Women in Engineering and Science

Alice E. Smith *Editor*

Women in Industrial and Systems Engineering

Key Advances and Perspectives on Emerging Topics

Springer

Women in Engineering and Science

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This volume is dedicated to my parents, Lois Elizabeth Krutsch Chupp and John Paul Chupp, now both deceased. My mother was the first in her family of immigrants from Russia to attend college, and while she was a mathematics student at Purdue University, she had the good fortune to meet Dr. Lillian Gilbreth. My father came from a humble Swiss Amish farming stock, but his father had advanced himself by earning a doctorate at Cornell University and was then a professor there for many years. My father, a PhD in chemistry, was proud when I earned my doctorate, making three generations of PhDs. My parents' examples and encouragement facilitated my career in engineering academia, and I am grateful to them for that, as well as for so much more.

Foreword

Margaret L. Brandeau is the Coleman F. Fung Professor of Engineering and Professor of Medicine (by Courtesy) at Stanford University. My research focuses on the development of applied mathematical and economic models to support health policy decisions. My recent work has examined HIV and drug abuse prevention and treatment programs, programs to control the opioid epidemic, and preparedness plans for public health emergencies.

My undergraduate studies were at MIT, in mathematics. I followed in my father's footsteps to MIT. However, while he studied electrical engineering, I chose math, a subject I have always loved. I was finished with my degree by the end of junior year, but did not want to graduate so soon, so I started taking some interesting applied mathematics and systems analysis classes. Then, I found out that the courses I was taking would fulfill the requirements for a master's degree in operations research—a discipline I had never heard of—so I also earned an MS degree in operations research. After working for 2 years, I moved to Stanford, where I earned a PhD in Engineering-Economic Systems—again taking interesting classes in applied mathematics and systems analysis. Along the way, I published a number of papers about the projects I was working on. I didn't realize it then, but this was great preparation for being a faculty member.

I joined the Stanford faculty in 1985 and have been there ever since, working on interesting problems with amazingly talented students and colleagues. I wouldn't change a single day!

Broadly speaking, industrial engineering focuses on determining how best to organize people, money, and material to produce and distribute goods and services.

Industrial engineering has its roots in the industrial revolution in the mid-18th to early nineteenth century. As production shifted from small enterprises to large-scale factories, and the production of goods became increasingly mechanized and specialized, factory owners realized that improving the efficiency of these new production processes could reduce waste and increase productivity.

One of the first scientific studies of work processes was *The Principles of Scientific Management* by Frederick Taylor (1911). Taylor, who is known as the father of industrial engineering, set forth principles for organizing, planning, and standardizing work. Around this time, a young man named Frank Gilbreth, who had started a job as a bricklayer's helper, began to study the practices of different bricklayers, trying to determine "the one best way" to perform the task. In 1904, he married Lillian Moller, an engineer who also became his work partner in their business and engineering consulting firm.

Lillian Moller Gilbreth was one of the first women engineers to earn a PhD (in psychology). She worked for many years applying industrial engineering concepts such as time and motion studies to improve work processes, first with her husband and then on her own for many years after his death. Her work emphasized a human approach to scientific management. During her career, Lillian Gilbreth published numerous books and papers, some with her husband and some on her own. If Frederick Taylor is the father of industrial engineering, Lillian Gilbreth is surely the mother of industrial engineering.[1]

From this beginning nearly 100 years ago, it is wonderful to see an entire volume of work by women industrial engineers. Since those early days, industrial engineering has of course changed, and this is reflected in this volume. Once focused on factory control, industrial engineering now focuses more broadly on both manufacturing and services. Once focused on techniques such as time and motion studies and Gantt charts, industrial engineering now includes a wide range of modern computational and analytical techniques.

In this volume, 59 women (and 3 male coauthors) present their work in 25 chapters covering such diverse topics as logistics costs in warehousing, container depot operations, multimodal transportation systems, price contracts in manufacturing, crop cultivation, food supply chains, healthcare operations, patient safety, clinical decision-making, disease modeling, and education. Methodologies discussed in these chapters are similarly broad and include human factors engineering, statistics,

[1]Lillian Gilbreth also had 12 children. Her family life was famously immortalized in the book *Cheaper by the Dozen*, written by two of her children, Frank Gilbreth Jr. and Ernestine Gilbreth Carey. Growing up, this was one of my favorite books. In 1994, I had the great pleasure of meeting Ernestine.

decision analysis, graph theory, simulation, optimization, stochastic modeling, and machine learning.

Industrial engineering has come a long way since its beginnings on the shop floors of England. Looking to the future, services are forming an ever-increasing share of economic output, both in the United States and elsewhere. Entire industries are being rapidly transformed via analytics and computation. Digitization and machine learning in the workplace are changing the nature and structure of work and the nature and structure of organizations. Automation and robotics have replaced many jobs once done by people. Increasing numbers of people are employed as "knowledge workers." Digital platforms that allow for spontaneously matching customer needs with available resources are becoming more pervasive. Industrial engineering has evolved and will continue to evolve in the face of these and other changes.

I hope that, as industrial engineering evolves, the numbers and roles of women in industrial engineering will also continue to evolve. The field of industrial engineering has been greatly enriched by the contributions of women. Women bring a diversity of experiences and viewpoints and, often, creative new ways of solving problems. This book showcases the work of 59 such women. I hope that many more amazing women will contribute to solving the important problems of the future—and help us determine how best to organize people, money, and material to produce and distribute goods and services in our changing world.

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Lillian Moller Gilbreth: An Industrial Engineering Pioneer

Jill S. Tietjen

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1.1 Introduction

Career interest tests. The butter dish, egg tray, and vegetable and meat drawers in your refrigerator. The pump and return water hose on your washing machine. The foot pedal trash can. The design of the kitchen triangle. Accommodations for disabled people. What do these all have in common? They are the legacy of the "First Lady of Engineering" also called "The Mother of Industrial Engineering," "the Mother of Ergonomics," and "the greatest woman engineer in the world," one of the founders of the field of industrial engineering, Lillian Moller Gilbreth. She and her husband, Frank Gilbreth, are considered two of the cornerstones of the field of industrial engineering—a branch of engineering that is concerned with optimizing complex systems, processes, and organizations. Frank's focus was "The One Best Way" to do any task or series of tasks. Lillian's strength was bringing the social sciences to bear in combination with the mathematical and physical sciences.

Popularized in books and movies as the mother of 12 children (*Cheaper by the Dozen* and *Belles on Their Toes*), Gilbreth (see Fig. 1.1) was not only a mother but also a significant force as a pioneering woman industrial psychologist and engineer. Her story is fascinating and too rarely known (Des 2013; Lancaster 2004).

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Fig. 1.1 Portrait of Lillian Moller Gilbreth. Courtesy of Walter P. Reuther Library, Wayne State University

1.2 Early Years

Growing up in a conventional household of the day, Lillian Moller (Gilbreth) (1878–1972) was the oldest of nine children, expected to conform to what was then deemed proper behavior for women. Very gifted academically, she was able to convince her father to let her attend the University of California while she lived at home and cared for the family. The first woman in the university's history to speak at commencement in 1900, Lillian received her B.A. in literature at the top of her class (although she did not make Phi Beta Kappa due to her gender). After briefly attending Columbia University, she reentered the University of California, earned her master's degree in literature in 1902 and began work on her Ph.D. (Des 2013; Proffitt 1999).

As was also common for women of her social class of her day, Lillian took a trip abroad before delving too deeply into her doctoral work. While in Boston preparing to board her ship, the chaperone for the trip—Miss Minnie Bunker, who was a teacher in the Oakland, California schools—introduced Lillian to her cousin Frank, who owned a construction business. Frank Bunker Gilbreth, who had not attended college and whose passion was finding the "One Best Way" to do any task, and Lillian became enamored with each other. Frank and Lillian decided to marry—embarking on the One Best Marriage—which involved a sharing of home life and work life. After their engagement was announced but before their marriage—Lillian on the West Coast, Frank on the East Coast—Lillian was already editing Frank's manuscripts for publication and critiquing his advertising brochures which he sent to her for this exact purpose. She edited his confidential management booklet "Field

System," reorganized it, fixed the grammar, and added an index. They were married in October 1904 (Des 2013; Lancaster 2004; Proffitt 1999; Yost 1943; Gilbreth Jr 1970).

1.3 The One Best Marriage

After their marriage, it became apparent that Lillian's selected areas of study for her Ph.D.—English and Comparative Literature—were not going to work for the couple's idea of shared work life. Instead, she became Frank's engineering apprentice, learning the types of work he used in his construction business. That education began in earnest on their honeymoon. As their family began to grow, much of that apprenticeship actually occurred at home. And, it was decided that her Ph.D. would be in the field of industrial psychology (Proffitt 1999; Yost 1943, 1949).

As Frank wrote about his original work methods, Lillian served as editor, thus learning the business thoroughly. She also took care of all client calls. In addition, Lillian was the researcher. She also went on site visits and met Kate Gleason, one of the very few, if not the only, woman heading an engineering company at the time, during a visit to Rochester, New York. Lillian located and sifted through the materials that would be incorporated in Frank's speeches at universities and at pitch meetings to clients. Her role of editor and writer was such that she should have been acknowledged as the co-author of Frank's books including *Concrete System* (1908), *Bricklaying System* (1909), and *Motion Study* (1911). *Concrete System* and *Bricklaying System* were two books that Lillian insisted be written to document methods already in practice on Frank's jobs and to expand the Gilbreth system. *Bricklaying System* described what Frank called "Motion Study" to cut product costs and increase efficiency. Frank and Lillian said "Motion Study" should be applied to all industries so that workers and management would share the benefits (Des 2013; Lancaster 2004; Yost 1943; Gilbreth Jr 1970).

Lillian also became convinced that human beings in the industry needed to be approached through psychology. The tragic fire at the Triangle Shirtwaist Factory in 1911 further reinforced her belief that the workers needed to be considered and she worried that much damage had been done through the introduction of efficiency mechanisms without consideration of the cost to human beings (Des 2013; Lancaster 2004; Yost 1943).

Her ideas began to appear in these works. For example, in *Motion Study* (1911), there is mention of a worker's physiology as well as his temperament and contentment in the factory. Further, workers needed adequate tools, an environment that was pleasing, some form of entertainment, and a clear understanding of the reward and punishment system in place. [These same ideas appear in Lillian's first doctoral dissertation.] In *Field System* (1908), employers were encouraged to set up suggestion boxes and to ensure that workers had periodicals that would provide mental stimulation. All workers, including factory hands, office workers,

schoolteachers, homemakers, farmers and store clerks—a much broader range of "worker" than incorporated in the new field of Scientific Management—were included in the Gilbreths' writings (Des 2013).

Their home became their office and laboratory. Their children shared family responsibilities that included investigating the One Best Way. These included the One Best Way for dusting, for setting and clearing the dinner table and for washing dishes, among others. During summers, their efforts were filmed and the children could watch themselves to determine how to do a task more efficiently and in less time. Sometimes the tasks applied to work projects that Frank and Lillian were working on—such as the best way to pack soap in boxes. One time, it involved picking berries—which turned out to be one of the earliest films ever made to show motions in agricultural processes. Another time it involved touch typing. The children tested two theories—one of which involved color coding keys and fingers—and went to school with multi-colored fingernails! (Yost 1943; Gilbreth Jr 1970).

Each person was expected to participate according to his or her aptitudes and abilities. The 3-year-old participated, but only to the extent that worked and made sense. Lillian believed that personal capabilities were a sacred trust that each individual should develop. She helped management and workers understand the benefits of collaboration and to accept the responsibility for working together and not at odds with each other. She became an expert in the areas of worker fatigue and production. Her expertise and insights were of great benefit as these were the years during which scientific management was being developed and just coming into general use (Proffitt 1999; Yost 1943).

Lillian's remarks at the Tuck School of Dartmouth College for the first Conference on Scientific Management in 1911 at which she was probably the only female presenter, where she reported on the key tenets of her first Ph.D. dissertation, offered the perspective that humans were the most important element of engineering tasks and thus psychology needed to be considered by industrial engineers in putting together their programs. She had been introduced for her turn at the podium as "We have all been watching the quiet work of one individual who has been working along lines apparently absolutely different from those being followed by another worker in the scientific management field and I wonder if Lillian Gilbreth would like to say a few words about her work" (Des 2013; Proffitt 1999; Yost 1943, 1949). Lillian remarks included (Lancaster 2004; Graham 1998):

> *I did not expect to speak in this place but I feel as though I must. I feel that the gap between the problems of academic efficiency and industrial efficiency, which is after all only an apparent gap, can be easily closed if only we will consider the importance of the psychology of management. I spent several years examining and studying it and it seems to me that Scientific Management as laid down by Mr. Taylor conforms absolutely with psychology. Principles of vocational guidance may be studied along psychological lines to train the individual so he will know exactly what he does want to do. It is the place of the colleges to train the man so that when he comes into his work there will be no jar. Since the underlying aim is the same and since psychology is the method by which we are all getting there, isn't it merely a question of difference of vocabulary between academic work and scientific work? Why not bridge this gap and all go ahead together?*

The audience was receptive to her comments and the Dartmouth Conference has been referred to as Lillian's "coming out." The audience consisted of manufacturers and businessmen and provided an opportunity for a dialogue with engineers who had applied the principles of scientific management to industrial operations (Des 2013; Proffitt 1999; Yost 1943, 1949).

Lillian was interested in keeping people happy and eliminating antagonistic behavior, as well as such questions as: if a trained pianist makes a faster typist than an untrained pianist, what skills are transferable? In addition, she advocated for having workers be responsible for ideas for greater efficiency as well as training others on the new techniques (today what we call "buy-in"). Her emphasis on the worker's psychology made the Gilbreths different from the other scientific managers and Frank's emphasis on motion instead of time looked more humane than other methods in vogue at the time (Des 2013; Proffitt 1999; Yost 1943).

Their process of evaluating work efforts relied on basic elements or "therbligs" (very close to Gilbreth spelled backwards). These elements (which had associated colors and symbols) are [Graham]:

- Search
- Find
- Select
- Grasp
- Transport Loaded
- Position
- Assemble
- Use
- Disassemble
- Inspect
- Preposition for Next Operation
- Release Load
- Transport Empty
- Rest for Overcoming Fatigue
- Wait (Unavoidable Delay)
- Wait (Avoidable Delay)
- Plan

This framework could be applied to any job whether in the classroom, kitchen, or at an industrial plant. In a breakthrough application, the Gilbreths relied on films from moving picture cameras that recorded movements of workers with a clock in the frames. A film could be run over and over again, run in slow motion, stopped, backed up. Machines could be redesigned to be operated far more safely and with less fatigue to the workers. Chairs could be what we today call "ergonomically" designed at a height to fit the motions of the operator so to keep him/her off his/her feet and to reduce fatigue. They also measured a worker's movement spatially as well as with lights to make time-exposed photographs. Their motion studies included process charts, micromotion photography, and chrono-cyclegraphs. This led to "The One Best Way"—the least taxing method moving the fewest parts of the

body in the least amount of space in the fastest time. Frank considered micromotion study his most important contribution to motion study because it could be used in any field—from surgery to loading a machine gun. The micromotion, chronocyclegraph, and therbligs comprised the Gilbreth system (Des 2013; Gilbreth Jr 1970; Yost 1949; Goff 1946).

The Gilbreths introduced the process (or flow) chart to the field of scientific management. The charts show graphically the arrival of materials at a factory and each step in the "process" as those materials move from piece of equipment to piece of equipment and result in a final product. Such a chart quickly and obviously demonstrates bottlenecks and any backtracking that occurs. Like process charts, the Gilbreths invented the chrono-cyclegraphs—this time to study the motions of speed typists. A small flashing light was attached to a hand, finger, or moving part of a machine and then a time-exposure picture was taken of the entire cycle. The result of the time-exposure photography was a dotted white line on a black background with the path of motion in two dimensions. It was possible to take pictures stereoscopically to create three-dimensional images. Then the Gilbreths were able to determine time and speed as well as acceleration and retardation (Gilbreth Jr 1970).

Lillian became well known as an outstanding psychologist in scientific management circles and was asked to present her views and work in print and at meetings around the world. Her dissertation was completed and much to the Gilbreths' surprise, rejected by the University of California at Berkeley in 1912 as university officials decided that her residency requirement had not been waived (Des 2013; Gilbreth 1990). She instead published the work serially under "L.M. Gilbreth" in the journal *Industrial Engineering* as publishers were not willing to have what would be obviously a woman-authored work published in the field. In 1914, it finally was published in book form (authored by L.M. Gilbreth whom Frank humorously said he was related to "only by marriage") as *The Psychology of Management: The Function of the Mind in Determining, Teaching and Installing Methods of Least Waste* and then reprinted in 1917 and 1918. Its "human" approach to scientific management attracted immediate attention (Des 2013; Lancaster 2004; Proffitt 1999; Yost 1943; Gilbreth Jr 1970; Graham 1998).

A key quote from the book is: *The emphasis in successful management lies in the man, not the work. Efficiency is best secured by . . . modifying the equipment, materials, and methods to make the most of the man. . . with knowledge will come ability to understand the rights of others . . . lead the way to the true Brotherhood which may some day come to be* (Gilbreth Jr 1970).

In 1921, when she became an honorary member of the Society of Industrial Engineers (the first honorary female member and the second in total—Herbert Hoover being the first), it said (Des 2013; Yost 1949; Trescott 1983):

> she was the first to recognize that management is a problem of psychology, and her book, *The Psychology of Management*, was the first to show this fact for both the managers and the psychologists. . . Today it is recognized as authoritative.

Her book was the first time that anyone had brought together the basic elements of management theory including (Trescott 1983):

1. Knowledge of individual behavior
2. Theories of groups
3. Theories of communication
4. Rational bases of decision-making

She dealt with problem-solving, decision-making, planning, communicating, measuring, and evaluating in various work and managerial environments. Her book focused on group behavior and the coordination of activities among work groups. She pioneered in considering the individuality of the work and focused on individual teaching, incentives, and welfare. She even dealt with how workers feel; a topic that had received little attention up to that point in time in scientific management literature. Lillian set the groundwork for further developments in modern management including the field of human relations (Des 2013; Lancaster 2004; Graham 1998).

In 1912, the Gilbreths moved to Providence, Rhode Island to work on a project with the New England Butt Company which manufactured braiding machines for shoelaces and wire insulation—one of the leading firms in this field. Lillian enrolled at Brown University intent on completing her doctorate in the area of applied management—a program of study created especially for her. She would have to do additional coursework and write a new dissertation. When completed, this second dissertation was titled "Some Aspects of Eliminating Waste in Teaching." She received the degree in 1915. Now that she had a Ph.D. after her name, her name as well as Frank's could appear on their professional papers; 50 were produced in the next 9 years. She was the first of the scientific management pioneers to earn a doctorate. And, she was now Phi Beta Kappa, having been elected an alumna of the University of California at Berkeley (Des 2013; Lancaster 2004; Gilbreth Jr 1970).

Her efforts in validating teaching (as the focus of her dissertation), even though it was women's work, was important for the work she would become known for later in her career. At her home, she established a micromotion laboratory for her experiments with women. These initial experiments involved making beds and, similarly to her Ph.D. work with teachers, would become important later in her career (Des 2013).

In 1914, Lillian and Frank started the Summer School of Scientific Management. Here, students learned new ideas about management with an emphasis on the study of motion and psychology. The school filled the need that the Gilbreths saw to teach the teachers—bridging the gap between the academic and the practical. Professors were invited to attend so that they could obtain information on scientific management and then use that material to develop courses at their home college or university. They were exposed to the theories that Lillian had espoused in her first doctoral dissertation: that the psychological element was the most important one in scientific management and that workers needed to be taught properly in order for scientific management to succeed. She addressed overfatigue from a psychological viewpoint as well as insecurity that resulted from work inconsistencies or foremen

who did not value the workers. Frank addressed the developing partnership between his motion study approach and her psychological approach: "I did not know anything about psychology until I was married, and Mrs. Gilbreth told me the courses she had taken. The new animal psychology that has been put out by Professor Thorndike and Professor Colvin has quite revolutionized the whole thing, and I believe we are going to see that the psychology in this management is the big thing." The school operated for 4 years (Des 2013; Lancaster 2004; Proffitt 1999; Yost 1949; Graham 1998; Gilbreth 1998).

She considered herself and was considered by others to be an expert in fatigue study, in the study of skill and its transference among industries and jobs, in precision in measurement, and in standardization of the work of both managers and laborers, as well as in the psychological areas (Trescott 1983). Their book, *Fatigue Study*, which came out in 1916, includes both of their names as authors and was written primarily by Lillian. A second edition was published in 1917, and it sold more copies than their other books. Many steps were recommended to improve productivity by minimizing fatigue. As much as could be individualized to the worker was seen as key—chairs, footrests, armrests, and an adjustable workbench. Additional steps to reduce fatigue included improved lighting, sensible clothes, supplies located close at hand, and regular rest periods. The book concluded: "The good of your life consists of the quantity of 'Happiness Minutes' that you created or caused. Increase your own record by eliminating unnecessary fatigue of the workers!" (Des 2013; Lancaster 2004; Gilbreth Jr 1970).

The years prior to and during World War I called on the strengths of the Gilbreths as industries and the country geared up for national defense. Believing that women would be called on to support the industrial efforts, they wrote papers on how to reorganize work and make it more efficient. Their motion study work was deemed by the press to be the Gilbreths' patriotic contribution to the country (Des 2013).

As part of their joint work, the Gilbreths showed how work could be adapted so that a disabled person could perform jobs that previously had only been considered possible for able-bodied individuals. This was particularly important in the aftermath of World War I and the many returning disabled veterans, especially amputees. It was also important to provide employment opportunities for individuals who had been injured in industrial accidents [Perusek]. The Gilbreths focused on individuals with disabilities and ways to make work environments more accommodating so that such individuals could be productive and efficient. Their work, *Motion Study for the Handicapped*, was published in 1920, after the war and after Frank had recovered from a significant illness (Des 2013).

Frank suffered his illness while he was in the Army at Fort Sill, Oklahoma. Prior to getting sick, his job was to make training films on efficient ways to conduct the business of the artillery such as loading a rifle or caring for a horse. Even in this work, Lillian was his unofficial "Advisor on the Project." She suggested ways to make the films more effective and how to deal more tactfully with officers and soldiers. When she was elected to honorary membership of the Society of Industrial Engineers in 1921, the citation recognized her contribution in this area: "acted as Consulting Psychologist in the field, working under the general Staff, standardizing

the methods for teaching the 4,000,000 officers and men" (Des 2013; Lancaster 2004).

Lillian began lecturing independently on industrial psychology and time and motion studies. Her first solo appearance was at the Massachusetts Institute of Technology in 1918—her talk was titled "The Place of Motion Study and Fatigue Study in Industrial Development." A few months later, she substituted for Frank at a meeting of the American Society of Mechanical Engineers and spoke about the use of motion study films to retrain disabled veterans. During the rest of her career, she would make hundreds of speaking appearances and occasionally broadcast on the radio (Lancaster 2004). She was also invited to lecture at universities around the USA including Stanford, Harvard, and Yale (Proffitt 1999).

During her lectures, she used the family and humorous events to illustrate her speeches:

> *In our family, we make a game out of Motion Study and we all try to see how we can cut down our own motions. This is especially important in the mornings when you have seven or eight children to get ready for school. One of my young sons insists he could improve his efficiency by at least fifty per cent, if we could eliminate baths and replace the back stairs with a fireman's pole. And a young daughter who has the job of setting the breakfast table says the One Best Way to do her job is to have everybody go out into the panty and get his own dishes and silver. Her suggestion, which was rejected by a ten-to-one vote in our Family Council, bears out what our cook and handyman says about us, I fear. He says the Gilbreth System is to get everyone else to do your work for you. (Gilbreth Jr 1970)*

1.4 On Her Own

After Frank Gilbreth dropped dead of a heart attack in 1924, Lillian had the responsibility of educating the 11 surviving children, all under the age of 19, and carrying on the business of Gilbreth, Inc. And, carry on, she did. She decided that she would work for the acceptance of the Gilbreth System and its creation of Happiness Minutes for workers and the disabled (Gilbreth Jr 1970).

She went to Europe in the summer of 1924 as she and Frank had planned and gave a talk on "First Steps in Fatigue Study." She published her biography of Frank *The Quest of the One Best Way*. She continued with the Family Councils (meetings with the children and people who ran the household) and they decided to stay in Montclair, New Jersey. She completed consultancy work for European clients. But, all was not so easy in America (Lancaster 2004).

With Frank gone, Lillian was exposed to sexism, some blatant, some more subtle. Major clients gave notice that they would not be renewing their contracts. They were not willing to have a woman—no matter her level of competence—upsetting their factories. She could not install the Gilbreth System in their plants due to her gender (Gilbreth Jr 1970).

She was paid less than Frank had been when she lectured at universities. She was turned away from venues where she was an invited guest or speaker due to their male-only rules. Although some men whom she had worked with or knew

professionally were willing to help her professionally, in general, engineers (who were almost all men) were not going to hire Lillian to install the Gilbreth system in their plants. She was going to have to use a different approach (Des 2013; Lancaster 2004).

One possibility was suggested to her by a vice president at Johnson and Johnson—she could teach at a school of motion study for Johnson and Johnson managers. Through press releases and letters, she described the course she would be offering: (Des 2013; Proffitt 1999; Gilbreth Jr 1970; Yost 1949; Graham 1998)

> *. . . to prepare a member of an organization, who has adequate training in scientific method and in plant problems, to take charge of Motion Study work in that organization. The advantage of this Course is that his understanding of both plant problems and of plant psychology usually insures cooperation and is a great assistance both in teaching and maintaining the better methods involved by the Motion Study investigation. The cost of the course is $1000. This Course can [as] desired be supplemented by a certain amount of subsequent teaching, inspection or consultation on the Motion Study problems of the organization sending the student. We also furnish reports and recommendations which are in the nature of a Survey, based upon more or less extended investigations of members of our staff. These indicate possible savings and outline methods.*

Her first class in 1925 included managers from Johnson and Johnson, Borden Milk and Barber Asphalt. The next semester students came from as far away as Germany and Japan. Motion study techniques were being taught to "disciples" of sorts and being spread around the world. She continued her classes—a total of seven courses over a period of 6 years—until she saw that engineering schools were now teaching time and motion complete with laboratories outfitted with photographic devices and movement measurement tools (Des 2013; Proffitt 1999; Gilbreth Jr 1970; Yost 1949).

Lillian knew that membership in professional societies was needed for peer recognition and she believed that membership in the American Society of Mechanical Engineers (ASME) was imperative. She wrote to the Membership Committee to determine if her application for membership would be received favorably. Although initial reaction was mixed, she lectured at several ASME technical sessions including in December 1925 when she spoke on "The Present State of Industrial Psychology." She was admitted to full membership in July 1926 (Lancaster 2004; Graham 1998; Perusek 2000). Her description of her work experience in her application for membership in the American Society of Mechanical Engineers reads:

> *I was also engaged in the perfecting of the methods and devices for laying brick by the packet method, and in the design and construction of reinforced concrete work. This work had to do with the management as well as the operating end.*
>
> *In 1914 our company began to specialize in management work. I was placed in charge of the correlation of engineering and management psychology, and became an active member of the staff making visits to the plants systematized in order to lay out the method of attack on the problems, being responsible for getting the necessary material for the installation into shape, working up the data as they accumulated, and drafting the interim and final reports. I was also in charge of research and teaching, and of working up such mechanisms, forms and methods as were needed for our type of installation of scientific management, motion study, fatigue study and skill study. These had to do not only with the handling of men, but with the simplification and standardization of the machinery and tools, for the use*

of both the normal and the handicapped. During Mr. Gilbreth's frequent and prolonged absences, both in this country and abroad, I was in responsible charge of all branches of the work. This was also the case while he was in the service, and while he was recovering from his long illness incurred therein.

Since Mr. Gilbreth's death, June 14, 1924, I have been the head of our organization, which consisted of Consulting Engineers and does work in management, and I have had responsible charge of the research, installation and the teaching, in this country and abroad. (Trescott 1983)

She began to make a name for herself in the field of industrial psychology. The editors of *Industrial Psychology* and *Iron Age* asked her to contribute articles to their magazines. Her expertise on the topic of women industrial workers had become more widespread after her participation in the Woman's Industrial Conference of 1926 and her work for the U.S. Department of Labor's Women's Bureau. Companies came to her with problems related to their women workers as well as serving women customers (Des 2013).

She secured Macy's as a client from 1925 to 1928 at a time when American retailers were desperately trying to figure out how to appeal to the female customer. Lillian's status as a psychologist and a mother led others to believe that she had the right combination of scientific thinking and intuition. Her work involved revamping the physical layout of the aisles in the New York flagship store to make it both more aesthetically pleasing and easier for customers to navigate. Her other efforts included better systems for posting and filing employee records, different light fixtures to reduce eye fatigue, padding walls to reduce noise, and eliminating duplicate recording of sales checks. She introduced procedures to reduce counting errors and to minimize the time that a customer needed to wait for change (Des 2013; Lancaster 2004).

Since management wanted to generate greater profits, an evaluation of the psychology of the female work force was very important. Lillian found that the information male researchers had uncovered in efforts before hers had not gotten to the root of the issues facing the female workers. Very little of the workers' issues related to the physical requirements of the job. Instead, they related to family burdens or social plans after the work shifts. She recommended that managers communicate with the sales clerks and endeavor to understand the wants and needs of each employee on an individual basis. She understood that how individuals related to the larger social group was also important. Although common practice today, these recommendations were unheard of at the time! (Des 2013).

Her work with Johnson and Johnson expanded. She tackled a problem that no male executive at Johnson and Johnson had been able to solve: how to develop and market sanitary napkins. Lillian was the right woman for the job! She hired female market researchers who gathered data from the targeted customers. They found out that women wanted greater comfort, protection, and inconspicuousness with a product that could be discreetly obtained and thrown away. At her home, Lillian put together a consumer testing lab analyzing the products on the market to come up with a design that met customer needs. In the end, the product that

was developed—Modess—had a slogan that was accurate and effective: "Women designed Modess. Johnson and Johnson made it" (Des 2013).

Her work at companies including The Dennison Company and Sears and Roebuck involved understanding the psychology of the female work force and undertaking time and motion studies on female employees. Companies in Belgium wanted her to assist them in understanding and motivating their employees, too. The study of women's work around the USA and worldwide became her bread and butter. By 1926, she was presenting herself as a role model on the compatibility between marriage and a career. She interwove the theme of how scientific management could make this balance possible. Her position proved very popular in the 1920s (Des 2013; Lancaster 2004; Yost 1949).

Lillian began a long-lasting relationship with the Women's Bureau of the U.S. Department of Labor in 1926. She worked with Mary Anderson, the bureau's director, in enacting protective legislation for women workers. She attended the Women in Industry conference and later served on the technical committee whose function was to research the effects of labor legislation on women's work (Lancaster 2004).

By 1926, Lillian had decided that the best way forward was to present herself as an expert on women's work. Her differentiating skills were in her concentration on the minimization of fatigue and the application of psychology—what could be termed "household engineering." Her "coming out" of sorts occurred at a conference she organized and directed at Teachers College, Columbia University in 1927. This conference was the first organized effort to explain scientific management to home economists. The home economists were impressed with the pairing of efficiency and psychology (Lancaster 2004; Graham 1998).

A significant boost to her fortunes came in 1928 when the University of Michigan made her an honorary master of engineering—the first time such a degree had been awarded to a woman by any college. Now, she had an engineering credential in addition to psychology (Gilbreth Jr 1970).

This was particularly fortuitous during and after the Great Depression. Her work in classrooms and department stores would now move to the kitchen—with her emphasis on frugality, efficiency, and psychology so relevant to those difficult economic years. Lillian used her femininity to her—and women's—advantage by bringing efficiency to women's domestic endeavors. She now undertook to systematize women's operations. By framing such innovations in the home as a matter of economic necessity (helping out American families, not solely American women), she was able to gain acceptance where others had been less successful. Out of economic necessity and the reluctance of the scientific management profession to accept her, Lillian reinvented herself as a domestic consultant (Des 2013).

Her timing was excellent—and Lillian had found a good niche. Indoor plumbing and electricity were widely available. Women were beginning to demand labor-saving appliances and efficiently designed kitchens. The days of servants were diminishing which meant the lady of the house needed to do the work herself. Refrigerators were just electric iceboxes without the shelves, drawers, and accessories that we know today—Lillian came to the rescue. What did housewives

use the most? Eggs, milk, and butter. Lillian applied therbligs and recommended putting them at a level where the housewife wouldn't need to stoop. Women did not want to open a valve to drain soapy water bucket by bucket from an electric washing machine—Lillian had the washing machine manufacturers install a pump and wasterwater hose. Voila—more Happiness Minutes (Gilbreth Jr 1970; Graham 1998).

Her decision began to pay off. In 1927 and 1928, she published two books, *The Home-Maker and Her Job* and *Living with Our Children*. In these volumes, she advised on the One Best Way to can baby food and to design a workspace. The One Best Way was communicated through radio addresses and, most successfully, through her kitchen designs. In 1929, she designed the "Kitchen Practical" (which was really the Gilbreth Motion Study Kitchen) for the Brooklyn Gas Company which was unveiled at the national Women's Exposition. Although that kitchen, to meet the needs of her client, was outfitted with gas appliances, the one for Narragansett Light Company had electrical outlets to display the company's light fixtures. She encouraged women to customize the arrangements and appliances to their individual needs (Des 2013; Gilbreth Jr 1970).

Lillian designed not only the kitchens, but also items to go with them. These included the "Door Closet" and the "Management Desk." The closet was a thin cabinet attached to the back of the kitchen door that housed mops, cleansers, and associated items for ease of access. The desk had a clock, adding machine, radio, telephone, children's reference books, and charts to allow the person to organize household chores. Homemakers and corporate men liked her designs—she designed a Management Desk for IBM for the Chicago World's Fair in 1933 (Des 2013).

Lillian saw the need for efficiency in both the home and the workplace. In fact, she (Dr. Gilbreth, internationally famous industrial engineer—as she was referred to in customer booklets) said that if homemakers would employ her recommended methods in the kitchen that they could reduce the distance they traveled in a year from twenty-six miles to nine! She recommended heights of shelves, stoves, sinks, and counters to minimize fatigue. She also advocated for splitting housework fifty-fifty (wife/husband) and her Teamwork Kitchen, with its ability to adjust for height and lengths of workspaces, actually served to accommodate women, children, and men. She designed a foot-pedaled trashcan to minimize kitchen movements. She developed electric stoves, refrigerators, and washing machines. She designed specially rigged kitchens for the American Heart Association that would benefit wheelchair-bound women and women who suffered from heart disease (Des 2013; Lancaster 2004; Gilbreth Jr 1970; Graham 1998).

A detour to politics occurred, however, along the way. An active supporter of Henry Hoover's campaign for President, she had been friends with both the President and his wife Lou Henry Hoover, who were both engineers, since their Stanford days at the turn of the century. She often was invited to events at the White House after he won the office. Lou Henry Hoover asked her to join the Girl Scouts national Board of Directors in 1930, an offer she accepted; she served until 1947. In August of 1930, Hoover put her on a subcommittee of the National Conference on Home Building and Home Ownership (Des 2013; Lancaster 2004; Gilbreth Jr 1970; Yost 1949).

Fig. 1.2 Dr. Lillian Moller Gilbreth with Colonel Arthur Woods, President's Emergency Committee on Employment, 1930. Courtesy, Library of Congress

In October 1930, President Hoover asked her to head the women's division of the President's Emergency Committee on Employment (PECE) which required her to spend much time in Washington, DC (see Fig. 1.2). Her children were quite supportive of her accepting this assignment. Lillian instituted a "Spruce Up Your Home" program where American homes who could afford "handymen" were matched with unemployed workers with the requisite skills. She mobilized nearly three million middle-class women to generate jobs. She developed a "Follow Your Dollar" campaign to encourage women to buy American goods but also to investigate the companies behind the products to ensure that they were working to stabilize employment and make work better for their employees. During this time, Lillian made Ida Tarbell's list of the "Fifty Foremost Women of the United States." She was also one of 22 women featured in a *Good Housekeeping* readers' poll to discover America's 12 greatest living women; she did not make the final cut. Following her service on PECE, she served on the President's Organization on Unemployment Relief. She left government service and returned to her non-political life in 1931 (Des 2013; Lancaster 2004; Yost 1949).

In 1932, in a radio talk, she reported (Yost 1949):

> *. . .It was heartening to find that the best thinkers in the European group agree with ours that what is needed today is not less but more planning. . . .The manufacturer must think back to his raw materials, machines and men, and forward to the distribution and use of his product. . . . The engineer has done a fine job of making things, possibly – it was felt – too good a job. That is what he was asked to do, make things as cheaply and as well as possible. The need to extend the same careful techniques to distribution and consumption should be a challenge and not a warning, and not only to engineers but to industrial and business leaders and to the consumers.*

In 1934, Lillian designed three of the rooms in "America's Little House" for Better Homes of America: the kitchen, a clothery, and a nursery. These rooms were designed to deal with "the food problem, the clothing problem, the care of the child problem, and the problem of keeping the house clean and in order." Columbia Broadcasting System was a co-sponsor of the project and she broadcast from the

house in February 1935. She investigated the correct height for kitchen equipment. A somewhat hostile magazine article said that "Dr. Lillian Moller Gilbreth does a man's job in a woman's sphere—the home" (Lancaster 2004).

After providing many guest lectures at Purdue University starting in 1924 and looking for a source of steady income, Lillian joined the Purdue University faculty in 1935 as a full Professor of Management in the School of Mechanical Engineering, the first woman to be so appointed in an engineering school. After Amelia Earhart's death (leaving vacant the position as advisor on careers for women), Lillian took over her position on the Staff of the Dean for Women. While at Purdue, she did some consulting work in addition to her university duties. At Purdue, she lectured on management engineering in all of the schools of engineering (Mechanical, Civil, Electrical, and Chemical), created a motion study laboratory, and helped set up an honors course where students worked in local industries. She was asked to retire in 1948—at the age of 70! This freed her to consult for the Girl Scouts, serve as one of two women on the Chemical Warfare Board, and serve on the Civil Defense Advisory Council under President Harry S. Truman (Des 2013; Lancaster 2004; Yost 1949).

During World War II, Lillian undertook three types of work: she served as a government advisor, as a role model to other women, and as an ergonomics expert (Lancaster 2004). She sat on the education subcommittee of the War Manpower Commission, on the education advisory committee of the Office of War Information and on the boards of the women's army and navy auxiliaries—WACS and WAVES (Des 2013). She also continued her association with the Women's Bureau. Her fingerprints are visible on a 1942 publication issued by the National Industrial Information Committee titled "Recreation and Housing for Women War Workers." The Code of Ethics for Volunteers included as Appendix B incorporates language that reads "I believe that all work should be carefully analyzed in order that work methods may be standardized. I believe that people should be studied in order to determine what jobs they can do and like to do and that, as far as possible, they should be assigned to jobs they can do well and enjoy." Her influence can also be seen in "Employing Women in Shipyards" published in 1944 that includes in its table of contents: "Select and place women carefully," "schedule rest periods," and "set up an effective women counselor system" (Lancaster 2004).

One specific example of her consulting is illustrative. The Arma plant in Brooklyn, New York had an all-male workforce of several hundred and was getting ready to hire 8000 people, including 3000 women. They were panicked and didn't know what to do about the coming influx of women. They said to Lillian "We've never had women in the shop before. We don't know how to start. We're counting on you to tell us everything we have to do to get ready for them." Her stunning reply: "If that's all my job is, I can finish it with this one sentence: Build separate rest rooms" (Gilbreth Jr 1970).

She was called upon by President Franklin Delano Roosevelt to devise work methods for crippled and female workers. Teaming with author Edna Yost, in 1944, their book titled *Normal Lives for the Disabled* was published, in memory of Frank. Lillian believed that her work for the handicapped had been her most important

career achievement as she said it had done the most good (Perusek 2000). As she lectured around the country as a psychologist and engineer, she said "The mental state of the disabled is all-important. If a person has the normal American outlook, the optimism, the belief in God, man and the future, it is a beginning." She served on committees for other Presidents as well including Eisenhower, Kennedy, and Johnson dealing with topics including civil defense and the problems of aging (Lancaster 2004; Gilbreth Jr 1970).

At the end of the postwar recession, she had numerous work assignments both in the USA and overseas. She also was well known as a scientific researcher in academic circles. Her work style was described thusly: (Lancaster 2004)

> *The pattern is always the same: first, Dr. Gilbreth has a helpful idea; next she inspires someone to start a pilot project to explore the idea. She herself stands by to help if needed. She offers few suggestions but asks many, many penetrating questions. As the pilot project develops she spreads the news, mentions it in her talks, discusses it with people who have something helpful to offer, particularly management people and generally stimulates an exchange of ideas until finally the baby project is "born" into a welcoming climate where it can grow and prosper and expand.*

From 1954 to 1958, she worked with Harold Smalley to apply industrial engineering to hospitals. In his textbook, issued in 1966, he stated "one of the most significant developments in the methods improvement movement occurred in 1945 when Dr. Lillian M. Gilbreth . . . began to urge that hospitals take advantage of the tools and techniques of industrial engineering." With Smalley, Lillian researched nursing, organization of hospital supplies and the best types of hospital beds (Lancaster 2004).

Her postwar work also extended her efforts with the disabled; her audience was now primarily "handicapped homemakers" in lieu of the "crippled soldiers" with whom she was involved after World War I. For almost 10 years, she worked in this area which she regarded as her most important contribution to motion study. She demonstrated how disabled women could perform a variety of tasks around the house including keeping house in a wheelchair, peeling a potato with one hand, and making a bed while on crutches. The Heart Kitchen, which she developed in collaboration with the New York Heart Association, was an outgrowth of the Kitchen Practical where the kitchen was fitted to the height of its occupants. She taught courses at Rutgers where students learned to place items requiring water near the sink and those implements needed for cooking near the stove. She worked with teams comprised of industrial engineers, home economists, rehabilitation experts, psychologists, and architects to build a model kitchen. Many non-disabled people would see the kitchen and wonder if it was possible for them to acquire the Heart Kitchen (Lancaster 2004; Gilbreth Jr 1970).

From 1953 to 1964, Lillian served as a consultant to the University of Connecticut. Originating from a conference she organized on work simplification for the handicapped, Lillian helped the University procure a vocational rehabilitation grant to study work simplification for handicapped homemakers. Part of the grant was the production of a movie *Where There's a Will* and Lillian appeared on camera at the beginning and end of the film. Her efforts in work simplification led to

her 1954 book *Management in the Home: Happier Living Through Saving Time and Energy*. In 1957, she was instrumental in ensuring that a conference of home economists and psychologists was organized to discuss the feasibility and contents of a course on work simplification for working women. This led to a book issued by the U.S. Office of Education titled *Management Problems for Homemakers* (Lancaster 2004).

In 1955, the University of Wisconsin named her the Knapp Visiting Professor (Lancaster 2004). She maintained a torrid pace of consulting, travel and lectures for 20 years after her "retirement"—from Purdue—until 1968 when her doctor forced her to rest (Des 2013; Lancaster 2004).

In 1952, she was described as "The World's Greatest Woman Engineer" because of "her impact on management, her innovations in industrial design, her methodological contributions to time and motion studies, her humanization of management principles, and her role in integrating the principles of science and management. Although we may be unaware today, she influenced the way we work, the way we arrange our houses, and our attitude toward time" (Lancaster 2004).

1.5 Honors and Awards

The recipient of 23 honorary degrees, her first honorary doctorate of engineering degree came from the University of Michigan—the first time a woman was so honored. The institution that had refused to grant her a Ph.D.—the University of California at Berkeley—named her its Outstanding Alumnus in 1954, while praising the work which they had refused to acknowledge earlier. In 1931, she received the first Gilbreth Medal, awarded by The Society of Industrial Engineers, "For distinguished contribution to management." In 1940, she was made an honorary life member of the Engineering Women's Club of New York. That citation read: "For your scientific achievements in the field of industrial psychology, for your pioneer work in applying these principles to the practical problems of the efficiency of human labor, for your intelligent womanhood, and for the esteem in which you are held by your fellow members" (Des 2013; Lancaster 2004; Yost 1949; Goff 1946; Chaffin n.d.).

Lillian and Frank were both honored (Frank, posthumously) with the 1944 Gantt Gold Medal: "To Dr. Lillian Moller Gilbreth, and to Frank B. Gilbreth posthumously . . . the 1944 Gantt Medal, in recognition of their pioneer work in management, their development of the principles and techniques of motion study, their application of those techniques in industry, agriculture and the home, and their work in spreading that knowledge through courses of training and classes at universities." Lillian said receipt of the Gantt Gold Medal was the best news of her life as it meant Motion Study and the Gilbreth System had been acknowledged by the arbiter of professional accomplishment—the American Society of Mechanical Engineers (Des 2013; Lancaster 2004; Gilbreth Jr 1970; Yost 1949; Goff 1946). The Western Society of Engineers presented her with its Washington Award in 1954 "for accomplishments which pre-eminently promote the happiness, comfort

and well-being of humanity" and for her "unselfish devotion to the problems of the handicapped" (Lancaster 2004).

In 1965, Lillian became the first woman elected to the National Academy of Engineering. In 1966, she received the prestigious Hoover Medal, an indication that she was regarded by her peers as having achieved the pinnacle of the engineering profession. This medal is jointly bestowed by four leading engineering organizations (Des 2013). The citation read: *Renowned engineer, internationally respected for contributions to motion study and to recognition of the principle that management engineering and human relations are intertwined; courageous wife and mother; outstanding teacher, author, lecturer and member of professional committees under Herbert Hoover and four successors. Additionally, her unselfish application of energy and creative efforts in modifying industrial and home environments for the handicapped has resulted in full employment of their capabilities and elevation of their self-esteem* (Lancaster 2004). She remained the only woman to have received that medal until 2005 (Giges n.d.).

A strong supporter of the Society of Women Engineers (SWE), Dr. Gilbreth was the first honorary member of the organization (see Fig. 1.3). Her membership

Fig. 1.3 Dr. Lillian Moller Gilbreth on the left of the head table at the 1957 Society of Women Engineers National Convention, Houston, Texas. Courtesy of Walter P. Reuther Library, Wayne State University