she wanted Curie to accept the radium in person, before her American admirers. While Curie agreed that a gesture of appreciation would be appropriate, she had not imagined the pomp and circumstance Meloney had in mind—in the form of a widely publicized tour, with ribbon cuttings, speeches, and ceremonies—exactly what the reclusive scientist had spent her life trying to avoid. She would lunch with the ladies of the Radium Fund Committee and visit with students at women's colleges before attending a massive reception of the American Association of University Women at Carnegie Hall. Standard Chemical and the Department of Mines also planned to host events where she would be presented with specimens of carnonite and other precious ores. She was scheduled to dedicate the mining bureau's new low-temperature laboratory, where, in the name of American ingenuity, she would push a button to set its machinery in motion.[36]

Others were quick to seize on the fascination for all things Curie. R. H. Macy and Company launched a series of books about radium to coincide with her tour, and executives of chemical companies bought space in the *New York Times* to welcome Curie to the United States. The American Museum of Natural History in New York also made preparations for the tour, opening an exhibit with photographs and specimens of the ore she had used to isolate her first batch of radium.[37] University men paid tribute to her as well, awarding her honorary degrees at the Universities of Pennsylvania, Pittsburgh, and Chicago, and at Northwestern, Columbia, and Yale. At Harvard the mood was less generous, however. William Duane, a former student at the Curie Institute, convinced university president Charles Eliot that she was unworthy of special honors. "I agree with you that Mme. Curie might possibly have some good influence while in this country on present discussions of feminism," Eliot told Meloney, but "since her husband died in 1906 Mme. Curie has done nothing of great importance."[38] Meloney defended her friend, citing studies confirming her accomplishments. When all else failed, she used maternity:

> It is hardly fair to say that Mme. Curie has [not] done anything of great importance since her husband's death in 1906. She had done nothing comparable with the discovery of radium and probably never will surpass that achievement. But she has contributed enough to science and to life to justify any praise or honor which might be bestowed upon her. She had carried on her scientific work, but the outstanding virtue of these years lies in the fact that having discovered radium and come into prominence she turned to her home as a normal mother and gave the intimate minute attention to her children which motherhood should impose.[39]

Reporters at the *New York Times* aided her case, reminding readers that Pierre Curie himself had insisted that his wife had been the more deserving recipient of their Nobel Prize. When men at Harvard, as at Princeton, refused to change their minds, Meloney simply pressed on, for men and women in many other organizations thought Curie the perfect vehicle for advancing their public profiles. The Philosophical Society, the American Chemical Society, the Mineralogical Club, and the Associations of Polish and Canadian Women organized formal gatherings in her honor. The National Institute of Social Science planned to host a formal dinner at the Waldorf, where Vice President Calvin Coolidge planned to present Curie with the institute's gold medal of honor. The grandest of displays was reserved for the White House itself: President Warren Harding was to present the radium as a gift to Curie from American women. Politicians, industrialists, and socially important women hoped to benefit from their associations with Marie Curie. The skepticism of a few university men could not damage her.[40]

The itinerary was "very intimidating," Curie confided. Since her arrival in France in 1891 she had rarely traveled outside the country, and when she did it was under an assumed name to protect her privacy. Her fear of ceremony bordered on phobia. When she won the Nobel Prize in 1903 she feigned illness so that she could accept the prize at a later date with less fanfare.[41] Her American tour could proceed, she told Meloney, only if she would insert days of rest in the schedule and if her daughters, now twenty-three and sixteen, could accompany her as companions and ready stand-ins. She asked that the voyage overseas proceed "with the minimum of publicity," and it did until she reached the United States. When she disembarked from the USS *Olympic* the scene was chaotic. Student groups sang Polish, French, and American anthems, and international dignitaries and gift-bearing Camp Fire Girls all bombarded her at once. Customs preliminaries were waived to facilitate her progress through the crowds of admirers that had been gathering since the early morning hours. Curie claimed to be woozy from seasickness and begged shelter from the press, but Meloney convinced her to pose patiently for dozens of waiting photographers. She was relieved to be whisked away in a limousine that Louise Carnegie had arranged for her escape. When she reached Meloney's apartment on West Twelfth Street, she asked for seclusion. Admirers sent flowers, but she turned callers away. When she finally emerged, a motorcar took her to the Carnegie home on Ninety-first and Fifth, where Mrs. Cornelius Vanderbilt and socialites of the Radium Fund Committee welcomed her to the United States.[42]

Curie graciously nodded, smiled, and shook hands, but wondered why no woman scientist was in their midst. In the weeks that followed she traveled from venue to venue as a great maternal figure, her science excised from her legend. A few women scientists noted the discrepancy. Untenured Columbia University instructor Christine Ladd Franklin reminded readers of the *New York Times* that Curie was, above all else, an exemplar of women's potential in science. Look at the accepted scientific nomenclature, she argued, for "the curie" had become the unit of radioactivity much like the volt, the coulomb, the ohm, the farad, the henry, and the ampere had become units of measure in other fields.[43] But Ladd's reminders fell on deaf ears even at women's colleges, where administrators thought Curie was best used to push maternalist agendas. At Carnegie Hall, American Association of University Women members from nearly every college admitting women along the Eastern Seaboard lauded her scientific achievement as evidence of women's greater maternal influence. They, too, interpreted her work with radium as a gesture of humanitarianism rather than as evidence of scientific acumen. Bryn Mawr College president M. Carey Thomas urged her collegiate audience to pursue science if so inclined, but more important, to use science to exert influence on politics and pacifist diplomacy. American women had won suffrage months before, and Thomas hoped Curie would inspire them to form into a voting bloc to bring about disarmament—"human legislation," as she called it.[44]

Curie must have been perplexed. Never in her lifetime had she considered herself a political being of any sort, let alone a pacifist or feminist. The family of her late husband was openly radical, but she was too busy in the lab to join them as card-carrying members of the Communist Party. During World War I she and Irene volunteered to operate portable X-ray machines to treat injured soldiers on the frontlines. If this made her political, she defied someone to label her politics. Her independent choices implied a feminist sensibility, but the moment someone called her a feminist her reaction was denial.[45]

The college women she met on the tour insisted that they had much in common with her, but she didn't see it. Her college days had been Spartan and somber, but the young coeds who greeted her appeared fresh faced, well fed, and even giddy as they serenaded her with school chants. She was taken aback by their facilities—the lavish campus trees, the extensive sports equipment, the recreational rooms, and the spotless dormitories and sanitary showers. More impressive still were the clean and modern laboratories, more luxurious than hers in Paris. From her perspective the American conception of women's education was radically different from her own experience. College women seemed to be taken seriously, and yet few seemed truly impassioned by science, as she had been in her youth. At Smith College Curie hoped to meet serious-minded women, but instead she was overwhelmed by empty pomp and circumstance. The wife of Vice President Coolidge and the mayor of Northampton joined a crowd of two thousand to honor the retiring scientist. The gathering was mere prelude to the thirty-five hundred college women who greeted her at Carnegie Hall in New York City. As honored guest she sat through choral performances and yet another ceremony, this time one awarding her the Ellen Richards Memorial Prize. She was close to collapse as she tried to thank the women graciously for their medals and fleur-de-lis, but her remarks were brief and barely audible even to people ten feet away. Assuming she had said enough, her hostesses responded with rigorous applause. Curie walked away in something of a daze; by now her cataracts were so bad, she could barely see the emotion she had stirred up before her.[46]

With diminishing energy, she plodded on with her scheduled engagements. Men stopped production at radium plants so that she could consecrate the grounds, researchers at hospitals of radium therapy bowed in her presence, and society women opened their homes and pocketbooks on her behalf. The most prestigious of scientific men conferred honors no woman had won before her from the American Philosophical Society, the College of Physicians, and the American Chemical Society. The American Museum of Natural History made her a fellow, a status never before achieved by a woman. At Wellesley, hers was the first honorary degree in the history of the college. Administrators at the University of Pennsylvania announced that for the first time in school history they would hold a special ceremony to bestow the degree.[47]

The ceremony at the White House was perhaps the most difficult for her, since it had come to signify more than Curie wanted to represent. President Harding handed her a key that opened a box in which her radium would be placed, though for now it remained at the Bureau of Standards. The absence of the very radium for which she came was of no consequence to the cabinet officers, military men, Supreme Court justices, foreign diplomats, and elite scientists who convened before her. Representatives of women's societies welcomed her to the United States as its new "adopted daughter," and Harding declared the radium a symbol of the "convergence of intellectual and social sympathies" between Curie and the American people. American women, he said, offered their gift of radium much as they would shelter to the homeless or food to the hungry: "It has been your fortune, Mme. Curie, to accomplish an immortal work for humanity. . . . We lay at your feet the testimony of that love which all the generations of men have been wont to bestow upon the noble woman, the unselfish wife, the devoted mother. . . . The zeal, ambition and unswerving purpose of a lofty career could not bar you from splendidly doing all the plain but worthy tasks which fall to every woman's lot."[48]

Curie said nothing, but her companions sensed her growing anxiety; she had become everything to everyone, an icon too big and distorted to rein in. All along she had asked Meloney to tone down the publicity, particularly this fictitious association with cancer research. Meloney made sure newspapers retracted statements proclaiming that radium cured all cancers, and at Vassar College Curie timidly reminded her audience that her discovery of radium was the work "of pure science . . . done for itself" rather than with "direct usefulness" in mind. But her maternal altruism had been established. Exhausted by the misplaced attention, she increasingly let Eve and Irene accept honors on her behalf. On a train to yet another destination, she insisted that stepping foot in the public car was more than she could handle: "I cannot go in and be stared at like a wild animal," she whispered. Before reaching the Western states, she was asking to go home.[49]

Publicists found it difficult to conceal that the admiration she inspired wasn't necessarily returned. By the time the tour reached its third week, her irritation with American hospitality had become a topic for print. "Mme. Curie is 'completely tired out,'" the *New York Times* reported. "Questions and the 'small talk' of American women and men also have fagged her brain." The following day a journalist reported that the customary handshaking was "beginning to bore the French scientist"; she wore a sling to avoid the grips of admirers. The American press excused her behavior, supposing her aloofness to be an unfortunate symptom of radium illness, the after effects of decades of humanitarian devotion to science. "Mme. Curie is somewhat anemic, as nearly all persons of confined, studious pursuits are," the *Times* reported. "She had been confined most of her life to work in the laboratory. She is a woman of 53 years. With a delicate physique and unaccustomed to outdoor life, she has been attempting to put through a strenuous program in this country and it has tired her."[50]

Americans forgave, but didn't necessarily know what to make of the woman, for the press coverage on her was also a flurry of contradictions. Observers noted her tireless energy, as well as her unceasing fatigue; her confident command of English, but also her broken, inaudible whispers. Did Americans interest her or bore her? Did her "severely plain" dress suggest that she was masculine, too stuck in her head to be concerned with fashion; or feminine, too saintly to succumb to vanity? Did her "angular" face, her penetrating, deeply set gray blue eyes, and her protruding forehead betray masculine intellect or maternal warmth?[51] Observers couldn't make up their minds. In the summer of 1921, Marie Curie stood squarely at the center of conflicting thoughts about women and science.

As Curie packed her bags for France it was clear that Meloney's tour of mutual admiration had been, in the end, a calculated transaction. Curie received one hundred thousand dollars of radium, twenty-two thousand dollars of mesothorium and other precious metals, two thousand dollars from the Ellen Swallow Prize, sixty-nine hundred dollars in miscellaneous fees, fifty-six thousand dollars of leftover donations to be set aside in a fund, and a fifty-thousand-dollar advance for her impending autobiography. In return, she gave American women and chemical producers the license to manipulate her image to promote maternalist feminism and American innovation. Meloney had not placed women scientists into her plan. Aside from brief words by medical researchers Florence Sabin and Alice Hamilton at Carnegie Hall, no women scientists had been featured in her events. Curie had not spoken at primary or secondary schools, where she might have inspired impressionable young girls; aside from her visit to science students at Hunter College, none of her activities seemed to promote women scientists specifically. This was of little concern to Curie herself. Except on Irene's behalf she had never made special accommodations for women at the Curie Institute and in fact refused the young nuclear physicist Lise Meitner when she had applied for work there. Although she was one of the only women who graduated from the Sorbonne, Curie never tried to extend that distinction to others, nor did she openly challenge the sexism that plagued her own career both before and after Pierre's death. In the American press she never disclosed her keys to success, nor did she concede her disappointing defeats. American women inferred through her silence that they had to outperform men to succeed.[52]

In this we see two sides of the image-making coin: Meloney deliberately had shaped Curie into a maternal martyr who had used science for womanly ends; but this portrait also evoked an image of a superwoman, too smart, too dedicated, too focused, and too talented to be emulated by ordinary women. Trying to shape Curie in appealing ways, Meloney unwittingly kept alive popular stereotypes about women and science. To succeed in men's fields, women couldn't be themselves; they had to perform better than men, much as Curie had. Institutional sexism remained unchallenged, as women told themselves simply to work harder or publish more. Meloney had created a schizophrenic figure: a serious scientist (a masculine type) and a sacrificing woman (a maternal type), both inherently incompatible. In the minds of male employers women would always fall short of the ideal, and women who internalized their alleged deficiencies could not move forward. If Meloney's portrait of Madame Curie was supposed to inspire women, it may have done the reverse.

Postscript

Throughout the 1920s American women kept informed about their French investment. Louise Carnegie and other former committee members organized a trust fund to ensure a steady income for Curie's pursuits. Eleanor Clay Ford, daughter-in-law of Henry Ford, provided a new car, and Mrs. Henry Moses a chauffeur to take Curie to and from her lab. Meloney's associates also arranged for the overseas delivery of X-ray tubes, galvanometers, electromagnets, voltmeters, and other specialized instruments to the Curie Institute. Their devotion was unwavering, for the French scientist allowed them to realize their professional ambitions vicariously. "It is very comforting . . . but makes me feel the responsibility ahead of me," Curie confided. As American schoolteachers continued to request pictures and autographs to place in their classrooms, it was clear that Curie as symbol had transcended anything she had imagined.[53]

Curie continued to hunt for radium, this time for the Curie Institute newly installed in Warsaw. The price of it had halved since her American tour, but it was still prohibitively expensive. In 1928 the Radium Committee raised another fifty thousand dollars to purchase another gram on Curie's behalf, and thus Meloney clamored for another American tour. Curie voiced her litany of health concerns but agreed to come under stricter conditions: no long engagements, no social occasions, no interviews, no shaking of hands. Train rides in cold weather and the Girl Scouts were out of the question! The fewer appearances the better, and they had to be related to work! "Remember," she wrote

Meloney, "I am now many years older. . . . You have already forgotten how ill I had been during my visit to [the] United States in 1921." Unquestioningly, Meloney typed up a statement of her conditions to distribute to the press.[54]

Throngs of admirers were not waiting when Curie's steam liner arrived in New York in the fall of 1929. She took a back stairwell to the lower level of the pier, where a limousine took her once again to Meloney's apartment. Now Herbert Hoover would present the radium to her, or at least a check to pay for it. Reluctantly, she visited the White House and attended an event at the National Academy of Sciences building. Her only public appearance in New York City was at the annual dinner of the American Society for the Control of Cancer. Administrators at the General Electric plant in Schenectady closed down operations for a day so that she could run experiments before dedicating the new chemistry building at St. Lawrence University nearby. At the request of Henry Ford she grudgingly traveled to Dearborn, Michigan, to attend a dinner in honor of Thomas Edison on the golden anniversary of his invention of the incandescent bulb. En route to the Midwest she complained bitterly of the cold. At the dinner she refused to autograph menus, even as Ford and the president signed them beside her.[55]

American women accepted Curie's requests and tuned her schedule to suit her, yet this final U.S. tour was hardly about them at all. Aside from an event hosted by the New York Federation of Women's Clubs honoring her as a humanitarian, Curie's appearances served to reinstate masculine science. At Edison's Golden Jubilee one prominent male inventor paid homage to another, and at General Electric the inventor of the X-ray tube served as her guide through laboratories occupied exclusively by men. Alumna Emily Eaton Hepburn donated a statue of Curie to go alongside the chemistry building she dedicated at St. Lawrence, but men flanked her at the ceremonies. Physicist George Pegram spoke: "We, with the rest of the world, honor Mme. Curie for her very life, for her steadfast devotion to science, her patriotic service, her modesty. We honor her as a wife and mother. The nobility of her life is such that our admiration for her character almost turns our attention from her scientific rank."[56] On this tour, as on the last, Curie's science—and more important, the science of American women—had been erased from view. The cult of maternity overrode substantive discussion of women's work in American science.

As she sailed back to France, tour officials took precautions "to shield her from excitement," but they were not needed in the end. Upon her arrival in Europe flares went off in the Gare Saint-Lazare for two more celebrated women passengers, silent film stars Pola Negri and Alice Terry. The diversion suited Curie, for all she ever wanted to do was return to her anti-natural path. For a time she had had to step off it to keep her science alive. Reporters in the United States sensed her focus on the science much more in 1929 than in 1921. In their hands she turned less identifiable and more eccentric. In 1930 the *New York Times* described her no longer as the saintlike humanitarian, but rather as the brooding recluse, not nearly as likeable as Albert Einstein, the scientist who had since won over Americans with his charms. The *New York Times* reported that at a meeting of the League of Nations' Committee on Intellectual Cooperation, she rudely declined all social invitations after the business meeting had adjourned. She refused to be photographed or interviewed or to tell reporters what it was that kept her so occupied. Einstein, meanwhile, was congenial. Like all brilliant men he appeared a bit scattered, forgetting to light his pipe before placing it in his mouth, but his smile was engaging. He could laugh at himself and the world, unlike the stoic Curie. Yale radiochemist Bertram Boltwood reflected on her second tour and thought the unlikable woman had "made a good clean up over here." Even so, he "felt sorry for the poor old girl, she was a distinctly pathetic figure."[57]

Meloney hoped that the tours would be mutually beneficial to Curie and American women, but Curie may have been the greater beneficiary in the end. Women's opportunities in American science did not grow as a direct result of her tours. Forty-one women earned science PhDs in 1920 and 138 in 1932, three years after Curie's second tour. Fewer than one thousand women earned science doctorates over these twelve years—an increase from the previous decade, but not the substantial change many had predicted. In Curie's field of physics women averaged less than three doctorates a year, and because men, too, were taking more degrees in these years, only 5 percent of doctorates in all science fields taken together were earned by women.[58] When Curie left New York the second time, check in hand, the fallout of Black Tuesday on Wall Street was just settling in. Her departure coincided with the fiscal unraveling that devastated many sectors of the American economy, not the least of which was the chemical industry that her discoveries and image had propped up and that American women had hoped to enter. Women scientists who had found jobs in laboratories after Curie's first American tour relinquished them to men after the second. Their professional aspirations appeared inappropriate amid pressures to contribute to shrinking family wages, and thus many of them turned to pink-collar sectors for employment.

During the Depression, walking Curie's path seemed an impossible dream. She represented women's untapped potential less and less and became more and more clearly a superhuman anomaly. While young American women might admire Curie's accomplishments, they would see her simplicity and asexual appearance and behavior as unappealing relics of a bygone Victorian era. If they were to emulate any Curie, it was not likely to be Marie or Irene but Eve, the fashionable cosmopolitan artist who wore lipstick and had sex appeal. The sociologist Lorinne Pruette confirmed that even by 1924, Marie Curie's name had no resonance for teenaged girls of the flapper age. When 347 teenagers were asked to name a heroine, real or literary, who inspired them, only three girls chose Curie, the more glamorous Cleopatra beating her out thirty times over. Respondents who desired careers chose social science before physical science and artistic careers above all (46 percent), further underscoring how impractical and unwomanly they perceived Curie's choices for their own lives. In the postsuffrage era women with professional aspirations wanted to combine marriage and career, and yet 89 percent of the women who appeared in *American Men of Science* in 1927 were unmarried, and in Curie's field of physics, the percentage was even higher. The French woman seemed, in her later years, to be—and perhaps to have been—a joyless spinster who had chosen science over sexuality, and the trade-off was not especially appealing.[59]

In the end the Curie tours were not useful for women in science. Sex-typed employment remained constant in scientific sectors, and any headway women had made in science fields as a result of World War I was afterward virtually erased, to the seeming indifference of Curie herself. American women had to wait for the next world war to make new gains—only to suffer yet another closing of opportunities in its aftermath. Fatigued by their failure to make inroads in the upper echelons of science, women assumed a nonconfrontational stance, characterized, according to Margaret Rossiter, by deliberate overqualification and personal stoicism.[60] Even the most accomplished women scientists in the

1950s and 1960s continued to insist that the key to success was to perform head and shoulders above male competition, sacrificing family, health, and sanity for research. This remained the unconscious strategy of women scientists until second-wave feminists began to see the Curie complex for what it was: a mirage that kept women from making headway in science in any substantive terms.

The Curie tours of the 1920s were an opportunity that had come and gone—and women scientists sensed it. In 1921 industrial engineer Lillian Gilbreth and astronomer Cecilia Payne-Gaposchkin imagined bright prospects in their respective fields of science. Both were products of doors opening in American universities: Gilbreth at Berkeley and Brown, and Gaposchkin at Harvard. But the expansion of science training for women in universities did not translate into an expansion of opportunities in scientific work. Gaposchkin first appeared at the Harvard observatory in a period when the old guard of amateur women "computers" was on its way out and a new breed of professional woman astronomer was emerging. In these years she got her foot in the door, but she also hit a glass ceiling at almost the same time. She discovered that in the university, women either remained on the lower rungs of the promotional hierarchy or were ghettoized in feminized fields. Gilbreth experienced no less hostility in the industrial sector. Initially an engineering consultant who publicly (though not actually) was an assistant to her husband, she found it difficult to maintain their business when he died tragically in 1924. She, like so many women, had to work within feminized niches of science where the male establishment offered little resistance. Her choices did not necessarily signify failure, for she found rewarding her work on efficiency in schoolrooms, department stores, and domestic spaces, and her impact on the lives of women and families was palpable and ultimately lasting. She and Gaposchkin reveal the mixed legacy of the 1920s, when women suffered dashed professional dreams, but found ways to succeed on their own satisfying terms.

Notes

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2 Making Science Domestic and Domesticity Scientific: The Ambiguous Life and Ambidextrous Work of Lillian Gilbreth

It was Mother the psychologist and Dad the motion study man and general contractor, who decided to look into the new field of the psychology of management, and the old field of psychologically managing a household of children. They believed that what would work in the home would work in the factory, and what would work in the factory would work in the home.

—Frank Gilbreth Jr. and Ernestine Gilbreth Carey, *Cheaper by the Dozen*, 1948

The family, what is it but an experiment. The Quest of the One Best Way!

—Lillian Gilbreth, *The Quest of the One Best Way*, 1925

Here I may be a Scientist
Who measures as she makes
Here I may be an Artist
Creating as she bakes
Here busy heart and brain and hand
May feel and think and do
A kitchen is a happy place
To make a dream come true.

—Promotional pamphlet for *Lillian Gilbreth's Kitchen Practical*, 1931[1]

On June 17, 1924, in Montclair, New Jersey, a mother of twelve sat at the table with her children for their most urgent "Family Council." The topic of discussion was not allowance or curfews, but how to proceed now that the patriarch of the house, industrial engineer Frank Gilbreth, was no longer present and in charge. Just a few days ago he had died of a heart attack in a phone booth at the local train station. It was the same day that his second-eldest daughter was graduating from high school, and he was rushing around before the ceremony to get visas processed for an upcoming trip across the Atlantic, to attend the World Power Conference in England and the International Management Congress in Prague. He and his wife planned to represent the American Management Association at these events, but he had suddenly felt worried about the passports. So he stopped to call Lillian and asked her to check his desk drawer. She did, and when she picked the receiver back up, he was no longer on the line. The train must have arrived, she thought, but bystanders confirmed that Frank had collapsed and died instantly on the platform.[2]

Six years earlier, when he had fallen ill while consulting for the U.S. military, doctors had warned that Frank's heart wouldn't take his breakneck pace. At Fort Sill he organized the rehabilitation of disabled soldiers and he taught active soldiers how to clean and assemble Lewis and Browning machine guns with a minimum of physical motion and muscle fatigue. But there he was struck with rheumatism, then uremic poisoning, followed by a bout of pneumonia that kept him bedridden for months. He recovered, but his heart had been compromised. Lillian made sure he dieted and carried a heart stimulant at all times, yet he seemed to gain more and more weight as Lillian turned more waiflike. When he collapsed in 1924, he weighed nearly 230 pounds.[3]

Fearing the worst hadn't prepared Lillian for the tasks of raising the children and paying the bills alone. Her youngest, Jane, was only a baby, and the next-oldest boys were toddlers; except for Anne, all the children still lived at home. They had been prepared for college, but the older girls now contemplated taking time off to make ends meet. The Mollers, Lillian's parents, wondered why their daughter had chosen a life of less privilege and more chaos than that to which she had been accustomed. They offered to take the children, but Lillian refused. She was not a victim; the life she had chosen was not second-rate but the path less traveled, and she felt privileged to have traveled it with a man who hadn't insulted her by expecting less. "I have over twenty perfect years to remember," she told her mother. "I have had the best. . . . He will wait for me." As daunting as the future seemed, she hadn't regretted the choices she had made.[4]

Lillian planned Frank's service without flowers or music and donated his brain to Harvard Medical School, as he had wanted. The children agreed that she should leave immediately for London to appear in their father's place at the World Power Conference. They had their standing orders, they assured her: each older child knew to watch over a younger one, and their system of charts and files would ensure that the household chores got done. Anne and Ernestine would round up the children and take them to the family's home in Nantucket for the summer. The next eldest, Martha, would take over the family finances while Mom took over Dad's speaking engagements. But no one had planned for what happened next: nearly all the children contracted chicken pox within days, and the youngest four got the measles; the baby was delirious. The family was in unprecedented crisis, and yet Lillian had faith in the unflappability of the domestic system Frank had devised. In the end she presided over his sessions in Europe and gave his papers on the Gilbreth brand of "motion study."[5]

This part of Lillian Gilbreth's story is familiar to Americans who read the book or saw the Hollywood film *Cheaper by the Dozen* after World War II. According to the story written by Ernestine and Frank Jr., Dad's death wasn't a crossroads in Mom's life, but the end of her existence in the shadow of a more charismatic spouse. The tale solidified her status in the popular consciousness as the proverbial "woman who lived in a shoe," but scholars since have also recognized something subversive underneath. Indeed the Gilbreth children played out the fantasy of traditional patriarchal authority in their recollections, but this authority was subtly undermined by the quieter, more effective control wielded by a mother who, while not the protagonist of their account, was implicitly a partner of equal standing.[6]

Readers knew her anxieties as a widow, but not the extent of her dilemmas as the living half of a business and scientific partnership. Together, Frank and Lillian had run an engineering consulting firm; given scores of professional papers; published eight books and hundreds of articles; run a summer school on industrial management; and maintained a household of servants, schedules, and a dozen children. To the outside world Lillian appeared the helpmeet to a more qualified scientific husband. But in the Gilbreth household everyone understood that Mom was an industrial consultant, a credentialed psychologist, an originator of ideas, a writer of texts, a runner of motion-study experiments, a supervisor of homework, and a soother of scrapes and hurt feelings all rolled into one.

Lillian pronounced her child-raising years with Frank the most significant period of her life, and yet her leaving for Europe in 1924 marked the beginning of a substantially longer and gratifying chapter. Her children didn't predict it: "Before her marriage, all Mother's decisions were made by her parents. After her marriage, the decisions were made by

Dad. It was Dad who suggested having a dozen children, and that both of them become efficiency experts. If his interests had been in basket weaving or phrenology, she would have followed him just as readily."[7] But with Frank gone and children to feed, Lillian followed her own professional compass. For fifty years after Frank's death she continued to be a mother, but not always a hands-on one. She reinvented herself as a civil servant; a popular advice-giver; a professional consultant and educator; a domestic icon; and, as all of these, a new brand of scientific practitioner—one who challenged established boundaries between science and domesticity, male and female spheres. Hers was a path with no blueprints, and thus it is difficult to classify the kinds of science and feminism she espoused in her career, if we can call them science or feminism at all. Rather than focus on classification, perhaps we will understand more if we study the ways in which Lillian negotiated through stereotypical labels of her time.

The daughter of a wealthy San Francisco businessman, Lillie Evelyn Moller was shy and intensely bookish, a cause for her parents' concern, since they feared she would limit her prospects for a good marriage. They balked at the idea of college, for at the turn of the century higher education was for the career minded, and a career was only for women who hadn't the privilege of being cared for. Cultivated ladies could be avid readers, musicians, and seasoned travelers, but they did not pursue formal studies with a profession other than teaching in mind—and teaching was to be relinquished upon marriage. The Moller men were providers who deferred to the Moller women on all things domestic, rarely feeding or changing the babies of the household for fear of the emasculating effects.

Lillie looked the part of the well-groomed socialite, but she identified more with such contemporaries as Jane Addams and Marie Curie: she was a straight-A student who sought a purpose outside the home. Reluctantly, her parents let her attend Berkeley to study English, but she also took philosophy and psychology and justified the indulgence as necessary equipment for her teaching certification. Her parents were shocked when she insisted on renaming herself the more sophisticated "Lillian" and on moving to New York to enroll as a graduate student in philosophy and comparative literature at Columbia. When a literary scholar refused to accept female students, she returned to Berkeley to focus on Elizabethan literature. With a master's degree in hand in 1902, she prepared for her doctorate, this time in psychology. But before beginning a life in academe, she traveled once more to Europe, her chaperone for the fashionable trip the cousin of a man whose red Winton Six Coaching Car immediately caught her eye. Its driver was the consummate bachelor Frank Bunker Gilbreth.[8]

Frank and Lillian seemed to have almost nothing in common when they met in 1903. She was a tall, slim society girl breaking away from her cloistered life; Frank was a thickset man ten years her senior and rough around the edges. She was painfully shy and soft-spoken; he boasted ad nauseum of the name he was making for himself in the gritty world of construction. As Lillian told it years later, his story was truly one of self-making. Just shy of seventeen, he had been poised to enter MIT, but studying didn't appeal to his restless spirit. He became a bricklayer's apprentice and took mechanical engineering courses at night and within two years was a foreman, two years later a superintendent. As he mastered the bricklaying trade he developed the quickest techniques for handling corners and built rigging to minimize needless movement and lifting. Traditional methods required as many as eighteen compartmentalized movements to lay a brick; he had whittled them down to five, allowing a man to double his hourly yield. After patenting his adjustable scaffold, he invented concrete mixers, conveyors, and other apparatuses that allowed him to build houses, mills, canals, skyscrapers, and the basic infrastructure of whole towns in record speed. He started his own construction company in 1895 and went back to MIT to orchestrate the building of its electrical laboratory in a stunning eleven weeks.[9]

Frank Gilbreth and Company had grown to be one of the largest construction firms in the country by the time Frank met Lillian in 1903. They courted for a year and married in San Francisco, honeymooning at the St. Louis World's Fair. From the beginning Lillian could see Frank's penchant for efficiency: her engagement ring was engraved with the date of their engagement before he had even popped the question. He had already started apprenticing his wife on the train ride to St. Louis; passengers watched as he pulled out pen and paper and gave her a lesson in masonry. If it seemed strange that a man reared in late nineteenth-century New England considered sharing his professional endeavors with his wife, one has to recall that Frank had not grown up with typical women. His sisters were his academic superiors; one had become a musician and the other a botanist, both world class. Frank had watched them cultivate their talents outside the home and swore that should he ever marry, his wife would do the same. He asked Lillian to show him a list of qualifications she brought to their new partnership—a “job analysis” that she later compared to the “surveying and outfitting” performed by an engineer as he first meets a client. Like any engineering contract, Frank’s marriage required an assessment of assets so that the partners could “meet the world as a firm.”[10]

“The One Best Marriage was to be secured through The One Best Way”: The Efficient Partnership of Lillian and Frank Gilbreth, 1904–1912

At a ceremony recognizing Lillian as the first female honorary member of the Society of Industrial Engineers, a beaming Frank joked that his success had come from the sweat of his frau. There was truth to the wisecrack. He swore that had he known how fruitful their partnership would be, he would have married her immediately rather than wasting idle months in courtship. Their regular conceiving of children thereafter was, no doubt, the efficient man’s way of making up for lost time. He contended that children could literally be “cheaper by the dozen,” and Lillian agreed to test his theory, conceiving a child every year and a half for the next eighteen years. When all was said and done, she had been efficient indeed, birthing twelve children in thirteen pregnancies. Six were boys and six were girls, just as Frank envisioned. She nursed each baby, and other than her youngest, bore them at home in ritualized fashion. “She’d supervise the household right up until each baby started coming,” the older kids recalled. “She had prepared all the menus in advance, and the house ran smoothly by itself during the one day devoted to delivery.”[12]

The Gilbreth union was a sort of companionate marriage, a partnership in business and parenting—in science as much as domesticity—but not without some initial adjustments. In his thirty-six years of bachelorhood Frank had become fixed in his ways and wasn’t eager to relinquish his central place in the lives of his mother and Aunt Kit, who waited on him “by inches.” Lillian marveled that they never asked Frank to raise a finger, that after a day’s work he always returned to “a smiling welcome, a bountifully spread table, keen admiration." His "duplicate mothers" sought a suitable apartment on the Upper West Side of Manhattan for all four of them to move into after the honeymoon, and they furnished it fully, forcing Lillian to put her items in storage. When Frank left for long business trips, Lillian was compelled to fend for herself and often was reduced to tears.[13]

As an ex–boardinghouse matron who cooked Frank's favorite meals and darned his socks, Martha Gilbreth would always be her son's beloved domestic whiz. But Lillian learned to make the situation work for her. Once Lillian bore Anne in 1905 and Mary in 1906, Martha's insistence on running the house allowed Lillian to focus solely on the children and engineering. She had a lot to learn on both fronts, but Frank could see that she had a unique perspective to offer. One of her first days apprenticing at a building site proved enlightening: the contractor watched the stone and Frank watched the masons' motions; Lillian stood watching the mason, trying to decide if he truly liked the work. Frank could see that in her studious reserve, she had become observant of people and instinctively aware of what made them tick.[14]

Frank appreciated Lillian's attention to the "human element," but it was hard to make a case for its incorporation into the field of scientific management, to which he aspired. The undisputed originator of the discipline, Frederick Winslow Taylor, had earned acclaim in the 1880s for time studies that set standards for per hour production at industrial plants. When he could replace human workers with cheaper, faster machines, he did. When the human element could not be removed, he turned people into smaller cogs of a bigger industrial machine. Once a worker had been a skilled artisan, a master of his domain; but Taylor made him exploited and expendable, with no power to defend his turf—all apparently in the name of science. Taylor's streamlined processes worked because human contingency had been removed from them.[15]

Frank defended Taylor in a primer on scientific management in 1912; Lillian helped to write it but was never awestruck by Taylor's ideas.[16] Her subjective observation of human needs had no place in his disembodied processes, nor did her interest in the "unscientific" fields of management and education. With Frank's blessing she convinced Berkeley administrators to let her resume doctoral research in educational psychology, namely on theories of habit formation in industrial workers. Ergonometric chairs and workbenches, adequate lighting, incentives, and regular breaks were good for efficiency, she insisted, but they were also of benefit to the physical and emotional well-being of the worker. Lillian studied in California until she was ready to deliver her third baby girl. In 1909 the Gilbreths left their Manhattan apartment for Plainfield, New Jersey, where the expanding family had more room. Lillian left her daughters in the care of Martha and a German nursemaid while she conducted field research at the sites of Gilbreth contracts.[17]

Frank approved, but didn't dissuade his wife from putting aside her thesis in order to help him establish himself in the efficiency movement. She indexed a new edition of *Field System* and soon was doing the lion's share of the preparation of manuscripts and papers for Frank's academic and professional meetings. Initially Taylor thought the Gilbreth writings worthy contributions to his movement, borrowing heavily from Frank's bricklaying studies to write *Principles of Scientific Management* in 1911. But he also found the Gilbreths more rebellious than his other disciples, since their means for achieving efficiency revolved less around the study of *time* than around that of *motion*. If one could cut down the movements required to perform a task, they claimed, the result was not just quickness but less worker fatigue. The key was breaking down all tasks into basic elements called "therbligs" (nearly Gilbreth spelled backward). Whether laying a brick or typing a memo, all workers engaged in some sequence of searching, finding, selecting, grasping, positioning, assembling, using, disassembling, inspecting, transporting, loading, prepositioning, releasing, waiting, resting, or planning. By reducing the number of therbligs in a process, they reduced the motions and necessarily the time and physical and material resources required to complete a task.[18]

Thus while Taylor collected data with a stopwatch, the Gilbreths relied on visual images in the form of micromotion films and cyclegraphs. They recorded workers' movements and placed a special clock, a microchronometer, in view to indicate the expenditure of time in fractions of seconds. They marked off workspaces into four-inch squares or photographed this cross sectioning onto film so that workers' movements could be measured spatially when projected onto screens and studied under magnifying glass. Data from their films was recorded onto Simultaneous Motion Cycle (or "simo") charts that revealed when therbligs were needlessly duplicated, dispensable, or performed simultaneously by other body parts. Drawing on recent innovations in chronophotography, the Gilbreths strapped lights onto the limbs of workers and captured on time-exposed photographs the paths of light created as workers performed their tasks. The shorter and more fluid the lines, the more efficient the movements. Negatives viewed through a stereopticon revealed motions in three dimensions; and because they set up their cyclegraph with an interrupter that made the lights appear to flash at a known rate per second, they could count white dots on their photographs, measure distances between them, and determine workers' speed and relative acceleration with greater precision than with a stopwatch alone.[19]

The Gilbreths boasted that they had found "the One Best Way"—the least taxing method to move the fewest body parts through the smallest space quickly. Critics called their chronocyclegraphs gimmick, not science, but Frank and Lillian insisted that their methods achieved precision and were thus more scientific than Taylor's. Moreover, they were humane. Their emphasis on diminishing *fatigue* put them in the business of conservation, not exploitation. Motion study, as they perfected it, did not strip workers of autonomy because it brought skill and pride to their work; in fact since workers participated in the micromotion films, they became integral members of the Gilbreths' investigative team. Ideally, workers also benefited from the efficiency they created, as profits got passed down to them. Amid unionists' mounting criticism of scientific management's dehumanizing effects, the Gilbreths claimed to achieve better science and humane working conditions all at once.[20]

The Gilbreths described facets of the "One Best Way" in *Concrete System* (1908), *Bricklaying System* (1909), and *Motion Study* (1911), books published under Frank's name only. Lillian understood that, in a field defined and dominated by men, her inclusion would undermine their ideas; yet the reality was that she worked so closely with Frank on publications that even he thought it impossible to tease out his contributions from hers. They stayed up late into the night laying out drawings and galley sheets, often handing off babies as they worked. "I never had so much fun as I have planning these things with you," he told her. "You are always such an inspiration and always go me one better on all my ideas." To others she claimed only to provide snacks and pillows to make Frank comfortable as he wrote, but quietly she drafted whole books in his absence. *Fatigue Study* was hers, as were other works that stressed the conservation of human energy over maximized production. In the end, the things that were most important to her won the Gilbreths the reputation as the "good exception" in the eyes of organized labor.[21]

On occasions when Lillian accompanied Frank on business, she was typically pregnant or with a baby in her arms and had left the older children at home with Martha. But for most of the tens of thousands of miles Frank traveled each year, Lillian stayed behind to run the business and household alone; she accepted that her work lay "behind the scenes," or at least that it should seem that way. Her letters to Frank in these times serve as remarkable windows into her multifaceted consciousness as mother and wife, professional and engineer; she devotedly discussed the problems of clients as well as the birthdays, first steps, and milestones Frank missed at home. His letters were affectionate, but also laundry lists of orders: "I'll begin by planning your work so that you can do it with less fatigue and in less time," he prefaced from Germany, and then itemized detailed instructions for files and correspondence. Item 16: "Take a *real* vacation before doing anything. You need it badly." The reminder was typical but farcical and never at the top of the list.[22]

Lillian may have been overly accommodating, but she felt joy to be part of Frank's vision and grateful also to have purposeful work. Frank increased her responsibilities in the consultancy, although medical men had long alleged that intellectual pursuits posed a threat to women's reproductive health.[23] Clearly, Lillian would have been an exception in their expert eyes; while other men sent their wives off to water cures for rehabilitation after childbirth, Frank gave Lillian more to-do lists to fill her weeks of postnatal confinement. Correcting galleys for Frank's upcoming books seemed to pass the time better than anything else. *Applied Motion Study* and *Motion Study for the Handicapped* were products of her forced convalescences.

Just months after childbirth, Lillian was eager to attend the first Conference on Scientific Management at the Tuck School of Dartmouth College. Nursing a newborn forced her to keep a low profile, and yet at the final session the chairman asked her to address the audience. Reluctantly, she talked about the "human element" and managed an impromptu case for bringing the study of *human psychology* to bear on systems of efficiency.[24]

The Dartmouth conference was her coming out of sorts. She made such waves among academics that Frank urged her to get back to writing the PhD thesis. There was no time to lose; she had to publish while the iron was hot. He put her on a rigorous writing schedule and hired stenographers to transcribe notes she spoke into a Dictaphone placed near the home office phone. Even as she nursed, she could save time and energy by speaking into the mouthpiece. She finished quickly and rushed the thesis off to her committee at Berkeley, but her submission of "The Psychology of Management" was not nearly as momentous as Frank had hoped. University officials decided not to waive the required year of residence on campus, and her thesis was summarily denied.[25]

The bad news turned out to be the least of her problems. Taylor attributed the advent of motion study to himself during hearings in Washington, while Lillian was ministering to two diphtheric girls at home. Anne recovered, but Mary, her five-year-old, died at the end of January in 1912, the day after Taylor's damning testimony. Frank regrouped by securing a long-term contract at the New England Butt Company and moving the family to Providence, Rhode Island. He welcomed the change of scenery, and his sister was nearby to supervise the children's music training and to lend a hand at home, for Frank Jr., the first Gilbreth boy, was born amid the grieving. Still, the death in Plainfield left permanent scars. Lillian had wanted nothing more than to hold her girl in her arms through the child's final days, but Martha and Frank forbade it, worried about the health of her unborn child. Lillian continued to believe that she could have saved her daughter if given the chance, with motherly love if nothing else.[26] This was the human contingency for which one couldn't plan, and it reinforced her desire to understand the human element. She forever saw efficiency as a noble aim, but not at the expense of an individual's emotional needs. Whether her perspective was the consequence of her biology or her social need to mother, it soon became her lasting imprint on the fields of industrial management and engineering.

"The Human Element": Lillian Gilbreth Feminizes Scientific Efficiency, 1912–24

Providence was a place of new beginnings. Lillian birthed six children there and helped Frank solidify his place in the efficiency movement. Engineers watched closely as husband and wife reorganized the New England Butt Company, introducing micromotion study and one of their most innovative management devices: the "process" or "flow" chart, for visual analysis of production at all its stages. Other clients called on them. A handkerchief manufacturer watched them reduce the movements of workers so significantly that they finished three times more cloth per hour, without added fatigue. Secretaries at the Remington Company learned to perform calisthenics to add to their flexibility, strength, and blood flow; the Gilbreths helped them win the National Typewriting Championships in 1916. Surgeons meanwhile discovered they could remove the therbligs "search," "find," and "select," from their operating repertoires by calling out numbered instruments as nurses placed them squarely in their palms, and major league baseball teams signed up to have their batters, catchers, and pitchers filmed and analyzed. As World War I began, motion study facilitated the reintegration of disabled soldiers and amputees into the civilian workforce.[27]

Taylorites insisted that there was nothing unique about the Gilbreth system, but Frank's patent portfolio grew in Europe and domestically once Taylor died in 1915. Pierce Arrow, Zeiss, Lever Brothers, Eastman Kodak, U.S. Rubber, and Erie Forge Steel were just a sampling of his clients. He printed glossy pamphlets and supplied films to serve as pictorials for his micromotion experiments. "The One Best Way" appeared to be a humanitarian mission rather than a capitalist exploit, since the films included women and disabled workers. Frank erected "Fatigue Museums" that contained badly designed chairs, workbenches, and "instruments of needless torture," underscoring the benevolence of motion study by contrast. Soon the Gilbreths opened a summer school for college teachers of industrial management; Frank was away so often that the running of it fell to Lillian—yet again a case of his tireless promotion and her dogged follow-through.[28]

Frank's business gained from positive publicity about his growing family in the local and national press, where the image of Lillian tending to babies and school lessons humanized his work. More important still, Lillian's knowledge of social science helped him make his definitive mark, for her ideas about the psychology of workers filled his books. In *Motion Study*, for example, he focused on the physiology of workers, but also included their "temperament" and "contentment." It wasn't enough to provide workers with good lighting and ventilation, he told managers. They needed entertainment and a clear understanding of the systems of "reward and punishment." In *Field System* he (and Lillian to an undetermined extent) told managers to cater to workers' needs with "suggestion boxes" and periodicals that stimulated their minds. Lillian developed these ideas further yet, with intricate systems of communication, incentives, fatigue control, and self-regulation in the Berkeley thesis she submitted in 1911, but for three years no publisher dared to print it.[29]

"The Psychology of Management" occupied a precarious place in efficiency literature: it seemed to legitimize the practices of scientific managers and undermine them at the same time. Taylor's disciples had relied on the irrefutability of empirical measurements of time and profits, and yet Lillian surmised that the unquantifiable emotions of individuals crept into their scientific processes. Scientific management was as much process as bottom line, art as much as science. The study of the mind was appropriate in the training of not only teachers and philosophers, she argued, but also engineers, since efficiency ultimately relied on the human worker. One must modify equipment, methods, and materials to make the most out of *him*, she explained. *His* mind "is a controlling factor in his efficiency." Scientific managers "Taylorized" work, but Lillian tried to "tailor" work so that it might fit a man like a glove. Tasks could be surrounded with individualized incentives to accommodate his needs and wants. Suddenly extemporaneous movements were eliminated on the production line, as workers increased output at lower cost to their employers. The benefits felt by capital were shared in her vision; the worker received higher wages but also gained self-esteem as his unskilled labor grew more efficient and even skilled. The gap between the apprenticed worker and the college-trained one diminished, as the relationship between labor and capital turned cooperative. The result was industrial peace.[30]

Lillian's ideas piqued the interest of unionists, social reformers, and academics, but capital industrialists and managers felt threatened by her attention to the human element. When Frank tried to sell her thesis, publishers wrote it off as both archaic and ahead of its time. It didn't help that prominent academic men were starting to write in a similar vein. Harvard psychologist Hugo Munsterberg, most notably, became known as "the father of industrial psychology" after *Psychology and Industrial Efficiency* came out in 1913, and other established scholars jumped on the bandwagon. Desperate to get Lillian's work out in any form, Frank arranged to have parts of her manuscript published serially in *Industrial Engineering* under "L. M. Gilbreth" before Macmillan agreed to publish it in its entirely under the same gender-neutral name. In all the marketing for the book there was no mention that its author was a woman; its reprinting in 1917 and again in 1918 suggests that the strategy worked.[31]

None of this was of much consequence to Lillian, who at the height of the publishing frenzy had delivered an underweight son. But Frank was convinced that Lillian would be above reproach if she had the PhD. He had revisited the issue when they first moved to Providence, but Lillian was lukewarm to the suggestion. The Butt Company contract and the children kept her busy, she told him, but Frank had already been down the street pulling strings with Brown University administrators, who were interested in conferring a degree in "applied management." They'd give Lillian credit for course work already completed and would let her take oral examinations, but she would have to write another dissertation from scratch. "Don't worry, Boss," Frank assured her, "You can see our house from the classrooms. If you see one of our girls climbing out a window, you can run home and catch her before she hits the ground."[32]

It did make all the difference that the university was down the street. Lillian ran home between lectures to nurse the baby before anyone realized she had left. Once the house at 71 Brown Street grew too cramped for the expanding family the Gilbreths moved next door, to a corner lot better equipped with office and lab space for motion study. Lillian watched the children and took notes almost seamlessly once Frank installed Dictaphone equipment on both the first and second floors. "If I haven't but fifteen minutes to dictate," she told a reporter, "I utilize that time"; this was "the secret to the annual book." Every accommodation was made for efficiency; had it not been for the motion studies, the summer school, and the birth of Lillian Jr., she might have taken one year to complete courses instead of two. For most of these months Frank was nowhere to be found; on assignment overseas, he charged his wife with running the office and laboratory and getting the children fluent in German as soon as possible.[33]

It would have been overwhelming had there not been plenty of hired help in the house. Lillian didn't make a meal or scrub a floor; the children were her only persistent chore. There was the domestic supervisor, the cook and handyman, the governess, the maids, and the part-time laundress and hairdresser to lighten the load, and Grandma Martha was still vigorous enough to oversee operations. Time was at a premium, but Lillian was helped by a schedule: two hours for breakfast and the grooming of the children in shifts, two hours to write, a fifteen-minute break with the children before lunch, another hour with children, a half-hour nap, a half hour with the youngest baby, another hour writing, an hour for callers, an hour with the children, a half hour for miscellany, and an hour for dinner before putting the little ones down, helping with homework, and reading bedtime stories. Lillian insisted that the key to keeping focused was her afternoon nap: ten minutes of lying flat on her back did more to eliminate fatigue than ten hours of sleep once overtiredness set in.[34] With this system of efficiency in place, her thesis write-up still went more slowly than Frank would have liked, for Lillian tolerated the children's interruptions and only later instituted a chart to keep them to a minimum. On top of babies and clients, she was also conducting research for *Fatigue Study* and serving on the PTA and the Association of Collegiate Alumni. Frank offered words of encouragement from abroad and kept Lillian regimented with work charts. "I hope that the thesis will not give you nervous prostration," he wrote—hollow words as his pregnant wife feverishly prepared for orals.[35]

Lillian managed to write a four-hundred-page document called "Some Aspects of Eliminating Waste in Teaching," a culmination of hundreds of hours of observation in Providence schools to bring efficiency to the classroom. She gave recommendations for lighting, clothing, ventilation, desks, supplies, and classroom layouts to economize on physical motions, and she advised teachers on how to plan lessons in advance. But again the strength of the thesis was its insight into the human element—what motivates teachers to teach and students to learn. She described what psychologists would later call "the Hawthorne Effect": like the workers involved in her micromotion studies, teachers and students proved eager when they were made active partners in classroom experiments.[36]

As Lillian was finishing her manuscript, her tenth wedding anniversary came and went; Frank could not be Stateside, but he wrote of his undying affection—as well as with instructions for a session at the American Society of Mechanical Engineers (ASME) annual meeting. He returned to Providence after Christmas but was back in Europe in early 1915; he would miss Lillian's graduation in June. She walked in the late spring processional as the lone woman doctor, content in knowing that her older children were to greet her on the campus green afterward. Brown University president W. H. Faunce wrote Frank in admiration of his wife: "I do not know another woman in America who has achieved what she has done in the realm of study, and at the same time fulfilled every duty of motherhood in her constantly enlarging home." Indeed her household continued to enlarge, but not right away: the baby girl Lillian carried under her doctoral robe was stillborn that September. She and Frank said nothing about it to stave off criticism that she was trying to do too much.[37]

Lillian was the first of her peers in scientific management to have the distinction of a doctoral degree. With "PhD" beside her name it now appeared with Frank's on professional papers—more than fifty in total over the following nine years. And yet for all her new access to the profession, her daily existence felt much the same. She nursed babies, transcribed notes, and tended to professional correspondence as Frank sat in hotel rooms pouring out his ideas for the future. "I'm still thinking of the paper you wrote for the Academy of Science. I think that and the Toronto paper and one or two at Dartmouth and some of the old ones printed in *Industrial Engineering* would make a good book for say $1.00 . . . Yes Boss, I see many books that we can put over, easily one a year the rest of our lives and perhaps two."[38]

Late in 1916 Lillian was wrapping up another semester of the Gilbreth Summer School and checking galleys for *Fatigue Study* when Fred, her eighth child, was born. Frank was out of town, as he would be when Dan, the ninth, came thirteen months later. One would think it time to settle in at home, but with U.S. intervention imminent in the war overseas Frank announced that he was leaving to don a military uniform. With no initiation on the part of the army's Engineering Corps, he offered his expertise in motion study. Lillian, as always, let him dream in superlatives—the most successful consultancy, the biggest family, the greatest impact on his country and the efficiency movement. Never would she allow her need for time, space, or physical recovery get in the way of this dreamer's best-laid plans.

And so Lillian held down the fort as "Major Gilbreth" set off for Washington. "If you take care of the kids and answer the mail you will have [done] more than enough," he assured her, but almost immediately he began writing with his fussy requests. She wrote back to assure him that she was getting everything done: she sent the motion models to the Smithsonian and the stills to colleagues, phoned the clients, sent the requested reprints, planned the "Tech talk" she was giving in his stead . . . All was well at home, she reiterated, though the children's interruptions were to blame for any typos on the page. She had dashed up to the school for parent-teacher conferences, taken Anne shopping, attended Ernestine's violin lesson, nursed the baby, put the little ones to bed, and worked in her office as she supervised the older children's homework. She moved the piano into the library and the bookshelves to the parlor. "Now the children have a nice warm place to practise in, and I can inspect typing and piano, and work at my desk all at once."[39]

Rather than cordon off family obligations here and professional ones there, Lillian grew comfortable combining the two, and did it in productive ways. This skill came in handy one month later, when Frank took ill at Fort Sill. She arrived in Oklahoma to find him comatose; immediately she took over, directing his caregivers and instructing the children and domestics through letters sent home. When Frank was moved to Walter Reed Hospital, she shuttled back and forth between Providence and Washington to keep him abreast of the projects she ran in his absence. By August he was discharged to rest with the family in Nantucket. He hobbled on a cane as Lillian ran the household and consultancy and nursed him back to health. She was losing hair and weight, but this was no time to slow down. Gilbreth Incorporated lost money during Frank's convalescence, and it grew clear that they were in need of a bigger house once again. In 1919 the Gilbreths moved to an old, sprawling estate in Montclair, New Jersey, where the schools were good, close associates lived nearby, and Frank would have easy access to his paying New York clients. Lillian made an office out of one of the two ground-floor living rooms and converted the barn into a laboratory with a built-in darkroom.[40]

Modern science was, by definition, not a domestic affair, but for the Gilbreths efficiency demanded the collapse of personal and professional space. This had already been the case in Providence, when the need to remove the tonsils of four of the five eldest children turned into an opportunity to run experiments in surgical time-saving measures right in the house. The Remington contract likewise called for the children to be filmed in typing trials in the room where they normally did their homework. The eldest children served as lab rats for Frank's experiments with colored-coded and Braille keys, and Lillian recorded the typos and times. In the more spacious accommodation in Montclair, Frank outfitted the rooms more completely for motion study. Bathrooms became micromotion labs, as the children groomed to German lessons simultaneously piped into the walls. Bedroom ceilings were painted with Morse code messages and astronomy lessons for absorption during morning and nighttime routines. The children counted in Latin while doing their calisthenics, exercising both body and mind at once.[41]

"Efficiency," Frank Jr. recalled, had become a byword in the Gilbreth household, "the most overworked single word in our vocabularies." The children played with their parents' speed clocks and time exposure equipment and kept their own time as accurately. Lillian did not object when Frank took the children into clients' plants or asked them to stand in for workers in his films. The children turned into consultants as they sat around the movie projector and analyzed the movements of women packing soap flakes. They saw the household bills for the hourly services of repairmen and medical professionals and learned that time is money—don't let family resources go to waste. Everyone chose outfits the night before to wear the next day—a practice arguably *too* efficient to be practical, until the children's studies determined that weather forecasts were accurate 85 percent of the time.[42]

Frank used work charts to plan and regulate the children's activities. Martha's, for example, read "open bed," "dress as far as wash," "wash or bath," "brush teeth," "clean nails," "complete dressing," "hang up night clothes," "piano," "take down wraps," "breakfast," "take school money," "walk to school," "school," "ride home," "wash," "comb hair," "lunch," "walk to school," "school," "ride home," "play," "hang up wraps," "typing," "wash," "supper," "cello," "languages," "report on chart," "undress," "wash or bath," "brush teeth," "lay out clothes," "prayers," "bed." When she completed tasks on time, she marked corresponding squares in blue. Yellow meant completed but late; red meant not completed at all. Frank Jr.s' morning routine from 7:00 to 7:30 didn't allow for a minute of waste: Martha called for him to rise and shine on the hour, and he was to turn into the bathroom by 7:01. By 7:02 he was playing German records as he brushed his teeth and bathed. He weighed himself and recorded it on his weight chart at 7:07, combed his hair, washed the ring out of the tub, started the bath for Bill, and wound up the Graphophone at 7:08. By 7:10 he woke Bill and turned on the French records to listen to while dressing. At 7:16 he shined his shoes, made his bed two minutes later, and straightened the room three minutes after that. By 7:31 he was ready for breakfast—if he was keeping pace.[43]

The children had their "standing order forms," "output charts," "pay charts," "evaluations forms," "telephone charts," and "bath charts,"—even charts recording chest expansion at inhalation and exhalation. The charting grew obsessive but was part of Frank's "One Best Way" to run a household. A journalist for the *Montclair Times* likened the house to a well-run "industrial community," with Frank as the municipal employer, Lillian the manager, and the children their dutiful employees. To understand how literal the analogy became, one needed only witness the children's submission of bids to take on household projects. Frank posted orders for yard work, painting, or repairs, and the child proposing the quickest, cheapest services secured the contract. As if in the factory, each child had an assigned number for routing intra-family memoranda, and Frank installed his "three-point" promotional system, whereby the children were offered incentives to learn, master, and teach household skills at all times. Tasks in the home were broken down precisely to fit the children's physical and mental abilities. Rather than assign a single child to dusting, for example, taller children took the tabletops and high shelves and shorter children the legs and lower shelves. Heights and weights were recorded regularly for the purpose of reassignment. The children took part in these unusual experiments because Dad had instilled the belief that efficiency made them successful people. It was part of his master plan that they skip grades, and most of them did, since they had been taught foreign languages and "mental math" as toddlers. Even the infants were trained to retrieve slippers from marks placed on the closet floor to another set of marks at the foot of his bed.[44]

Such experiments may seem dehumanizing, but Lillian tacitly approved. Watching her children's reaction to them made her sensitive to the psychological needs of workers in the plant, and the lessons served the children, too, when they left home to fend for themselves. Throughout their childhoods, as they prepared statements for weekly family councils, they learned to get points across succinctly for future business meetings. They trained their siblings and received training in return, so that they knew what it was to manage others and accept criticism. They learned to draft their own charts, choosing wording and paper colors that were precise and psychologically pleasing. Lillian insisted that making a fifteen-year-old file income tax reports was too enriching not to do it. The key to compliance was no different from what she espoused in *The Psychology of Management*: provide incentives for the work and provide suggestion boxes that open channels of communication with "management." But most crucial was her behind-the-scenes emphasis on "worker satisfaction." As she watched her children's rigorous routines, she reminded them that they were loved and appreciated for their individual attributes.[45]

This emphasis was hers alone, for Frank was too concerned with a master plan for the group to cultivate individual personalities. He rationalized that the time his children saved could be banked for one-on-one "happiness minutes," but Lillian was the parent cashing them in. "She knew what every one of her individual children wanted, needed, dreaded, and dreamed about," Frank Jr. recalled. "And when a child talked to her, she listened and listened, and made sure she understood." Years later Lillian still advocated for "standardization" in the home. It made sense to maintain uniform sets of buttons, kitchen utensils, and underwear, since that made them cheap and easy to replace. But the practice had to be discarded once it cramped a child's sense of self; in the home, as in the factory, the *individual* was her primary interest.[46]

The Gilbreth children revered their father but recognized that Mom's humanizing perspective was the key to their joint success, both as parents and engineers. It was not coincidence that after Frank's death many of the household systems grew lax, some defunct. Lillian never said much while he lived, but she could see that, in Frank's haste to write papers and graduate children, something had been lost. He could not understand why editors looked so critically at the manuscripts he dashed off, but she knew that they were lacking in art and substance. In business, he conceived the most efficient industrial practices, as she quietly humanized them; and at home, he installed the science she gently improved upon. A reporter noted that, while Frank seemed frantic, his wife "radiated efficiency" without "the slightest evidence of nervous drive or hurry about her. There was a calm and placidity—and femininity" that she found "restful and refreshing." Frank once said that his wife's greatest accomplishment was the *Psychology of Management*, but Lillian disagreed. Babies trumped books, she insisted—always the human element in the end.[47]

"If the only way to enter a man's field was through the kitchen door, that's the way she'd enter.": 1924–

Grandma Martha outlived Aunt Kit and died in Montclair at eighty-six years of age. Jack, baby number ten, was months old, and number eleven was on the way. Lillian mourned the loss of Martha's help at home. To afford their mortgage, she had let go of much of the personnel they had had in Providence, but Frank was confident that with his procedures in place, she would not have to relinquish her professional endeavors. In fact after the birth of Jane, baby twelve, the Gilbreths had planned a seven-week lecture tour in Europe. Lillian looked forward to giving the keynote address to the British Society of Women Engineers, but this time an emergency hysterectomy, not a birth, kept her grounded. The trip with Frank was never to be, for he died the following June. With blinders on, Lillian proceeded stoically down Curie's anti-natural path: "The rest is bringing up the children, and proving I deserved all Frank gave me—and that was everything."[49]

Lillian was herculean in her efforts to parent and pay the bills after Frank died. She got her kids ready for school, supervised menus and budgets, sewed buttons, wrote the kids at college, read stories, and helped with homework—in addition to ten-hour days in the office and laboratory. Her older children said that she rarely missed a class play, a commencement, or a "Be Your Child" day at the Montclair schools (for which she hired a cab to chauffeur her to multiple classrooms at the elementary, junior high, and high schools for the day). But any woman who has ever tried to balance work and family knows that no path is walked without sacrifice. The family log indicates that there were years when she traveled more than she was home. When she went abroad the children made a ritual of waiting for the mailman to arrive with her letters. On her return from the World Power Conference in mid-1930, she could not go home immediately: Martha picked her up and drove her to a consulting job in Manhattan and then to catch a train to the Society of Industrial Engineers (SIE) meeting in Washington. Jane, who was too young to know her father, felt that she suffered the most. Her older siblings had enjoyed family vacations with both parents in Nantucket every summer, yet she was shuttled off to summer camp so Mom could go abroad "for the millionth time."[50] The astute observer of people, Lillian had to be aware of her daughter's resentment; yet as a single parent and breadwinner, she had to sacrifice the human element from time to time.

The day after Frank's death, Lillian wrote the president of SIE asking, in light of recent events, if she could speak at the Power Conference in London. The answer was an unequivocal yes, for colleagues thought the gesture not unlike Marie Curie's completing Pierre's lectures when he died in 1906: this was the loving tribute of a devoted wife, not the trespass of an ambitious woman. She gave her lecture in London, completed Frank's contracts in Holland, and received a warm reception in Prague. After she returned she published her favorable impressions of the trip in *American Machinist* and then fulfilled Frank's speaking engagements on college campuses throughout the country. In 1925 SIE published her biography of Frank, *The Quest of the One Best Way*.[51] Immediately after Frank's death, the profession appeared to embrace her.

But when the mourning period was over, like Marie Curie, Lillian discovered that the tributes to her husband were not a sign of her own acceptance. Within the year her three biggest clients canceled contracts or refused to renew. She paid visits to Winchester Laundries, Filene's, and other standbys, but they, too, were reluctant to rely on her for their managerial needs. Close colleagues offered her positions in their firms, which she politely declined in favor of keeping Frank's business afloat. To expand her contacts she turned to SIE, where, although women were not allowed to become regular members of the society, they could attend meetings, making it the most permissive of the national organizations. As an honorary member Lillian was able to become chair of its Fatigue Elimination Committee in 1926. The position brought her speaking engagements, as did several of Frank's university contacts, but the attached honoraria rarely covered the expense of travel. Frank had grown accustomed to first-class accommodation, but his wife booked upper births on trains and stayed with friends in college towns.[52]

The forces of institutional chauvinism pushed her further out of industrial engineering—and she wasn't alone. By 1938 the list of more than eighteen hundred women in *American Men of Science* included only five women engineers in any subfield. When Frank was alive she had been insulated from discriminatory practices; as a widow, however, she felt the wrath of a profession that relied on its virile image for definition. The engineer conjured in the American mind was rugged and outdoorsy, seemingly blue-collar in his affiliations. Shop floor workers and managers had always seen Frank as one of them, when he rolled up his sleeves and smoked his cigars. Needless to say, they could not view Lillian in the same manner, nor could other professional engineers. She was turned away from a dinner at the University Club in New York even though she was an invited guest: according to building regulations, she, like any woman, was not allowed on the premises. When a committee she was on convened over breakfast at the Engineers Club, she had to eat elsewhere, and colleagues never considered relocating to another venue. Men introduced her as Mrs. Frank Gilbreth, although men with identical credentials were referred to as "Dr." this or that.[53] Her reaction was always gracious; she saw no point in making waves.

Lillian managed to get honorary membership in the American Management Association and sought the same in the ASME, but the odds were against her. Kate Gleason, the only other female member, had courted such disfavor that another woman's candidacy seemed unlikely. Gleason was thirteen years Lillian's senior and had much in common with her, since she, too, had learned her trade "in the family," inventing worm gears at her father's machine tool company. But her single status troubled male peers, for without a husband, there was no one to whom her accomplishments could be attributed. Lillian found herself in the same position after 1924. A loyal few lobbied behind the scenes to see that she got an honorary membership in the ASME, but it was clear that she would have to refocus her energies in directions that male colleagues thought more appropriate to women. Gleason had left tool making to build low-cost housing; Lillian, too, turned to civic projects, assisting the down-and-out during the Great Depression. Under President Herbert Hoover she headed the women's division of the Emergency Committee for Employment and served on the Organization of Unemployment Relief.[54]

It was not unusual to see a woman engaged in social welfare work, for American women had worked inside church groups for generations and inside government agencies for decades. Rather than fight cultural assumptions about her strengths and proclivities, Lillian allowed them to buttress her position of authority in areas where her persona as mother of twelve and nurturer of the human element would be valued. If she could not work in the industrial plant, she'd take on the kitchen, the classroom, or the retail store. When mechanical engineers remained hostile, she gravitated to growing communities of management consultants and industrial psychologists. And when she couldn't get hired to install the Gilbreth system in plants, she decided to teach it to those who could. The vice president of Johnson & Johnson proposed that she open another school of motion study for his managers, and she embraced the idea since it allowed her to stay close to home. Charging students a thousand dollars for the course, she managed to pay the family's bills and college tuitions. Over six years she attracted managers from General Electric, Borden Milk, even international firms.[55]

The course was supposed to advance Frank's motion study, but her added views of plant psychology kept the students coming. Since her pioneering work had appeared, the number of organizations and publications dedicated to the subject had expanded. She became a frequent editor for *Industrial Psychology* and an instructor for newly formed institutes in the field. Increasingly, however, clients sought her out as an expert on the *woman* worker in particular, and she was willing to remake herself accordingly. In the early Depression heavy industrial sectors staffed predominantly by men were hardest hit. Until then, most middle-class women who worked were single. Now for the first time in American history significant numbers of married women entered light industry and pink-collar services to compensate for their husbands' lack of gainful employment. Their growing numbers reopened debates about protective legislation and women's proper place at home. Women were becoming integral contributors to the family wage, but their responsibilities as homemakers only intensified: pinching pennies and stretching leftovers were keys to weathering an economic decline. Their double burden as workers and homemakers was unprecedented, yet Lillian had lived it all along; there could be no better authority than she on women's work and efficiency, both in and outside the home.

Lillian combined her expertise on waged work with studies of domestic economy that women had pioneered since the late nineteenth century. Socialist feminists such as Charlotte Perkins Gilman had experimented with the idea of communal living arrangements and technologies to lighten the load at home and free women to pursue paying careers. These efforts had converged with those of Ellen Swallow Richards, Helen Campbell, and other women who reinvented themselves as domestic scientists when the academy refused them entrance to other science fields. By 1910 they had christened their field "home economics" and had created the American Home Economics Association

(AHEA). Such popular writers as *Ladies Home Journal* editor Christine Frederick helped sell books and magazines through this idea of alchemy in the home in the 1910s, and the Gilbreths, too, had begun to think of ways to make the homemaker self-sufficient.[56] Home economists from Columbia's Teachers College had come to their home to perform motion studies of bed making, and Lillian had adopted a cross-sectioned kitchen for more studies. The AHEA's response was enthusiastic, but in the Gilbreth household prestigious industrial clients had taken priority, since they helped to pay the bills.[57]

Ironically, once Lillian was alone, domestic efficiency was nearly the only form of scientific management for which clients sought her expertise. In 1927 Mary Dillon, president of the Brooklyn Gas Company, asked her to develop the prototypical "Kitchen Practical" for the Women's Exposition of 1929. The working space in this model room was circular—from the refrigerator, to the kitchen cabinets, the stove, the sink, and the serving table—and its diameter was the distance between the homemaker's outstretched arms, shoulder to fingertips. For optimal convenience, the service table had wheels so it could move anywhere in the room, and the heights of surfaces were adjusted to eliminate fatigue. Stools brought a child's workspace level with his or her mother's, for in this kitchen cooking became a *family* affair. In the promotional literature a man in business attire donned an apron and cooked alongside his wife and child with a look of contented bliss. Lillian insisted the kitchen be practical, but attractive enough to inspire creativity. This was a space where science integrated with domesticity as well as art to turn homemaking into a fulfilling endeavor for the American homemaker.[58]

Indeed Lillian believed that scientific management and homemaking were not antithetical. If installed correctly, scientific principles could eliminate physical fatigue, the psychological drudgery of housework, and the low self-esteem of the homemaker. Lillian gave many radio addresses touting the merits of motion study in the home, and she received back-to-back contracts to write *The Home-maker and Her Job* and *Living with Our Children* in 1927 and 1928, respectively. From canning baby food to designing workspace, Lillian's books advised on "the One Best Way" to run a household. Since readers were unlikely to have micromotion equipment, she encouraged them to design homemade experiments. Their children, for example, could reproduce a cyclegraph by retracing Mom's movements with a ball of string and pinning it every time she changed direction. Why not make simo charts to establish the best posture for washing dishes or count the therbligs to bake a cake?[59]

The methods Frank had applied to bricklayers and baseball players lent gravity to the housework of American women and turned them into experts in their own right. Lillian reminded women that, using both the human insights of psychologists and the analytic skills of engineers to run their homes, they were, in essence, managers of human beings and material resources. She also reminded them that efficiency was never an end in itself: it allowed them more time to spend with their children and in other endeavors that might afford them pleasure. If these activities took them outside the home, then so be it. Lillian's ideal homemaker was not a glorified one so much as a woman fulfilled. The distinction she made between the housekeeper and the homemaker depended on the degree to which an equilibrium between housework and career work, work for subsistence and work for vitality, work for others and work for oneself had been achieved. Housekeeping was science, but homemaking was "housekeeping plus"—the art of directing science toward the most creative ends.[60]

Lillian wrote her domestic books as she took on contracts to train secretaries and reformatory matrons because she saw the relationship between home and workplace as parallel and reciprocal. Eventually she merged her knowledge of both realms into a contract for Macy's, a department store where domestic consumers and female workers literally shared common ground. Eugenia Lies, a student in her motion studies course, was head of the Planning Department and invited Lillian's students to make a case study out of the Manhattan store, specifically in the problem area of the "tube room," where centralized cashiering took place. Lies convinced her bosses that Lillian's female sensibilities could provide solutions for the store's sales and human resource problems, for Lillian understood worker psychology and, like 85 percent of department store clientele, ran a household of her own. Management agreed that Lillian would be likely to understand and anticipate the spending practices of female shoppers, but they were dubious about her ability to understand the needs of the female sales force and cashiers. For more insight Lillian spent a summer working in store departments, getting into the heads of disgruntled women on the floor.[61]

No stone went unturned during the three years she spent tightening operations. She changed light fixtures to reduce eye fatigue, repadded walls to reduce noise in the tube room, determined the fewest therbligs for working the cashier desk, and did away with duplicate recordings of sales checks. She implemented procedures to reduce counting errors and the amount of time customers waited for change. One result was happier customers with more time and interest in spending money in a pleasing store, newly remodeled and easy to navigate. More efficient cashiers could ease the pressure on sales clerks, who needed to make their daily quotas quickly. The mainly female employees reaped rewards as profits were passed down in the form of time off, cash, and promotional incentives. Lillian revamped managerial practices, too, creating better systems of posting and filing of employee records, and opening channels of communication between managers and salesclerks. As she had insisted in *The Psychology of Management*, the individual worker practically managed herself when she was consulted about changes. Her fatigue decreased when jobs were fitted to her physical and psychological needs.[62]

By 1932 Lillian was speaking to members of the National Retail Dry Goods Association about her new expertise, "What the Customer Wants"—particularly the woman consumer. Her work at Macy's attracted Sears Roebuck, and Johnson & Johnson hired her to develop and market Modess sanitary napkins. Men with business degrees were stymied about how to amass consumer data on a product that, until only years before, women had privately made themselves. Kimberly Clark had tried to market Kotex pads, the first commercial feminine hygiene product, but no marketing team had mastered the art of selling them to women, who were too embarrassed to offer product feedback. Because Lillian and her research team were female, she got candid responses from consumers: They wanted greater comfort, protection, and inconspicuousness in a product they could discreetly obtain and throw away. Back in Montclair she created her own research lab, flushing, submerging, and pulling apart products already on the market and observing women's reactions to the size and shape of the boxes they came in. Lillian seized on the rare fact that a corporate bottom line relied on a thorough study of women's bodies; her report to Johnson & Johnson included exhaustive data on women's cycles and their attitudes about menstruation.[63]

Lucy Maltby, a contemporary, had developed Pyrex ovenware for Corning Glass Works. Lillian, too, had found a way to make being female seemingly enhance her expertise rather than diminish it. By 1931 the domestic guru was asked to promote "the Management Desk," a streamlined piece of furniture equipped with clock, adding machine, radio, telephone, child reference books, and charts for the organization of domestic chores.[64] The desk, as well as her prototypical kitchens, seemed to yoke women to the home by systematizing their domestic operations. But one could also argue that they had a liberating effect, when they saved homemakers time to enter the masculine professions. One of her designs was actually a kitchenette for a two-career household that became the blueprint for one she created for her daughter Ernestine, who had married and worked as a buyer for Macy's. Over the following three decades Lillian's ideas improved women's lives in a number of ways. Using motion studies, she taught wheelchair-bound women how to make beds and supper, and she created specially rigged kitchens for women debilitated by heart disease. She teamed up with home economists to publish floor plans that American women could purchase and adjust to any need—be it validation of their domesticity or efficiency to work outside the home.[65]

Regardless of the message women might read from her designs, Lillian's image was the best tool to market them; she represented glorified motherhood and ambitious careerism all at once. Exhibitors of her Kitchen Practical handed out coffee cake recipes to passersby that they claimed were hers—an ironic scene, given her actual experience in the kitchen. "Stoves burned her, ice picks stabbed her, graters skinned her, and paring knives cut her," Frank Jr. recalled. This was a woman who concocted a creation that her children privately referred to as "Dog Vomit on toast." When cameramen came to Montclair to shoot promotional films for her kitchen designs, she quickly had to remodel her own. And yet her remaking as a domestic guru was complete. Frank had invented an adjustable scaffold; she, a foot-pedaled kitchen trashcan. He had reduced motions for bricklaying, and she reduced the effort required to make the breakfast coffee. She developed electric stoves, refrigerators, and washing machines and described how to mix a cake, bake it, and clean up the dishes in just a few dozen steps—even if she had never taken them herself.[66]

Her popular image was fictitious to a degree, and yet she had been efficient enough to bank her happiness minutes so that she might realize a career on her terms. Engineers on shop room floors did not necessarily know who she was, but journalists for homemaking magazines referred to her in the same sentence as June Cleaver, Betty Crocker, and Dr. Spock. Americans admired her maternal patriotism, first as a consultant to relief agencies during the Depression, and then as an executive member of the Girl Scouts, the War Manpower Commission, and women's army and naval auxiliary boards (WACS and WAVES) during World War II. Agencies under Hoover, Roosevelt, Truman, Eisenhower, Kennedy, and Johnson used her motion studies to bolster civil defense, increase war production, rehabilitate the disabled, and care for the aged. Walt Disney made a Technicolor training film of her process charts, and her portrait appeared on postage stamps. In 1948 the American Women's Association named her Woman of the Year, and *Cheaper by the Dozen* made it to bookstands, increasing her celebrity status even more.[67]

Lillian treasured her life and work as a wife and mother, which her children glorified for postwar readers and filmgoers, but the truth was more complicated. She had also longed to engage in professional and intellectual pursuits that were seemingly in conflict with domesticity. She made working life acceptable by becoming a domestic icon even as she transgressed the stereotype. Her ideas for home efficiency did not appear to disrupt the notion that homemakers were female, and yet as early as the 1920s and 1930s she had been describing the work/family balance as a dilemma for men and women both. Her assessment of Frank's contributions to her own home may have been generously distorted, but she insisted that scientific management had equalized her marriage, just as it had democratized the shop room floor. As domestic journals of the 1950s told women to prepare labor-intensive meals to meet expectations of perfection at home, Lillian questioned the merits of such martyrdom, much as Betty Friedan did later in *The Feminine Mystique*. There was nothing virtuous about servicing others at the expense of oneself, she told homemakers. Drive-throughs, mail order, ready-made cakes, laundry services, and other modern conveniences were not enemies but possibly keys to a more balanced life. Lillian's own balance of home and work had taught her not to judge, but to give women the tools to work out the best balance for themselves.[68]

Lillian wanted women to feel fulfilled as homemakers, but that also meant turning her attention to where women made wages and bought their domestic goods. Wherever women were, she lent them legitimacy by systematizing their operations. To call her subversive may be at odds with what she intended, but it's hard to ignore the contradiction she embodied throughout her life. The press referred to her as the "First Lady of Engineering," but she was also honored in New Jersey as "Mother of the Year," suggesting that there was no consensus about which of her virtues to extol: her professionalism or her maternal excellence. Lillian didn't think it an either/or proposition, and indeed members of the Industrial Management Society seemed to agree when it named her "Mother of the Century" in 1959. Mills College president Lyn White thought her life "the biological phenomenon of this century," but Lillian believed that anything was possible with a scientific plan in place.[69]

By 1960 Lillian boasted membership in the Society of Women Engineers, and yet engineering remained the most male of scientific professions. Women made up 4.2 percent of the nation's physicists, 8.6 percent of its chemists, and 26.7 percent of its biologists, but it would take another decade before they made up more than 1 percent of engineers. The few women who dared to enter the field in the early twentieth century—women such as Kate Gleason, Bertha Lamme, Edith Clarke, and Ellen Swallow Richards—were greeted with hostility and settled often for projects that male peers refused. Lillian's marginalized status in the field may have afforded her the best perspective on engineering problems in the end. She had nothing to lose by rejecting the rules of scientific managers, and so she redefined and expanded them. Sound science, she declared, was in the home, the human element, and the culturally female sphere.[70]

Through all her years of hardship, Lillian had sworn that all her children would go to college, and this indeed came to pass.[71] It was not a coincidence that several went to colleges where she had already been given honorary degrees, for ultimately she received more than twenty. Rutgers awarded her a full-fledged Doctorate of Engineering in 1929, and six years later Purdue University broke all gender protocol by making her the first and only full-time female faculty member as professor of management in its School of Mechanical Engineering. She divided her time between motion study in the Department of Industrial Engineering and teaching in industrial psychology and home economics; she became the official "consultant on careers for women," but also enjoyed a week off every month to return to Montclair for family visits. Once she had fallen prey to rigid boundaries between home life, engineering disciplines, and academic and commercial work; in her sixties, she moved between these realms at will.[72]

As a young widow Lillian had carried an oversized pocketbook that contained a hodgepodge of items on any given day: sometimes a shawl she was knitting or socks she was darning, drafts of speeches, back issues of *Iron Age* magazine, and a notebook in which she jotted down reminders about work and her children. Her children noted the irony of there being "never anything very efficient about Mother's pocketbook."[73] Perhaps it is less ironic than emblematic of Lillian and her life. The pocketbook always contained projects—both personal and professional—that she was in the midst of completing placed indiscriminately next to each other. She pulled them out and worked on them whenever and wherever she could spare a minute, not in places and moments specially designated for them. It was not unusual in her younger years to find her feeding a baby as she drafted a scientific paper, or in later years crocheting as she was introduced at a professional gathering. When her kids became adults she continued to write them daily, often from the planes, trains, and taxis shuttling her from one speaking engagement to the next. One might think her a victim of circumstance—a woman who hadn't the luxury of drawing boundaries between her science and domesticity. Or one can see her as the hero of her own story—a scientist whose identity took on expanded meaning. Versatility and efficiency were the keys to her success. Where professional scientists have idealized a separation between worlds, Lillian Gilbreth brought their permeability to light and revealed endless possibilities.

Notes

FG: Frank Gilbreth
GC: Frank and Lillian Gilbreth Collection at Purdue University, West Lafayette, IN, selected papers (Cleveland, OH: Micro Photo Division, Bell and Howell, 1976)
LG: Lillian Gilbreth
LMG: Lillian Moller Gilbreth Papers in Sophia Smith Collection, Smith College, Northampton, MA

1. Brochure for the Kitchen Practical, 1931, Box 14, folder 12, LMG.
2. Lillian Gilbreth, *As I Remember: An Autobiography* (Norcross, GA: Engineering and Management Press, 1998), 190–92.
3. Frank Gilbreth Jr., *Time Out for Happiness* (New York: Thomas Y. Crowell, 1970), 156–57; Edna Yost, *Frank and Lillian Gilbreth: Partners for Life* (New Brunswick, NJ: Rutgers University Press, 1949), 308.

4. LG to Annie Moller, July 6, 1924, Box 11, folder 9, LMG.

5. Margaret Ellen Hawley, "The Life of Frank B. Gilbreth and His Contributions to the Science of Management" (master's thesis, University of California, 1925), 201 (microfilmed on reel 1, GC); "Family Log," entries from June 14, 1924 to June 22, 1924, Box 3, folder 2, LMG.

6. Jane F. Levey, "Imagining the Family in Postwar Popular Culture: The Case of *The Egg and I* and *Cheaper by the Dozen*," *Journal of Women's History*, 13, no. 3 (2001): 125–50.

7. Frank B. Gilbreth Jr. and Ernestine Gilbreth Carey, *Cheaper by the Dozen* (New York: First Perennial Classics, 2002), 205 (the original was published by T. Y. Crowell in 1948).

8. Gilbreth, *As I Remember*, 52–80; Gilbreth, *Time Out for Happiness*, 30–32; Jane Lancaster, *Making Time: Lillian Moller Gilbreth—a Life Beyond "Cheaper by the Dozen"* (Boston: Northeastern University Press, 2004), 21–64.

9. Lillian Gilbreth, *The Quest of the One Best Way: A Sketch of the Life of Frank Bunker Gilbreth* (Easton, PA: Hive, 1973), 13–21 (the original was published by the Society of Industrial Engineers in 1925); "Wife Will Carry on His Work," *Montclair Times*, June 28, 1924, reel 4, GC; Robert Kangiel, *The One Best Way: Frederick Winslow Taylor and the Enigma of Efficiency* (New York: Viking, 1997), 415.

10. Yost, *Frank and Lillian Gilbreth*, 25, 60; Gilbreth, *As I Remember*, 102–3; Gilbreth, *Time Out for Happiness*, 89, 96–97; Lillian Gilbreth, *Living with Our Children* (New York: Norton, 1928), 4–5, 33–34.

11. Gilbreth, *Quest of the One Best Way*, 25.

12. Gilbreth, *Time Out for Happiness*, 170; Gilbreth, *As I Remember*, 107; Typed reminiscence of Ernestine Gilbreth Carey, 1960, Box 3, folder 4, LMG; Gilbreth and Carey, *Cheaper by the Dozen*, 127.

13. Lancaster, *Making Time*, 92; Gilbreth, *Quest of the One Best Way*, 23; Gilbreth, *As I Remember*, 103–7; Gilbreth, *Time Out for Happiness*, 6, 69, 88; Yost, *Frank and Lillian Gilbreth*, 123–25, 149.

14. Gilbreth, *Time Out for Happiness*, 92.

15. Kangiel, *The One Best Way*; Brian Charles Price, "One Best Way: Frank and Lillian Gilbreth's Transformation of Scientific Management, 1885–1940" (PhD thesis, Purdue University, 1987), 7–8.

16. Frank B. Gilbreth, *Primer of Scientific Management* (New York: D. Van Nostrand, 1911). The publisher would not put Lillian's name on the cover. See Price, "One Best Way," 140–41; Kangiel, *The One Best Way*, 414–16.

17. Lancaster, *Making Time*, 111–14.

18. Price, "One Best Way," 288–91; Yost, *Frank and Lillian Gilbreth*, 156–62, 192–215; Gilbreth, *Quest of the One Best Way*, 35.

19. Frank Gilbreth and Lillian Gilbreth, *Applied Motion Study*, in *The Writings of the Gilbreths*, ed. William R. Spriegel and Clark E. Myers (Homewood, IL: Richard D. Irwin, 1953), 220–31 (*Applied Motion Study* was originally published by Sturgis and Walton in 1917); Sharon Corwin, "Picturing Efficiency: Precisionism, Scientific Management, and the Effacement of Labor," *Representations*, 84 (2004), 139–47; Brian Price, "Frank and Lillian Gilbreth and the Manufacture and Marketing of Motion Study, 1908–1924," *Business and Economic History*, 2nd ser., 18 (1989): 91; Price, "One Best Way," 224–37.

20. Brian Price argues that the Gilbreths were more successful at publicizing motion study as the humane alternative than in actually quelling tensions between workers and managers. Contemporaries such as Robert Hoxie argued that they achieved little more than "benevolent despotism" in the industrial plant. See Price, "One Best Way," 7–8, 334.

21. Gilbreth, *Time Out for Happiness*, 180; Gilbreth, *As I Remember*, 106–7, 113, 118, 144;

Lancaster, *Making Time*, 112; Yost, *Frank and Lillian*, 193; Price, "Frank and Lillian," 92–93; FG to LG, October 18, 1914, GC.

22. FG to LG, August 30, 1906; October 1, 1914; November 15, 1914; August 31, 1914, reel 3, GC.

23. The best known of the medical experts to take this view was Edward Clarke. See *Sex in Education; Or, a Fair Chance for the Girls* (Boston: Osgood, 1873); Rosalind Rosenberg, *Beyond Separate Spheres: Intellectual Roots of Modern Feminism* (New Haven, CT: Yale University Press, 1982), 5–13; Cynthia Eagle Russett, *Sexual Science: The Victorian Construction of Womanhood* (Cambridge, MA: Harvard University Press, 1989), 116–19.

24. Yost, *Frank and Lillian Gilbreth*, 193–94.

25. Lancaster, *Making Time*, 118.

26. Yost, *Frank and Lillian Gilbreth*, 208, 213; Typed reminiscence of Ernestine Gilbreth Carey, (1960); Gilbreth, *As I Remember*, 119.

27. "Movies to Help Baseball Players Economize Force," *New York Tribune*, June, 1913, reel 4, GC; Gilbreth, *Time Out for Happiness*, 128, 140–41, 148–49, 154; Gilbreth, *As I Remember*, 128; Gilbreth, *Applied Motion Study*, 220; Price, "One Best Way," 374.

28. Price, "Frank and Lillian Gilbreth," 88, 92; FG to LG, October 2, 1914, reel 3, GC; Yost, *Frank and Lillian Gilbreth*, 250.

29. Frank Gilbreth, *Motion Study*, in *Writings of the Gilbreths*, 152.

30. L. M. Gilbreth, *The Psychology of Management: The Function of the Mind in Determining, Teaching, and Installing Methods of Least Waste* (New York: Macmillan, 1921), 1–3, 18–19 (the original was published by Sturgis and Walton in 1914).

31. Gilbreth, *Quest of the One Best Way*, 36; Gilbreth, *As I Remember*, 120; Yost, *Frank and Lillian Gilbreth*, 213.

32. FG to LG, October 12, 1914, reel 3, GC; Gilbreth, *Time Out for Happiness*, 125; Lancaster, *Making Time*, 127.

33. Mayme Ober Peak, "She Conquers Fatigue—Woman's Greatest Enemy," *Beautiful Womanhood*, February 1923, Box 3, folder 18, LMG; Gilbreth, *As I Remember*, 121–32; Yost, *Frank and Lillian Gilbreth*, 253; Lancaster, *Making Time*, 131.

34. "Instruction Card," typed schedule [1912], Box 4, folder 2, LMG; "Mrs. Gilbreth Gives Formula for Happy Home," reel 4, GC; Peak, "She Conquers Fatigue."

35. Gilbreth, *As I Remember*, 122; Yost, *Frank and Lillian Gilbreth*, 228; Gilbreth, *Living with Our Children*, 230; Lancaster, *Making Time*, 130–31, 222; FG to LG, April 5, 1915, reel 3, GC.

36. Lillian M. Gilbreth, "Some Aspects of Eliminating Waste In Teaching" (PhD dissertation, Brown University, 1915); Lancaster, *Making Time*, 153–57.

37. FG to LG, October 14, 1914; October 18, 1914; April 5, 1915; W. H. Faunce to Frank B. Gilbreth, June 6, 1921, reel 3, GC; Lancaster, *Making Time*, 161–62.

38. FG to LG, April 29, 1915; May 13, 1915, reel 3, GC.

39. FG to LG, January 7, 1918; January 9, 1918; LG to FG, January 7, 1918; January 8, 1918; [2 letters, January 1918], n. d.; January 18, 1918; January 31, 1918, reel 3, GC.

40. Gilbreth, *As I Remember*, 152–61; Gilbreth, *Time Out for Happiness*, 168; Lancaster, *Making Time*, 184.

41. "Mother's notes on Typewriting-training," November 24, 1916, Box 3, folder 7, LMG; Elizabeth Ellam, "Gilbreth Nantucket Laboratory Most Interesting Place," *Nantucket Inquirer and Mirror*, September 8, 1923; LG to FG, January 29, 1918, reel 3, GC; Gilbreth, *As I Remember*, 147; Yost, *Frank and Lillian Gilbreth*, 269–70.

42. Gilbreth, *Time Out for Happiness*, 17, 132; Gilbreth, *As I Remember*, 169; Gilbreth, *Living with Our Children*, 173–79; Hawley, "The Life of Frank B. Gilbreth," 113–6.

43. "Daily Schedule of Ernestine Gilbreth" (Martha's schedule included), n. d., Box 3, folder 6, LMG; Hawley, "The Life of Frank B. Gilbreth," 113; Gilbreth, *Time Out for Happiness*, 147; Gilbreth and Carey, *Cheaper by the Dozen*, 2.

44. "Family Log," March 1, 1923; "Wife Will Carry on His Work"; Hawley, "The Life of Frank B. Gilbreth," 114; Frank B. Gilbreth Jr. and Ernestine Gilbreth Carey, *Belles on Their Toes* (New York: First Perennial, 2003), 2, 11–12 (the original was published by T. Y. Crowell in 1950). Gilbreth, *As I Remember*, 110; Yost, *Frank and Lillian Gilbreth*, 178; FG to LG, January 25, 1918, reel 3, GC; Gilbreth, *Time Out for Happiness*, 129.

45. Gilbreth, *Living with Our Children*, 227–38.

46. Gilbreth, *Time Out for Happiness*, 191; Lillian M. Gilbreth, *The Home-Maker and Her Job* (New York: D. Appleton-Century, 1936), 102 (the original was published in 1927).

47. Gilbreth and Carey, *Belles on Their Toes*, 200; Yost, *Frank and Lillian Gilbreth*, 294; Peak, "She Conquers Fatigue"; Ellam, "Gilbreth Nantucket Laboratory Most Interesting Place."

48. Gilbreth and Carey, *Belles on Their Toes*, 100.

49. FG to LG, July 28, 1922; July 31, 1922, reel 3, GC; LG to Minnie Bunker, July 6, 1924, Box 7, folder 12, LMG; Yost, *Frank and Lillian Gilbreth*, 306; Laurel Graham, *Managing on Her Own: Dr. Lillian Gilbreth and Women's Work in the Interwar Era* (Norcross, GA: Engineering and Management Press, 1998), 86–92.

50. Gilbreth and Carey, *Belles on Their Toes*, 57, 88–89, 131; Gilbreth, *Time Out for Happiness*, 190; "Family Log" entries, 1929–1930; March 26, 1934.

51. Hawley, "Frank B. Gilbreth," 202; Graham, *Managing on Her Own*, 90–92.

52. Gilbreth, *As I Remember*, 201–202; Gilbreth, *Time Out for Happiness*, 169, 187, 196–97.

53. Alice Rossi, "Barriers to the Career Choice of Engineering, Medicine, or Science Among American Women," in *Women and the Scientific Professions: The MIT Symposium on American Women in Science and Engineering*, ed. Jacquelyn A. Mattfeld and Carol G. Van Aken (Cambridge, MA: MIT Press, 1965), 97; Lancaster, *Making Time*, 228; Gilbreth, *Time Out for Happiness*, 188–89; Yost, *Frank and Lillian Gilbreth*, 356–57.

54. Martha Moore Trescott, "Women in the Intellectual Development of Engineering: A Study in Persistence and Systems Thought," in *Women of Science: Righting the Record*, ed. G. Kass Simon and Patricia Farnes (Bloomington, IN: Indiana University Press, 1990), 168; Yost, *Frank and Lillian Gilbreth*, 333–34; Graham, *Managing on Her Own*, 224–25.

55. Gilbreth, *As I Remember*, 202–17; Gilbreth, *Time Out for Happiness*, 203–5; Graham, *Managing on Her Own*, 95–100; Hawley, "Frank B. Gilbreth," 202–4.

56. Christine Frederick, *The New Housekeeping: Efficiency Studies in Home Management* (Garden City, NY: Doubleday, 1913); *Household Engineering: Scientific Management in the Home* (Chicago: American School of Home Economics, 1920); Sarah Stage and Virginia B. Vicenti, eds., *Rethinking Home Economics: Women and the History of a Profession* (Ithaca: Cornell University Press, 1997).

57. See, for example, Lillian Gilbreth, "Fatigue Study and the Home," *Society of Industrial Engineers Proceedings*, April 1921, 33–39; Graham, *Managing on Her Own*, 155–64.

58. "The Kitchen Practical Designed for the Brooklyn Borough Gas Company by Dr. Lillian M. Gilbreth"; "Kitchen Practical: The Story of an Experiment," 1931, Box 14, folder 12, LMG.

59. Lillian Gilbreth, "Is Your Home a Hazard?" Radio talk from "America's Little House," February 19, 1935, reel 3, GC; Gilbreth, *The Home-Maker and Her Job*, 21, 92, 96; Lillian Gilbreth, Orpha Mae Thomas, and Eleanor Clymer, *Management in the Home: Happier Living Through Saving Time and Energy* (New York: Dodd, Mead, 1955), v.

60. Gilbreth, *The Home-Maker and Her Job*, 20.

61. Price, "One Best Way," 619–20; Gilbreth, *As I Remember*, 204–5.

62. Graham, *Managing on Her Own*, 118–41.

63. Yost, *Frank and Lillian Gilbreth*, 321; Graham, *Managing on Her Own*, 218–21.

64. Regina Lee Blaszczyk, "'Where Mrs. Homemaker Is Never Forgotten': Lucy Maltby and Home Economics at Corning Glass Works, 1929–1965," in *Rethinking Home Economics*, 163–80; "A Modern Aid in the Solving of Home Management Problems," 1931, Box 14, folder 11, LMG.

65. "Heart of the Home," 1948–1949, Box 14, folder 13, LMG; Graham, *Managing on Her Own*, 182; Gilbreth, *Time Our for Happiness*, 214–15.

66. Gilbreth and Carey, *Belles on Their Toes*, 100–3; Graham, *Managing on Her Own*, 182–83; Gilbreth, Thomas, and Clymer, *Management in the Home*, 78–81.

67. Edna Yost and Lillian Gilbreth, *Normal Lives for the Disabled* (New York: Macmillan, 1944); Gilbreth and Carey, *Belles on Their Toes*, 218; Gilbreth, *Time Out for Happiness*, 219, 223, 231; Yost, *Frank and Lillian Gilbreth*, 336n.

68. "Man's Place Is in the Home," *Philadelphia Public Ledger*, January 31, 1932; Gilbreth, Thomas, and Clymer, *Management in the Home*, 47; Peak, "She Conquers Fatigue."

69. Lancaster, *Making Time*, 8, 331–33.

70. Martha Moore Trescott argues that American women have not provided the engineering field with significant numbers, but rather significant theoretical contributions as "systems thinkers." See "Women in the Intellectual Development of Engineering," 147–81, 149.

71. The Gilbreth children graduated from the following institutions: Anne, Michigan; Ernestine, Smith; Martha, New Jersey State College for Women; Frank, Michigan; Bill, Purdue; Lillian Jr., Smith; Fred, Brown; Dan, Penn; Jack, Princeton; Bob, North Carolina; and Jane, Michigan.

72. Gilbreth, *As I Remember*, 234; Yost, *Frank and Lillian Gilbreth*, 339–41.

73. Gilbreth and Carey, *Belles on Their Toes*, 80–81.

3 To Embrace or Decline Marriage and Family: Annie Jump Cannon and the Women of the Harvard Observatory, 1880–1940

If all the ladies should know so much about spectroscopes and cathode rays, who will attend to the buttons and breakfasts?

—Senior European astronomer to Sarah Whiting,
chair of astronomy at Wellesley, 1880s–1890s[1]

While we cannot maintain that in everything woman is man's equal, yet in many things her patience, perseverance and method make her his superior. Therefore, let us hope that in astronomy, which now affords a large field for women's work and skill, she may, as has been the case in several other sciences, at last prove herself his equal.

—Williamina Paton Fleming, "A Field for Women's Work in Astronomy,"
World Columbian Exposition, Chicago, 1893

We work from morn 'till night
For computing is our duty
We're faithful and polite,
And our record book's a beauty;
With Brelle and Causs, Chauvinet and Pierce,
We labor hard all day;
We add, subtract, multiply, divide,
We never have time to play.

—From the parody *Observatory Pinafore*,
written by women computers
of the Harvard Observatory[2]

IN 1931, A JOURNALIST FOR THE *CAMDEN DAILY COURIER* HERALDED THE recent recipient of the Henry Draper Medal for research in astronomical physics. For the first time in the history of the prize, it was a woman, the ebullient Annie Jump Cannon, curator of photographic plates at the Astronomical Observatory of Harvard University. That a woman would be so honored was astounding. Since most science fields had been professionalized toward the end of the nineteenth century, women had found themselves relegated to teaching posts at women's colleges, or they lingered imperceptibly at the lower echelons of the promotional ladder as lab technicians, or they quietly worked as assistants to husbands in the few home labs that remained. Without PhDs, they could not advance in rank or title; most could not even put their names on papers they researched and wrote themselves.

Annie Cannon was an anomaly to be sure, yet this journalist assured readers that thirty-five years in science had not tarnished her womanliness: she was affable, unassuming, and hospitable to guests in her home and the observatory both, and doted on children. She seemed to know her place in the natural order. She "would have been a first-rate housewife," he assured readers, but instead "took up light housekeeping among the stars":

> "Oh those untidy men folks," we can hear Miss Cannon say as she took up astronomy. "Let's get some order in this kitchen, I mean heaven."
>
> So she made her life work the cataloguing of the stars. Hundreds of thousands of them she "dusted off," as it were, and put back into their right places. . . .
>
> Housewives may be a little weak on astronomical physics. But they will understand just how Miss Cannon felt. Those heavens simply HAD to be tidied up.[3]

Later in the century, sociologists would theorize that a child's scientific proclivities come from the empirically minded patriarch of the family, but that was not the case with Annie Cannon. Her mother was the parent who opened the trapdoor to the roof of their Delaware home so that they might gaze at stars. Elizabeth Cannon encouraged her daughter to study mathematics, chemistry, and biology at Wellesley College, and eventually to study physics under MIT-trained astronomer Sarah Whiting. She was pleased when her daughter returned to Wellesley and Radcliffe for postgraduate courses, and ultimately accepted her daughter's choosing vocation over marriage. At thirty-four, Annie Cannon excused herself irrevocably from a traditional life as wife and mother by accepting a post at Harvard's astronomical observatory.[4]

Thirty-five years later the *Daily Courier* lauded her as a great scientist, rather than mocking her spinster's status. The praise was strange, considering that both men and women thought disinterested objectivity, the hallmark of the modern scientific expert, was achievable by men alone. In Cannon's day, anthropology, botany, and nutritional science seemed appropriate disciplines for women "assistants," since these fields could be viewed as germane to homemaking.[5] So why would anyone extol Cannon's womanly traits in astrophysics—a field so virile that women would be denied access to telescopes in the nation's observatories until the 1960s?

Within this male-dominated field was a domain in which presumably female traits such as patience, a tolerance for tedium, and general domesticity became assets. It was not a prestigious enclave and appeared supportive and peripheral to the work of credentialed scientists. Yet from this enclave Cannon found a way to revolutionize the field. She "laid the foundations of systematic study of the stars for all time to come," the *Daily Courier* exalted, not out of her brazen disregard for women's station, but just the opposite—out of her womanly proclivity to tidiness.

Compared with European astronomy, the American field that Cannon entered in 1896 was unorganized and small scale, not yet the full-blown professional science it would become in the twentieth century; but the Harvard Observatory was about to become the hierarchical bureaucracy that characterized the new era of "big science." Edward Pickering, an MIT physics professor, hastened the transformation when he became director in 1876, as did the advent of stellar photography. Amateur astronomer Henry Draper developed a method for photographing lines of stellar spectra viewed from telescopes onto glass plates, providing permanent, portable images of the sky. Pickering departed from the old astronomy of charting locations; he used the new photographic plates to focus on stars' brightness and color as clues to their distance and chemical composition. Women proved to be some of the most generous financial supporters of his projects. Catherine Bruce donated fifty thousand dollars for the erection of a photographic telescope, and Anna Palmer Draper, widow and former assistant of Henry Draper, donated large sums of money to the observatory for the Draper Memorial, a catalog of stars compiled through the technology pioneered by her husband.[6]

Pickering collected an overwhelming library of photographic plates from outposts in Cambridge and Peru, and he needed processors of the stellar information they contained. These "computers," as he called them, would not be "astronomers." He viewed them as doers, not thinkers; workers, not scholars; amateurs, not professionals with the expectations of compensation and promotion that professionalism brings. They were recorders of measurements taken from photographs, providers of raw data for trained astronomers to interpret. The work was not belittling in Pickering's eyes. His Baconian worldview had convinced him that the best science was that garnered through piles of facts, and his workers had the important job of gathering an abundance of data to achieve scientific truth. They would have the basic computational skills of high school and college graduates, rather than formal training in astronomy, making them three and four times more affordable than credentialed men. Most important, they would have patience and a penchant for detail, traits Pickering believed inherent in the female sex.[7]

Pickering's instincts about women were not novel at the time. Earlier in the nineteenth century, the study of stars, like the study of flowers or insects, seemed an appropriate avocation for women already deemed close to nature. Fathers and husbands observed alongside women from telescopes in attics or on city walls; the respective labor of men and women had not yet been perceived as divided between thinking and doing, analyzing and observing, professional and amateur. George Greenstein has estimated that between 1859 and 1940 one out of every three American astronomers was a woman, yet only a handful has been acknowledged in the historical record. In 1847 young Maria Mitchell was studying the heavens from a telescope at her Nantucket home when she spotted the comet that made her famous. She received a gold medal from the king of Denmark, recognition that propelled her in ways future amateurs would never know. Among other honors, in 1848 she became the first woman member of the Academy of Arts and Sciences, and in 1850, of the Association for the Advancement of Science. In 1865, she became the first woman professor of astronomy at Vassar College. Mitchell made an independent income computing tables of the positions of planets for the Coast Survey, and she did it all from home.[8]

Two of Mitchell's most promising students, Mary Whitney and Antonia Maury, left Vassar for Harvard, the former to study and the latter to innovate the classification of stellar spectra. A handful of other protégées were permitted to enter the Harvard Observatory to compute for the Durchmusterung catalog, and by 1886 an entire female computing staff worked on classifications for the Draper Memorial. The abundance of plates to be processed forced Pickering to become a good industrialist, eager "to secure the greatest possible output for every dollar expended." The prevailing assumption (though often not the reality) was that women who worked outside the home were earning wages supplemental to those of male primary breadwinners. Pickering paid his hires accordingly: twenty-five cents an hour for seven hours a day, six days a week. Although a respectable wage for factory workers, it was lackluster for retail, secretarial work, and other pink-collar trades. A few especially skilled women received a salary of six hundred dollars a year, two hundred dollars less than male assistants who engaged in "mechanical" work. But for the most part, twenty-five cents an hour remained the going rate until 1906.[9]

Exploitive as it seems, many women viewed computing as an opportunity too good to refuse, and Pickering never lacked for bright applicants. His most talented computers, first- and second-generation graduates from elite women's colleges, found few professional alternatives. A handful of their colleagues filled positions at women's colleges, but computing allowed a devoted scientist to do rather than teach. Like no other American observatory of the early twentieth century, Harvard had become the inner sanctum of astronomical advancements, and the busy work of women computers was largely the reason, since their data provided new answers to new questions. By 1893, seventeen assistants at the observatory were women, twelve of them responsible for identifying spectral phenomena in photographs, computing the measurements, and preparing results for publication. One hundred and sixty-four women worked as computers in American observatories between 1875 and 1920. The Dudley Observatory in Albany, the Yerkes Observatory in Washington, D.C., as well as the Lick, Columbia, Allegheny, and Yale Observatories opened positions to women, no doubt because of the success of Pickering's experiment. By 1921 eight of the twenty women astronomers listed in *American Men of Science* were computers as Pickering defined them. Women had found their niche in this masculine field of physical science.[10]

Annie Cannon was sure that the development of stellar photometry was what made her scientific career. She could obtain access to the dry-plate photograph's record of the sky regardless of her proximity to telescopes and university classrooms. Stellar photometry turned astronomy into a "daylight profession," she explained, "more suitable for women than when eye-observations had to be made at night in many sorts of wind and weather." Indeed the technology allowed "women to remain women"; they need not brave the harsh elements to study the stars, and they could engage in a brand of detailed busywork befitting of mothers and wives who would otherwise be measuring ingredients for a cake or counting needlepoint stitches. Scientific photography had created specialties for women in other fields too. Cannon's contemporaries Katherine Foot and Ella Strobell, for example, began the innovative use of microphotography in biology when hand drawings were still the practice.[11] The inherent tension provoked by their leaving home for professional science was eased, since as observers of photographs, the women appeared to be doing the work of helpmeets rather than being interpreters or experts in their own right.

Before Cannon arrived at Harvard, Williamina Paton Fleming had looked at photographic plates and classified spectra for the *Harvard Annals* and observatory circulars. Cannon built on Fleming's observations, sharpened her classification schemes, and codified twenty-eight spectral classes and subdivisions for the four hundred thousand stars of the Draper Catalogue and Draper Extensions. Cannon's work had to be conceptual—for how else could she have named her spectral categories—but Pickering continued to describe it as a form of observation that required little specialized understanding of stars. The women computers didn't argue, though they thought that Cannon's special talent could not be matched by men. The plates from which Cannon had worked provided little more than random dots, smears, blips, and shades of gray, yet with magnifying glass in hand she rapidly labeled the marks and called out identifications to women who frantically kept ledgers. Margaret Mayall, a chief assistant, thought Cannon's visual memory innate, not learned. "She had wonderful eyes," she recalled, "and she could see things that very few people would recognize until she pointed it out." Another colleague likened Cannon's visual recall to having a phenomenal memory for faces: it was not based on reasoning; "she simply recognized them." It was sensitivity for nuance that men just didn't have.[12]

Male astronomers previously had based their classification systems on theories about stars' life cycles, but the development of photometry made it possible for Cannon to discern differences that corresponded to the temperature of stars, their chemical composition, and other physical features. Her categories, which were formally adopted as the standard at the 1910 meeting of the International Astronomical Union, weren't named after her, as men's innovations are often named after them; hers was known as the "Harvard System."[13] The mnemonic "**O**h **B**e **A** **F**ine **G**irl, **K**iss **M**e" reminded astronomers of the labels for her categories, but also of her place in the social order of the observatory. Cannon accepted her label as "a fine girl" among males of supposedly superior intellect. Her matronly charm made her appear the embodiment of domesticity. She mothered the younger women and hosted visiting scholars of the observatory as if they were part of her extended family. She classified spectral phenomena on plates with the precision of a needleworker, presumably without interpreting what she saw to any scientific degree. It was not unusual for her to leave the observatory at six o'clock and return as others turned in for the night. She broke down boundaries between home and workplace, science and domesticity by collapsing the distance and time separating them to almost nothing.

Cannon was both an innovator and hostess at one of the world's leading astronomical centers; she brokered partnerships and exchanges of equipment between men in the international community and assumed an ambassador-like role outside it. Male astronomers had her to thank for helping to organize international meetings, but also for increasing their visibility and status in the popular media. She prepared scripts for radio about the study of stars and wrote books and articles for laypeople and children. It is not a requirement that science popularizers be women, though historically this has often been the case. In Mitchell's day English women such as Agnes Clerke popularized the study of the skies, and Margaret Huggins, wife and assistant to astronomer Sir William Huggins, called for a new class of "science worker," one who served as historian, critic, expert, and originator of scientific ideas all combined. Cannon also embraced her cultural work as an educator. As a woman on the professional periphery yet a major figure in the vanguard of discovery, she enjoyed a dual perspective men didn't share. You live in "the meridian of things astronomical," a colleague remarked, "ever alert to keep up with surprises that come in by letter and cablegram from everywhere—comets, novae, et. cet . . . [yet] it is gratifying to see that popular magazines and the Sunday editions are alive to the growing interest of the general public in star science."[14]

Cannon was supposedly an organizer, not a conceptualizer; a translator, not a creator. And yet her work was so significant that it made her famous. In Europe she became a member of the Royal Astronomical Society and received honorary degrees unprecedented for a woman of any nationality. Back at home Wellesley College admitted her as an honorary member of Phi Beta Kappa, and her portrait occupied "the place of honor" on the front pages of *Scientific American* in 1929. Two years later she was voted one of America's twelve greatest women, and two years after that she represented professional women at the World's Fair in Chicago. With Amelia Earhart, Mary Beard, and Jane Addams, she spoke on "the contribution of women to civilization," her part devoted to women in the natural sciences.[15]

Preparing for this appearance, she wrote the chairs of science departments of women's colleges, asking for lists of the most accomplished women scientists of the past one hundred years. The responses were discouraging. The director of the Smith Observatory could think of pedagogues, but no researchers. Mount Holyoke women came up with one of their own, zoologist Cornelia Clapp, but that was it. The faculty of the Wellesley zoology department came up with Florence Sabin but lamented that much of her work had been attributed to others. Colleagues in the chemistry and physics departments both claimed Curie as their sole female standout aside from Ellen Swallow Richards and the German physicist Lise Meitner. ". . . We have no Madame Curie in botany" wrote the Wellesley department chair. The Curie complex continued.[16]

Cannon was hard pressed to tell of women's greatness in physics or chemistry at the World's Fair, but she had plenty to say about women in astronomy. "There is nowadays hardly an Observatory, especially where research is undertaken, without one or more women on the staff," she reported. To her count, women had discovered forty-two hundred variable stars; of new stars, thirty-five had been discovered by Harvard women compared with sixteen elsewhere. Women studied at the observatories of Princeton, Michigan, Virginia, and Yale, and she avowed that the feminization of astronomy was not merely a national trend. The chief of the photometry bureau at the Sorbonne was Dorothea Klumpke, a woman who had taken her doctoral degree there in 1893, several years before Curie took hers in physics.[17]

While Cannon's significant work in her field could be viewed as a positive signal for women, one could also read the achievement differently. The field of astronomy had opened doors for women, but only to allow them to work in limited capacities. In the eyes of peers, computers were not transgressing but rather transferring domesticity to the observatory so that men might freely conduct the interpretive work of real science. Cannon embraced the supportive role offered to her. "Whose eye is keener than a woman's to examine these photographs?" she asked. "Whose hand is more deft to handle this precious and unique library of first and only editions?" And yet for all the accolades she attributed to women at the World's Fair, she conceded that men "held the lead" in "interpretive" enterprises.[18]

This makes Annie Cannon a complicated figure—a feminist and traditionalist in one. It became her special cause to make it possible for more women to live out their dreams of science. She traveled across the country, speaking to women's groups, asking for no compensation beyond train fare, hoping to reach amateur stargazers waiting to break into the field. As a charter member of the Maria Mitchell Association, she doled out scholarships to women such as A. Grace Cook, an enthusiast who spotted meteors through an outdated telescope from a deck chair eighteen miles from home. When Cannon won the Ellen Richards Prize of the Association to Aid Scientific Research by Women in 1932, she gave the prize money to the American Astronomical Society to support women astronomers.[19] And yet, for all her achievements, Cannon never challenged women's roles in science once they had gained entry to its institutions.

Williamina Fleming, Antonia Maury, and Henrietta Leavitt: The Politics of Invisibility

In demurring to men Cannon had won universal respect, but some of her female colleagues were not demurring types. Williamina Fleming wanted the pay of men; Antonia Maury wanted their prestige; and Henrietta Leavitt wanted men's God-given right to theorize about the natural world for herself. As inappropriate women, their careers have been far more obscured in the historical record than Annie Cannon's. Their stories tell cautionary tales, the flip side of being a woman pioneer in masculine science.

Without academic degrees, Williamina Fleming taught Cannon all she knew when Cannon first arrived at Harvard at the turn of the century. Fleming was a Scottish immigrant who came to the United States with her husband in 1878; within a year, she was abandoned, pregnant, and destitute. To survive, she found domestic work, fortuitously for Edward Pickering. Her timing was also fortuitous, for he was increasingly dissatisfied with his male assistants and impulsively declared one day that his twenty-four-year-old housekeeper could do their job better if given the chance. To prove his point he hired Fleming at the observatory in 1881, and she was grateful to work as his experiment. She started by copying records and doing the most elementary of computations, and within five years she could replace head computer Nettie Ferrar, who left the observatory to marry. In honor of the man who saved her, Fleming gave her son Pickering's name and encouraged him to study science; he went on to study engineering at MIT the same year his mother was promoted to curator of the Draper Catalogue, the first formal appointment of a woman in the history of Harvard. His mother had twenty women in her charge.[20]

What led Pickering to try such a risky experiment? Apparently he thought Fleming's domestic skills would be functional in his observatory. Known to craft dolls in intricate Scottish Highland costumes, this meticulous needleworker brought order to Pickering's plates just as she had brought order to his home. In addition to filing the plates, she examined each with a magnifying glass, noting peculiarities in the spectra that male staff members had never attempted to find. Much like organizing buttons by shape and color, she devised twenty-two classifications for more than ten thousand stars, making it that much easier for others to study them. In the sorting she discovered three hundred variable stars, ten novas, and fifty-nine gaseous nebulae, all of which made their way into the Draper Catalog.[21]

Fleming had had no formal training, yet a contributor to the *Chicago Examiner* called her an American Madame Curie. Both women had proved that "when a woman does turn her mind to science she brings into the field qualities that her proud 'lord and master' cannot match." Professional astronomers agreed. Fleming went on to become an honorary member of the Royal Astronomical Society and an honorary fellow of Wellesley College. Her work was painstaking, yet the journalist for the *Examiner* described it as perfectly suited to her female mind: "The amount of labor devoted by Mrs. Fleming to the patient study, under the microscope, of thousands upon thousands of photographs of the spectra of stars would have daunted most men and would have been utterly beyond their capacity, for it require[s] a combination of patience and persistence, and faith, and minute accuracy which is, perhaps, rather a feminine than a masculine characteristic."[22]

The ability to multitask was apparently yet another of her womanly characteristics. Not only did she perform the work of photometry, but she also edited publications and acted as Pickering's personal secretary. She chronicled her rigorous daily routine on a March day in 1900:

> Observatory from 9h 05m to 4h 45m. Final notes on Vol. XLV [of Annals], 0h to 6h relating to variable stars. . . . The work on suspected variables involved their examination on a number of photographs for confirmation of variation, and this work I continued with Miss Leland[,] some having already been done. Then I did some work with Miss Woods on "out of focus" plates, and later with Miss M. Stevens on the southern meridian photometry. Then went over the latter work with the Director, adopting constants, and entering and discussing atmospheric absorptions. We found that in the earlier part of the year, when two series of observations were taken on the same date (one early in the evening[,] the other in the morning) the value of the constant was smaller in the evening than in the morning, while towards the last part of the year the value of the constant was greater in the evening than in the morning thus seeming to indicate some change due to the season of the year. . . . We were able to read through a few more pages of Miss Cannon's "remarks" before the Director left at three o'clock. I then gave some time to Mr. Bailey on the work on the magnitude of his variables. Then returned to Miss Woods and "out of focus" plates.[23]

This entry reveals a relationship between Fleming and male astronomers more complex than that of a subordinate to her superiors. While men ultimately published her data under their names, interpretation of the data was increasingly a collaborative endeavor.

Men rewarded her with praise, but there were clear limits to how far her womanly assets could take her. In 1900 her salary was fifteen hundred dollars, generous compared with the compensation of the other women computers but insulting compared with the twenty-five hundred dollars a year male assistants received. Her salary was based on a seven-hour day, but she typically worked nine hours or more, while men left on time. She observed that many of the men "took things easy" at work. They operated at a slower pace by day and went home to wives who catered to them at night. "My home life is necessarily different from that of other officers of the University since all housekeeping cares rest on me," she pointed out. She employed a maid to lighten the load, but given her lesser pay, she couldn't afford one full time. On Sunday, her day of respite, she madly prepared food for the week and did the washing, for she hadn't a spouse to do it. Sometimes she couldn't get it all done and would have to leave the observatory midweek to pay bills and buy groceries for supper.[24]

By 1900 her financial situation had become untenable. Her son, Edward, still had another year at MIT; she couldn't maintain her home and pay his tuition without a raise. Pickering agreed that Fleming was a rare breed of workhorse, who took few vacations or holidays, but her salary had nearly doubled since her promotion to curator and she hadn't the credentials to earn more. "He seems to think that no work is too much or too hard for me no matter what the responsibility or how long the hours," she seethed. "But let me raise the question of salary and I am immediately told that I receive an excellent salary as women's salaries stand." She might have been content to proceed at her level of pay had she been able to pursue variable stars, but she was relegated to other tasks. "Looking after the numerous pieces of routine work which have to be kept progressing, searching for confirmation of objects discovered elsewhere, attending to scientific correspondence, getting material in form for publication, etc., has consumed so much of my time during the past few years that little is left for the particular investigations in which I am especially interested," she carped. "The Director, however, says that my time employed in the above work is of more value to the Observatory."[25]

Fleming thought she would try a temporary solution: she'd do routine secretarial work during the day, and she'd take the variable-star work home at night. In 1903, after regular working hours, she classified and took light measurements for more than thirty-five hundred stars. Still, her plan failed to bring her an increase in salary. In fact, by doing observatory work at home, she had helped to render it invisible; her work lost its value as scientific endeavor, as "specialty," as "work" at all. The long hours she labored wore her down physically and emotionally during her final decade at the observatory. Friends urged her to reconsider how much time she devoted to Pickering, but she would never disappoint him. Nurses had to exercise an arm she could barely move, so that she could complete assigned work on the plates. Ceaselessly, she continued until 1911, when, by all accounts, she had worked herself to death.[26]

Her martyrdom was not lost on newspapermen. Work like hers was never glamorous, one wrote—"no glad cry of discovery as some wonderful new star bursts upon sight. . . . Her work was simply poring over faint and ill-defined photographs, peering, and noting, and comparing, and adjusting the light for better seeing, until the overtaxed eyes could do no more." While male astronomers attended conferences and filled their days with a varied diet of activities, Fleming did the same tasks over and over again. Only a woman could show this degree of devotion to science, this journalist believed, and do it without the incentives of money, fame, or discovery that motivated men. Pickering, too, extolled her virtues in eulogy. Along with raising a son, she had cared for her mother, and her brother's children, kept a spotless home, and "had a remarkable skill and artistic taste with her needle." But the domesticity he attributed to her was a double-edged sword. It was both the root of her competence as a computer and the assigned cause of her inadequacy as a scientist. It's what gave Pickering license to publish all but two of her papers in his name. She "formed a striking example of a woman who attained success in the higher paths of science without in any way losing the gifts of charm so characteristic of her sex," he wrote. He could pay no higher compliment for her years of devoted service.[27]

For a time Williamina Fleming and Annie Cannon had a collaborator named Antonia Maury, a woman who sought to advance as male astronomers did. The niece of Henry Draper and a student of Maria Mitchell, she thought herself well positioned to be the exceptional computer-turned-legitimate-scientist. After graduating from Vassar in 1887, she went to Harvard and started classifying the spectra of bright northern stars as part of the Draper Memorial. Almost immediately she made her ambitions known and proved eager to publish original research rather than to classify for classification's sake. She abandoned the spectral categories Pickering had assigned her for a two-dimensional system that accounted for factors of width and sharpness of spectral lines. Ever the scientific positivist, Pickering thought her system "unnecessarily elaborate," prone to subjective shades of gray when Annie Cannon's single dimensions presented distinctions in black or white. He was annoyed that Maury would question a good thing, but also that she would try to impose her own way of seeing his plates so that she could be recognized as a scientist in her own right.[28]

Eventually astrophysicists used her scheme to recognize subtleties in size and luminosity that would have been indistinguishable under earlier systems of classification, but recognition at Harvard eluded her. When her experience made visible the glass ceiling for women at the observatory, Maury's reaction was to bristle, for she felt entitled to better treatment. She told Pickering that her situation was unacceptable, and that she was willing to resign, but that she would not give up her projects until he formally credited her ideas: "I should have full credit for my theory of the relations of the star spectra and also for my theories in regard to B. Lyrae. Would it not be fair that I should, at whatever time the results are published, receive credit for whatever I leave in writing in regard to these further matters?" Shocked by her audacity, Pickering agreed to give her time to complete her original research rather than to pass it on. Illness delayed her and confrontations continued—but a squeaky wheel does eventually get its grease. In 1897, Antonia Maury was the first woman to receive formal recognition for her investigations on the title page of the observatory *Annals*.[29]

Although Maury won her battle, she didn't win the war, for she, not Pickering, capitulated about the best method for classifying stars: "I, being naturally unsystematic[,] was not able to understand what you wanted," she told him. Still, she couldn't help but qualify her concession: "You also, not having examined minutely into all the details, did not see that the natural relations I was in search of could not easily be arrived at by any cast iron system."[30] Maury had pored over the plates and discerned minute differences in the spectral lines of stars, much as the geneticist Barbara McClintock discerned the minute details in kernels of corn decades later. Both women would know the frustration of men's unwillingness to see nuance in the natural phenomena they studied. They were women who observed intimately. One's knowledge of corn mutation, like the other's knowledge of spectral lines, was almost intuitive, and male scientists didn't trust their intuition.

With nowhere to go, Maury begged to return to the observatory part time; Pickering took her in but complained about her perpetual tardiness thereafter. Her work on the Draper Memorial was belabored because of frequent illness and worsening eyesight, her progress on the northern stars not nearly as rapid as Annie Cannon's on the southern ones. Maury's instincts about spectra were just as keen, but she slowed down the process of classification even more by asking what it all meant. Cannon never asked, and as a result may have achieved more successfully than anyone the masculine disinterestedness that Pickering revered. She had no preconceived theories to which she hoped her data would conform. She identified, measured, recorded, and moved on; witnesses called her process virtually instantaneous. Although she was a warm and gregarious woman, she became hermetic around the plates, removing her hearing aids to avoid human distraction or influence. She worked too quickly to leave traces of human agenda or attachment behind. Maury, meanwhile, couldn't help but wear her curiosities and dashed hopes on her sleeve.[31]

Anna Draper did not defend her niece, but rather apologized for Maury's unacceptable attitude, for clearly Maury had broken the silent compact keeping womanly ambition in check. In the decades that followed, Maury was a presence in the observatory, but she was perpetually underappreciated and misunderstood. The astronomer Cecilia Payne-Gaposchkin described her in later years as "a dreamer and a poet," unconcerned with whether her socks matched but anxious to speak her truths to anyone who'd listen. If only Pickering had let her learn algebra or publish more papers or perform more original research, she'd pine. After his death the International Astronomical Union added the letter c spectral type to the others, delineating the differences in spectral lines that she had called for thirty years before. The American Astronomical Society awarded her the Annie Jump Cannon Prize for her research when she was seventy-seven years old. These small nods of recognition sustained her until she died in 1952.[32]

Henrietta Leavitt, a woman nearly the same age and temperament as Annie Cannon, was also deaf and worked without the distraction of noise or Maury's ambition. Like Cannon she also lived without children or husband and within walking distance of the observatory, giving her that much more focus on the business of classifying stars. She had attended Oberlin and Radcliffe Colleges and was drawn to astronomy by course work. The twenty-five-year-old asked Pickering if she could volunteer at the observatory in 1893. She was of independent means, she assured him; all she wanted was to get closer to the spectral plates. Stellar photometry suited her from the start; a Princeton man thought her a "variable star fiend," the way she sat hour after hour poring over the plates. She proved her worth; Pickering rewarded her with a paid position in 1902 at five cents better than the going rate.[33]

The Magellanic Clouds soon became her favored corner of the universe, and she discovered 1,777 stars in the region. As more photographs arrived from the observation outpost in Peru, she began to notice a striking correlation between the periods and luminosities of the stars captured in them. Cannon was less mindful of the correlation, but Leavitt saw that having a known value for a star's rhythm allowed her to calculate its inherent magnitude. If she compared this value with the known distances of closer stars, any star's distance could be calculated. The implications were enormous, but Leavitt was paid to measure and record, nothing more. In a brief paper she furnished for the Harvard *Annals* in 1908 she made it clear that she understood her place. Only in passing did she suggest that the longer periods of the brighter variables were "worthy of notice"; astronomers would "probably" observe the "apparent" relation between periods and emission of light if they cared to explore them.

Her passive language didn't fool astronomers who read the report; letters came in from all over the world asking Pickering for more data. It wasn't forthcoming, for he had reassigned Leavitt to the classification of stars in less exciting parts of the galaxy. Moreover, her failing health caused her to seek rehabilitation at a family farm in Wisconsin. Pickering was desperate for her to process photographic plates of the North Polar Sequence and posted them to her, and she garnered the strength to work on them two to three hours a day. The pace was sufficient to publish results under his name in the *Harvard Observatory Circular* in March 1912. Like Annie Cannon, Leavitt did what she was told and never complained.[34]

It took her years rather than months to provide the measurements verifying the period-luminosity relationship she theorized in 1908. Men, meanwhile, swooped in to exploit her initial observation. Young Princeton astronomer Harlow Shapley used her theory to make measurements in the Milky Way and ultimately to determine the size of the galaxy, an accomplishment that propelled him to the forefront of the field. Replacing Pickering as director of the Harvard Observatory in 1921, he expressed gratitude for Leavitt's pioneering work, even as he passed much of it off as his own. She observed, he maintained, but left him to think through the implications. In 1925 a mathematician from Sweden wrote to tell Shapley that he was seriously inclined to nominate Leavitt for the Nobel Prize. News of her idea about the period-luminosity relationship had reverberated throughout the international community, but apparently news of her death had not; Leavitt died four years before Shapley received the letter. It's unlikely she ever knew the full impact of what she discovered.[35]

Cecilia Payne-Gaposchkin: New Woman, New Astronomer, New Politics in the Stars

Annie Cannon, Antonia Maury, and Henrietta Leavitt were first-generation college-educated women; their place as pioneers was all too apparent in their limited choices after college. For them, career and marriage were mutually exclusive paths, and the first computers of the Harvard Observatory had decidedly chosen the former over the latter or they had left work when they married. Male scientists of their generation, like Pickering and his male assistants, were married and had children, along with better salaries and promotional prospects. For later generations, the tensions between computers' identities as women and professionals, as domestics and scientists, eased, but were never fully reconciled. More women combined marriage and career, or worked until children competed for their time. More of them entered coeducational doctorate programs and expected research careers afterward; they wanted to compete with men in theoretical science, to place their names on original research, and to attain equivalent promotions. They asked to be acknowledged as scientists, and sometimes they weren't disappointed.

The percentage of married women listed in *American Men of Science* rose in the 1920s and 1930s, though unemployment rates for married women rose as well because of nepotism policies that prevented wives from working in the same academic departments as their husbands. At the Harvard Observatory, an increasing number of women graduate students married men of similar rank, and in the 1950s, one of them, Cecilia Payne-Gaposchkin, became the first female full professor appointed at Harvard. Born in 1900, she was a generation or two younger than Annie Cannon and represented a new breed of professional woman scientist. Rather than perpetuate a separate female sphere at the observatory, she sought to become integrated with male astronomers in ways her predecessors never could. Annie Cannon had been childless but outwardly maternal; Cecilia Payne-Gaposchkin bore three children but appeared mannish by comparison. She stood on a robust five-foot-ten-inch frame, kept her hair short, and did not accentuate her womanly attributes. Cannon was bubbly and warm; Payne rarely laughed and avoided emotionally charged subjects. It may have been her British reserve, but it was likely also her way of attempting assimilation into the professional world of astrophysics.[36] While her career testifies to the ability of women to succeed on the same terms as men, it also shows the vulnerability of women attempting integration. From a man's perspective, the process could never be complete.

Growing up in rural England, Cecilia Payne knew she wanted to be a scientist. Her mother, like Annie Cannon's, had cultivated her daughter's love of nature. Emma Payne introduced her daughter to spiders, mimosas, and orchids; one day with her daughter still in the pram, she pointed to a meteor blazing across the sky. Unfortunately, schoolteachers attempted to dissuade the child from pursuing science, since they viewed it as antithetical to faith in God. One nun thought the girl would be "prostituting her talents," but stopped discouraging her once Payne developed facial hair: in lieu of marriage prospects, thought the nun, science might become the young woman's best means of support. "You've got brains. Make something of them," the family doctor told her. It stiffened her resolve to become a scientist.[37]

In grammar school Payne was drawn to botany, but at Newnham, the women's college of Cambridge, she moved into physics. Under Ernest Rutherford, the Cavendish laboratory attracted a well of international students. While many subdisciplines of physics were developed further in Europe than in the United States, tolerance for women physicists was nascent at best. Payne's experience in Rutherford's lecture courses was similar to Marie Curie's twenty years earlier at the Sorbonne. Payne sat separately in the front row of the lecture hall, ever reminded of her trespass. In labs she paired off with other women and felt like a perpetual "second-class student." Since pure physics seemed too hostile, she decided to become an astronomer.[38]

Payne biked up to the observatory and declared her intentions to Arthur Eddington, "the father of modern astrophysics." Amused and skeptical, he still agreed to help her prepare. Another rare, sympathetic advisor feared she would never be taken seriously by English academics. Most women in her class took up teaching positions after graduation, "a fate worse than death," as she saw it. She looked to the United States, where she would pursue a research career, leaving Cambridge, England, for Cambridge, Massachusetts in 1923. Harvard Observatory director Harlow Shapley was intrigued by assurances from her advisor that, "given the opportunity, [she] would devote her whole life to astronomy. . . . She would not want to run away after a few years training to get married." Shapley offered her a fellowship, figuring that when it ended, he would have another Annie Cannon at his disposal.[39]

When Payne arrived at the observatory, the ghosts of Pickering's original "harem" still lingered everywhere she turned. A few of the old "strutting hens" remained: Miss Woods, Pickering's former secretary, still displayed the medals for the novas she had discovered; younger women told Payne that the spirit of Henrietta Leavitt haunted the stacks. Payne took Leavitt's old desk, and hoped not to share her fate; she thought Pickering had condemned a "brilliant scientist . . . to uncongenial work" and that his decision to hire her to "work, not think . . . set back the study of variable stars for several decades." This wouldn't do for a self-professed "theorizing" type. A friend from Newnham College described Payne as perpetually absorbed in abstract questions. Sometimes she would sit in bed playing the fiddle or constructing mechanical toys as she worked through complex problems in her mind. She wanted to grapple, to explore, to be "in direct touch with the fountainhead."[40] Under Shapley it would be difficult. Since he had taken over the directorship the female computing corps had nearly doubled in size; twenty-five assistants worked full time, and he had exploited Radcliffe undergraduates during the school year, since "girl hours" were less of a blow to the budget. Payne worked as an independent fellow in her first year at Harvard, thus free to study the temperature and composition of stellar atmospheres as she wanted. But once the fellowship ended, she was at Shapley's mercy, and it was soon clear that she'd measure stellar magnitudes all day like the rest of the women computers.[41]

Payne feared that falling into standard photometry would make her indistinguishable from everyone else, but Shapley saw that she had special talent and encouraged her to pursue a doctorate degree. There was not yet an astronomy program at Radcliffe or Harvard, so she turned to the physics department and once again felt the hostility of men who thought she was trespassing. The department chair wouldn't admit her, so Shapley brought together a makeshift committee of doctoral examiners and shaped a graduate program in astronomy. Other women with whom she studied stopped at the master's degree and married; Payne, however, became the first recipient of an astronomy PhD at the college. She, like Annie Cannon before her, had become a pioneer of sorts, and she shared the ambiguous status that comes with being first.[42]

Like no other member of the observatory staff, she straddled worlds between photometry and spectroscopy, female doing and male thinking, tedious classification and inspired theory. The result was a dissertation in 1925 that married Pickering's pile of facts and Shapley's penchant for synthesis. She applied the ionization theory of physicist Meghnad Saha to the range of spectra that women computers had identified over the years but left unanalyzed. She concluded that stellar atmospheres were not made up of metals, as had been believed; rather they consisted primarily of hydrogen, with a bit of helium and traces of other elements.

When she showed a preview of her write-up to astrophysicists Arthur Eddington and Henry Norris Russell, they advised her to temper her stance. "It is clearly impossible that hydrogen should be a million times more abundant than the metals," Russell challenged. His stature in the field made Payne question herself, lose heart, and renege; in the final dissertation she made drastic revisions and decided that the stellar abundance she deduced for hydrogen and helium was "improbably high . . . almost certainly not real." Four years later, when Russell's data were in "gratifying agreement" with Payne's original contention, he was gentlemanly enough to cite her work, but the credit for the discovery was his. A colleague offered years later to set the record straight in a history of astrophysics, but she humbly refused. The mistake was hers for not pressing the point, she told him. Her self-doubt speaks to the age and gender politics involved.[43]

Until now gender and rank at the observatory had been virtually synonymous, but Payne's accomplishments in theoretical astrophysics muddied the waters. She was earning an international reputation; men thought her dissertation a sure classic in the field. She had become the youngest astronomer starred in *American Men of Science*, and in 1928 she was elected to the International Astronomical Union's Committee on Spectra. Still, university president A. L. Lowell swore that she, or any woman, would never get a university appointment while he lived to witness it. Payne was at once resentful, embarrassed, and resigned to her fate. Given her doctorate, her compensation exceeded that of computers, but remained far less than that of male doctorate holders. To family back in England she reported that she was a self-sustaining scientist, hiding from them that she was pawning off jewelry to make ends meet.[44]

She plodded on with the "spade work" assigned by Shapley. Her next work, a book titled *The Stars of High Luminosity*, she wrote grudgingly; it was not the work she wanted to do. In December 1930 she wrote Russell out of frustration; like Cannon she commanded respect outside the walls of the Harvard Observatory, so why didn't this translate to more credit, compensation, or autonomy inside it?

> I have during the past four years had a very unhappy time at Harvard; the chief reasons have been (a) personal difficulties within the Observatory particularly with Dr Shapley, and usually arising out of personal jealousies because he seemed to like others more than myself. (b) disappointment because I received absolutely no recognition, either official or private, from Harvard University or Radcliffe College; I cannot appear in the catalogues; I do give lectures, but they are not announced in the catalogue, and I am paid for (I believe) as "equipment"; certainly I have no official position such as instructor . . . (c) I do not seem to myself to be paid very much; quite honestly I think I am worth more than 2300 dollars to the Observatory. (d) In the seven years I have spent at Harvard I have not got to know any University person through my work (which confines my acquaintance to the Observatory staff and Professor Saunders); whereas the wife of any Harvard man of my status is called upon by the wives of dozens of others.[45]

Shapley tried to appease her with a slight raise in 1931. At twenty-seven hundred dollars a year, she was earning more than twice the salary of women computers, though not quite what a new male lecturer would earn. She demanded time away from Harvard to convene with "intellectual equals" and was granted leave to visit the great observatories out west and to go to see others in Europe. She hoped to clear her head and to get over still another affair of unrequited love. There had been several such disappointments since she first arrived in the States nearly a decade before.[46]

At the Astronomische Gesellschaft in Göttingen she met a Russian-born astronomer named Sergei Gaposchkin. As she spoke to him she was heartened to hear that her scholarly reputation had preceded her, for the man had recognized her name and expressed surprise that she was such a young woman. She thought him physically slight but charming, especially when he told her about his struggle to find a place in Germany where he could do research without being killed. She was so moved by Gaposchkin's story that she vowed to help him leave the country and begged Shapley to hire him. He agreed to create a temporary position, but told Payne that she would have to find the means to keep Gaposchkin at Harvard once the terms of his employment expired.

Payne had developed crushes on male astronomers before, but nothing had ever come of them. Big boned and awkwardly tall, the self-proclaimed ugly duckling had resigned herself to being alone. Her shyness, her chain-smoking, her lack of personal style, however, seemed not to diminish Gaposchkin's awe for her talents. She had a steady salary; an established reputation; a research agenda; and, since 1931, American citizenship to protect him. Colleagues worried that he was taking advantage of a woman clearly desperate for male affection. Within months of meeting, the couple eloped.[47]

It was likely no coincidence that many of the inroads Payne had made in spectroscopy from this moment forward were cut short. When Shapley assigned her husband to photometry, suddenly she was content to do that too, in order to support their joint research. Gaposchkin provided the data for eclipsing stars for their jointly written *Variable Stars* (1938); Payne provided everything else. She claimed that the ingenuity of the work was his, and colleagues thought that was probably the truth, for *Variable Stars* was her least successful work thus far.[48]

In the eyes of colleagues, it was unfortunate that this new breed of woman astronomer had a liability for a husband. Payne's professional admirers understood that she and Gaposchkin were a team and that he was very likely the reason she was denied attractive positions over the years, including the presidency of Bryn Mawr College. Scientists who knew both Payne and her contemporary Irene Curie saw them both in marriages to charismatic men who had pursued—in order to exploit—painfully shy and unattractive women with brilliant minds and professional connections. Frédéric Joliot benefited from the Curie name (he took it for himself) without any added domestic or professional burdens, since Irene Curie took on the child-care duties and refused to give up her lab work.[49] His wife was his link to international physics, just as Payne became Gaposchkin's connection to American astronomy. She wrote up her husband's work in English and shielded him from professional detractors. She never entertained the idea that her marriage was one of convenience, even though most people thought of them as incompatible personalities. "Like two magnets of opposite poles they stuck together," their daughter explained; somehow their differences became complements. Payne found happiness and, for the first time in her life, enjoyed the security of feeling like a "member of a team."[50]

Indeed she had a more collaborative partnership than most; Gaposchkin helped more at home than other men by doling out spankings and doing the lion's share of the housework. He eased his wife's domestic burdens although he didn't remove them fully, as the wives of Harvard astronomers did for their husbands. Payne took on traditional duties when she could; her daughter remembered her as a "domestic wife"—"an inspired cook, a marvelous seamstress, an inventive knitter," who loved to entertain on the rare occasion she was home. Speaking engagements, meetings of the major science societies, and visits to the Yerkes Observatory took her away from the children often, as did the extracurricular activities she refused to give up. When the children were still young she taught Sunday school and played the violin in the Observatory Philharmonic Orchestra. Gaposchkin's salary was always smaller than hers, and hers was of course more modest than her male peers', thus leaving the couple, for most of their married life, in a state of perpetual thrift. They took in borders to ease their burdens and hired domestic workers when they could afford them. Payne resorted to making undergarments out of nylon parachutes she purchased at the army surplus store and became a master canner in the winter months.[51]

Payne was the breadwinner and senior scientist, Gaposchkin the junior partner and helpmeet. The strange arrangement worked but inevitably created its tensions. "There were professional disagreements, not so much on scientific issues as on who should go where when," their daughter Katherine recalled. "She was more important scientifically, so she generally left him as babysitter if there were no other alternatives." At times the situation seemed to insult Gaposchkin's manhood. Male superiors at the observatory thought he had a chip on his shoulder. Toward women assistants he was overly solicitous and fancied himself an athlete with the muscular physique to prove it; they figured this was his pathetic way of compensating. Payne, ever the stoic, seemed to be oblivious to it all; if she thought her husband vain or arrogant, she wouldn't admit it. He needed to be appeased for the whole system to work.[52]

As much as she tried to be a traditional mother and homemaker, the fact was that Payne worked long hours when the expectation was that proper women stayed home with their children. Men at the observatory never questioned her competence as an astrophysicist, but their disapproval of her personal choices as mother and wife was palpable. Shapley was appalled when she scheduled a talk at Brown University in 1940: he thought her simply too pregnant to be discreet. She said nothing then, but in later years admitted resenting the scrutiny. Tensions mounted when, in lieu of affordable sitters, she resorted to bringing her children to the observatory as she worked. Colleagues rolled their eyes when the rambunctious kids ran up and down the spiral staircase among the plate stacks and played with the creaky dumbwaiter. Their father's office was relatively accessible, but to reach their mother's on the top floor of Building D it was necessary to "run the gauntlet of all the open office doors of the scientists," including the director's. Colleagues voted to make their displeasure known. She felt insulted and embarrassed in ways Sergei Gaposchkin likely didn't: in the eyes of her peers the unruly children were the result of their neglectful mother, not their overly indulgent father.[53]

Women of Annie Cannon's generation relinquished traditional family life for a long-term, single-focused commitment to the observatory, but Payne brazenly tried to have it all. Remarkably, the matronly Cannon came to her defense. Professional astronomy need not conflict with a woman's married life, she argued: "Research, which is not confined to fixed hours or necessarily to office walls[,] may easily be carried on by married women. A stellar photograph may be studied at home, during odd hours, and perhaps may not require more time from a wife or mother than is frequently given to bridge playing or various other social activities." She reminded critics, too, that since the establishment of the Pickering fellowships in 1916, ten of thirteen former female recipients, Payne included, continued to be engaged in scientific research or teaching.[54]

In truth, Cecilia Payne-Gaposchkin had been a good investment over the years, well worth her modest salary and then some. Shapley burdened her with excessive teaching and a disproportionate amount of "departmental housework" to free up her male peers for research. She worked at the observatory six days a week, staying often at night for lectures, seminars, and parties, since she was charged with fund-raising and social organizing. She had reason to fear that the added responsibilities made her look scattered, less focused; when it came to promotion she was passed over again and again for men who appeared to be innovating around the clock. When she saw what was going on she told Shapley to put her back on spectroscopy, but he offered spectroscopy positions to outside male candidates and relegated her to photometry so as not to step on their toes. In 1944 when she was passed over for a full professorship, administrators cited her "domestic situation" as the reason. She had heard the same explanation when denied an executive position in the American Astronomical Society in 1938.[55]

James Conant replaced Lowell as Harvard's president and promoted both Cecilia Payne-Gaposchkin and Annie Cannon as full-fledged "astronomers" in 1938, but Payne couldn't hope for further advancement so long as Shapley remained the director. Donald Menzel, who finally replaced Shapley in 1954, was shocked to discover in employment records that his able female colleague had been paid a fraction of his salary over the years. Immediately he set procedures in motion to double her salary, and shortly thereafter promoted her to a full-tenured professorship, followed by a department chair. Surprisingly, she was not particularly joyous upon hearing the news, for, as her daughter recalled, the position of chair was a source of anxiety that her mother "combated with cigarettes, coffee and an occasional pill." Payne was then almost sixty and ready to relinquish all administrative responsibilities to focus on research. The upside, of course, was that the formal university appointment increased her salary by a factor of four.[56]

Annie Cannon shared Cecilia Payne-Gaposchkin's international acclaim, and women in succeeding decades have shared her academic credentials, but no one had had both during her five decades at the observatory. Her status was unique, and thus also were her challenges as a mother, wife, and scientist. Younger women were grateful that she took many of the blows pioneers suffer to clear paths for others. Dorrit Hoffleit, the fifth woman astronomy doctorate holder at Harvard in 1938, had been shepherded into work on the light curves of variable stars (at the improved rate of forty cents an hour), before leaving during World War II to work as a missile trajectories expert at the Aberdeen Proving Ground. Similarly Henrietta Swope doubled as independent scholar and assistant to Shapley before moving on to research positions in the radiation labs of MIT and the navy's hydrographic division. One wonders if Payne would have been promoted sooner had she leveraged similar wartime positions early in her career.

Nevertheless, when the war ended, Hoffleit and Swope found themselves once again in "female" niches within astronomy. Swope took an associate position at Barnard and left in 1952 to assist in an investigation of variable stars of the Andromeda Nebula at Mount Wilson Observatory. Her supervisor, Walter Baade, assured her that she would be a partner of equal rank, but in the end administrators classified her as "a B.A., female computer." Swope was discouraged, but not surprised. "I have always held an innocuous title," a "research assistant" at Harvard, a "staff member" at MIT, and a "mathematician" in the Navy. She was proficient at classifying stars, but male astronomers found it hard to classify a woman with her skills and credentials. She understood what Payne must have felt for decades under Shapley.[57]

Swope remained out west, but was denied access to the telescope at the Palomar Observatory until the mid-1960s. Ultimately a telescope was named in her honor, much as awards were named after Annie Cannon. But her career path reveals the contours of the story told in different ways through the careers of Cannon, Payne-Gaposchkin, and the others: although astronomy was one of the first science fields to open professional opportunities to women, it simultaneously denied them and left them ghettoized in low-status work. Leaving home did not help the female pioneers of the field shed their associations with domesticity. Even as they engaged in a masculine brand of scientific inquiry, professional men interpreted their work as a sort of housekeeping among the stars.

Notes

1. Anonymous astronomer quoted in Patricia Ann Palmieri, *In Adamless Eden: The Community of Women at Wellesley* (New Haven, CT: Yale University Press, 1995), 86.

2. The script sat for decades until the staff put on the production in 1929. Typed script of observatory production of "The Observatory Pinafore," 1929, in Henrietta Swope Papers, Carton 2, folder 89, Schlesinger Library, Radcliffe College, Cambridge, MA.

3. "Good Housewives Will Understand," *Camden Daily Courier*, n.d., in "Clippings, Draper Medal 1931," Biographical Clippings, Annie Jump Cannon Papers, Harvard University Archive, Cambridge, MA.

4. M. E. Cannon to Annie Jump Cannon, September 14, 1880, Personal Correspondence, 1873–1941, A–P, Box 1 of 2, Annie Jump Cannon Papers; Edna Yost, *American Women of Science* (Philadelphia: Frederick A. Stokes, 1943), 28–29, 33–36.

5. Margaret W. Rossiter, "'Women's Work' in Science, 1880–1910," in *History of Women in the Sciences: Readings from Isis*, ed. Sally Gregory Kohlstedt (Chicago: University of Chicago Press, 1999), 292–304.

6. George Johnson, *Miss Leavitt's Stars: The Untold Story of the Woman Who Discovered How to Measure the Universe* (New York: W. W. Norton, 2005), 15–17; Pamela E. Mack, "Straying from Their Orbits: Women in Astronomy in America," in *Women of Science: Righting the Record*, ed. G. Kass Simon and Patricia Farnes (Bloomington, IN: Indiana University Press, 1993), 72–73.

7. Mack, "Straying from Their Orbits," 85, 87.

8. George Greenstein, *Portraits of Discovery: Profiles in Scientific Genius* (New York: Wiley, 2001), 25; Londa Schiebinger, "Maria Winkelmann at the Berlin Academy: A Turning Point for Women in Science," in *History of Women in the Sciences*, 58.

9. Rossiter, "'Women's Work,'" 289–90; Laurence Goodman, "Pickering's Harem," (thesis, Harvard University, 1989), 5–6, Harvard University Archives; Johnson, *Miss Leavitt's Stars*, 19; Mack, "Straying from Their Orbits," 76–79, 86, 89.

10. Mrs. M. Fleming, "A Field for Woman's Work in Astronomy," reprinted from *Astronomy and Astro-Physics*, no. 118 (read at the Congress of Astronomy and Astro-Physics, Chicago, August 1893), in "Clippings on Williamina Paton Fleming, HUG 1396.5, Harvard University Archives, 3; Mack, "Straying from Their Orbits," 89; Rossiter, "Women's Work in Science," 291.

11. Annie Jump Cannon, "Astronomy for Women" for the "Every Evening," February 7, 1929, Speeches and other manuscripts, Box 2 of 2, Annie Jump Cannon Papers; G. Kass Simon, "Biology Is Destiny," in *Women of Science*, 227–30.

12. Annie J. Cannon, "Williamina Paton Fleming," *Science* 33, no. 861 (1911): 987–88, in "Clippings on Williamina Paton Fleming," Williamina P. Fleming Papers, Harvard University Archives; Yost, *American Women of Science*, 39; Cecilia Payne-Gaposchkin, "The Dyer's Hand: An Autobiography," Typed manuscript, Schlesinger Library, Radcliffe College, 54–55; Mack, "Straying from Their Orbits," 100.

13. Johnson, *Miss Leavitt's Stars*, 86; Entries for March 2, 7, in "Journal of Williamina Paton Fleming—Curator of Astronomical Photographs, Harvard College Observatory," Harvard University Archives.

14. Examples of popular works by Clerke are *A Popular History of Astronomy During the Nineteenth Century* (1885), *The System of Stars* (1890), *The Herschels and Modern Astronomy* (1895), *Astronomy* (1898), *Problems in Astrophysics* (1903), and *Modern Cosmologies* (1905). Bernard Lightman, "Constructing Victorian Heavens: Agnes Clerke and the 'New Astronomy,'" in *Natural Eloquence: Women Reinscribe Science*, ed. Barbara T. Gates and Ann B. Shteir (Madison, WI: University of Wisconsin Press, 1997), 61–65; C. E. Barns to Annie Jump Cannon, April 4, 1926; December 22, 1929, Personal Correspondence, 1873–1941, A–P, Box 1 of 2, Annie Jump Cannon Papers.

15. H. H. Turner to Miss Cannon, April 29, 1925, Oxford Degree, 1925, folder, Professional Correspondence and other papers, 1883–1941; Annie Jump Cannon to Miss Katharine A. Jones, Chairman of Program, Chicago Woman's Club, April 30, 1921; May 1933 Bulletin of the Chicago Woman's Club, Chicago Woman's Club folder, Professional Correspondence and other papers, 1883–1941, Box 2 of 4, Annie Jump Cannon Papers.

16. Harriet Bigelow to Annie Jump Cannon, June 5, 1933; Anne S. Young to Annie Jump Cannon, May 19, 1933; Louise S. McDowell to Margaret Ferguson, April 18, 1933; Helen S. French to Margaret C. Ferguson, April 18, 1933; Margaret C. Ferguson to Annie Jump Cannon, April 21, 1933, in Women in Science Chicago Speech, Hall of Science, June 20, 1933 folder, Speeches and other manuscripts, Box 1 of 2, Annie Jump Cannon Papers.

17. Typescript of "Women in Science, 1833–1933," in "Women in Science Chicago Speech, Hall of Science, June 20, 1933" folder.

18. Annie Jump Cannon, "Astronomy for Women."

19. "A Report of the Methods & Results of Meteor Observing"; A. Grace Cook to Annie Jump Cannon, February 9, 1921, A. Grace Cook Folder, 1920–21; "The Annie J. Cannon Prize," Professional Correspondence and other papers, 1883–1941, Box 1 of 4, Annie Jump Cannon Papers.

20. "Mrs. Williamina P. Fleming Dead," *Boston Globe*, May 22, 1911; Cannon, "Williamina Paton Fleming"; Mack, "Straying from Their Orbits," 92–94; Johnson, *Miss Leavitt's Stars*, 20.

21. Annie J. Cannon, "Mrs. Fleming," *Scientific American*, June 3, 1911, in "Clippings on Williamina Paton Fleming."

22. Garret P. Stevens, "A Woman's Achievements in Astronomy," *Chicago Examiner*, June 29, 1911, in "Clippings on Williamina Paton Fleming."

23. Entry for March 10, 1900, "Journal of Williamina Paton Fleming."

24. Entries for March 1, 4, 9, 10, 11, 12, in "Journal of Williamina Paton Fleming."

25. Entries for March 12, 5, 3, in "Journal of Williamina Paton Fleming"; Goodman, "Pickering's Harem," 10.

26. Edward C. Pickering, "Henry Draper Memorial," in the Annual Reports of the President and Treasurer of Harvard College, 1902–1903, 253, electronic version, Harvard University Archives; Louise W. Carnegie to Williamina Paton Fleming, October 6, 1908, Miscellaneous Correspondence, 1905–1909, Williamina Paton Fleming Papers; Entries for March 4, 14–31, in "Journal of Williamina Paton Fleming."

27. Stevens, "A Woman's Achievements in Astronomy"; Edward C. Pickering, In Memoriam, "Williamina Paton Fleming," Williamina Paton Fleming Papers.

28. Mack, "Straying from Their Orbits," 94–97.

29. Goodman, "Pickering's Harem," 11–13.

30. Goodman, "Pickering's Harem," 13–14; Mack, "Straying from Their Orbits," 96.

31. Cannon classified spectra at the rigorous rate of more than three per minute. See Mack, "Straying from Their Orbits," 100.

32. Goodman, "Pickering's Harem," 11–12, 14; Mack, "Straying from Their Orbits," 96–97; Payne-Gaposchkin, "The Dyer's Hand," 48, 54.

33. Johnson, *Miss Leavitt's Stars*, 22–29, 34.

34. Jean L. Turner, "Henrietta Swan Leavitt," in *Out of the Shadows: Contributions of Twentieth-Century Women to Physics*, ed. Nina Byers and Gary Williams (New York: Cambridge University Press, 2006), 56–65; Johnson, *Miss Leavitt's Stars*, 36–38, 41–43.

35. Johnson, *Miss Leavitt's Stars*, 118–19, 90; Mack, "Straying from Their Orbits," 104.

36. Peggy A. Kidwell, "Cecilia Payne-Gaposchkin: Astronomy in the Family," in *Uneasy Careers and Intimate Lives: Women in Science, 1789–1979*, ed. Pnina G. Abir-Am and Dorinda Outram (New Brunswick: Rutgers University Press, 1989), 224; Katherine Haramundanis, "A Personal Recollection," in *Cecilia Payne-Gaposchkin: An Autobiography and Other Recollections* (New York: Cambridge University Press, 1996), 40–41.

37. Payne-Gaposchkin, "The Dyer's Hand," 7–17, 18.

38. Peggy Aldrich Kidwell, "Women Astronomers in Britain, 1780–1930," in *History of Women in the Sciences*, 221–33; Payne-Gaposchkin, "The Dyer's Hand," 26–36.

39. Peggy A. Kidwell, "An Historical Introduction to 'The Dyer's Hand,'" in *Cecilia Payne-Gaposchkin*, 13.

40. Payne-Gaposchkin, "The Dyer's Hand," vi, 47–49, 52, 109, 110.

41. Harlow Shapley to Gerard Swope, May 14, 1927, Carton 1, folder 17, Henrietta Swope Papers; Kidwell, "Cecilia Payne-Gaposchkin," 221–22.

42. Payne-Gaposchkin, "The Dyer's Hand," 111; Kidwell, "Cecilia Payne-Gaposchkin," 223; Vera Rubin, "Cecilia Payne-Gaposchkin," in *Out of the Shadows*, 164.

43. Rubin, "Cecilia Payne-Gaposchkin," 159; Greenstein, *Portraits of Discovery*, 16; Kidwell, "An Historical Introduction," 19; Payne-Gaposchkin, "The Dyer's Hand," 70.

44. Kidwell, "An Historical Introduction," 22–23; Payne-Gaposchkin, "The Dyer's Hand," 111, 61–69.

45. Cecilia Payne to H. N. Russell, December 11, 1930, H. N. Russell Papers, Princeton University Library, Princeton, NJ (letter cited in Kidwell, "An Historical Introduction," 26).

46. Kidwell, "An Historical Introduction," 27.

47. Payne-Gaposchkin, "The Dyer's Hand," 88–92; Virginia Trimble, "An Introduction," in *Cecilia Payne-Gaposchkin*, xix; Kidwell, "Cecilia Payne-Gaposchkin," 226–28.

48. Greenstein, *Portraits of Discovery*, 17–18; Payne-Gaposchkin, "The Dyer's Hand," 94; Kidwell, "Cecilia Payne-Gaposchkin," 229.

49. Irene Curie-Joliot to Missy Meloney, March 29, 1932, June 27, 1937; Dorothy Dunbar Bromley, "Two Who Carry on the Curie Tradition," *New York Times*, January 1, 1933, SM4, Box 2; William B. Meloney-Marie Curie Special Manuscript Collection, Columbia University Libraries, New York, NY.

50. Kidwell, "Cecilia Payne-Gaposchkin," 229–235; Haramundanis, "A Personal Recollection," 64; Greenstein, *Portraits of Discovery*, 22–23; Payne-Gaposchkin, "The Dyer's Hand," 93.

51. Haramundanis, "A Personal Recollection," 39–44, 64.

52. Haramundanis, "A Personal Recollection," 45, 64; Greenstein, *Portraits of Discovery*, 22–23; Kidwell, "Cecilia Payne-Gaposchkin," 234.

53. Haramundanis, "A Personal Recollection," 47–48; Kidwell, "Cecilia Payne-Gaposchkin," 232–33.

54. Report of the Astronomical Fellowship Committee," February, 1935, Fellowship Miscellaneous letters and papers, 1911–35 folder, Professional Correspondence and other papers, 1883–1941, Box 2 of 4, Annie Jump Cannon Papers.

55. Payne-Gaposchkin, "The Dyer's Hand," 111–12; Kidwell, "Cecilia Payne-Gaposchkin," 234.

56. Haramundanis, "A Personal Recollection," 60; Payne-Gaposchkin, "The Dyer's Hand," 112; Rubin, "Cecilia Payne-Gaposchkin," 164.

57. Dr. Walter Baade to Henrietta Swope, October 16, 1951; Henrietta Swope to Dr. I. S. Bowen, Mt. Wilson and Palomar Observatories, October 24, 1951, carton 2, folder 87, Henrietta Swope Papers.