The Effect of Introducing Biographical Material on Women Scientists into the Introductory Physics Curriculum

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Abstract

Student attitudes toward science and scientists were measured with a survey distributed to introductory physics students in a combined class consisting of elementary education majors and general education students. For the control group of students, only the biographical material in the textbook (which was not required reading) was available to students. Brief biographical materials on women scientists were presented to the experimental group of students, and, although this material was not tested on homework or exam questions, it changed student knowledge of women scientists, and also student perceptions of scientists.

Introduction

As of 1991, only 4.6% of working scientists with doctoral degrees in physics or astronomy were women. While this is an increase over a decade earlier (3%), it actually represents a slight drop from 1989 (4.7%) (National Science Foundation, 1994). While this small decline may in fact be due to improvements in the sampling method, the data clearly argue against a rosy picture of a steady increase in women's participation in physics and astronomy. These numbers still lag far behind the percentage of doctoral sciences in all disciplines that are women (22%) and come nowhere near approaching the percentage of women in the general population.

The reasons for this underrepresentation are probably many and complicated. Hedges and Nowell (1995, and references therein) have recently presented evidence of sex differences in intellectual abilities, which could be associated with sex differences in occupational status, however, even these authors allow for the possibility that the differences in test scores that they document may arise not from inherent differences but from differences in experience, stating "If, as seems likely, differences in ability arise because of differences in experience and socialization, more work is needed to document that these differences exist and are linked to ability." There is also a possibility that earlier reports of such differences (Benbow & Stanley, 1980) could themselves have promoted a gender difference in entry into science and engineering (Brush, 1991, and references therein.)

There can be little doubt that there are differences in the experiences of male and female students in the United States, both in their selection of courses, their treatment by teachers, and in the images and role models presented to them by American society (American Association of University Women (AAUW),1992; Brush, 1991). Further, while it has yet to be definitively documented that such differential experiences result in differences in ability, teacher expectations (Jones & Wheatley, 1988) and stereotype vulnerability (Steele & Aronson, 1994) have been shown to affect test scores. Previous work indicates that intervention at the elementary level, where some of the students in this study will eventually be teachers, can change fourth through sixth grade girls' attitudes toward careers involving science and engineering (Marshall & Buckingham, 1995).

In fact, increasing the availability of female role models, particularly the inclusion of material on female scientists in introductory textbooks, has been widely suggested as a remedy to women's underrepresentation (AAUW, 1992; Jones & Wheatley, 1988; Rosser, 1990). Further, while some would argue that increased inclusion of the work of female scientists is actually a misrepresentation considering their historically lower participation, it is often the case that women's *achievements* are discussed, even held up as pivotal accomplishments, without the women themselves being mentioned in association with their work (Brush, 1991).

A glaring example is the work of Inge Lehmann in determining the structure of the Earth's core. Although the work is highlighted in both introductory physics texts (for nonscience majors) and both introductory astronomy texts used at Utah State University in the last four years (one text even includes a redrawing of the figure from her original paper) Lehmann's name is not mentioned in any of these books. Neither is Vera Rubin mentioned in conjunction with dark matter or the velocity curves of galaxies, nor Margaret Burbidge mentioned in conjunction with nucleosynthesis. Only three women scientists or engineers (Marie Curie, Lise Meitner, and, as an aside, Irène Joliot-Curie) are mentioned in

one physics text and two in the other, compared with 71 men in the first case and 118 men in the other.

Furthermore, no woman scientist is mentioned among the examples of ongoing work in those texts. This might present an even grimmer picture of women's participation in science by making their inclusion seem to be "tokenism", what has been described as Phase (2) of Peggy McIntosh's interactive phases of curriculum development (McIntosh, 1984). Astronomy texts tend to do a better job generally (perhaps due to the high percentage of women in astronomy early in this century (Dobson & Bracher, 1992), but no book in a recent comprehensive survey of 55 astronomy books mentioned each one of ten famous women astronomers (Larsen, 1995).

Thus, the exclusion of women scientists in the physics curriculum poses an equity issue, but does it have an additional impact in depriving female students of role models? Would the inclusion of biographical material on women in science, in and of itself, have an effect on female students' attitudes toward physics, and perhaps thus an affect on their participation rate in physics and astronomy? There is certainly anecdotal evidence that biographical material on women scientists has had an influence on some women's decisions to enter science. Nobel Laureate physicist Rosalyn Yalow describes Eve Curie's biography of Marie Curie as having had a tremendous influence on her desire to be a scientist (National Institute of Mental Health, 1992). News of Yalow's award, as well as a personal introduction to Chien Shiung Wu, were tremendously influential to one of the authors (JM) at a time when her own commitment to continuing a career in physics was in question. But, as pointed out by Plucker (1994), it must be acknowledged that the effectiveness of such an intervention on the wider population of female students has not been evaluated; nor has the effect of such inclusion on male students been considered, although some "female-friendly" interventions have been shown to be an improvement for students of both sexes (Rosser & Kelly, 1994)

The goal of this work was to provide a quantitative assessment of the effect of expanded inclusion of biographical material on women scientists in the introductory physics curriculum on the attitudes of elementary education majors and general education students, in effect, to answer the question posed by Plucker (1994): Does a lecture on a woman scientist and her work once a month have a significant impact upon student perceptions? Specifically, the authors examined whether the materials had an effect on whether students' descriptions of scientists became more gender neutral after presentation of the materials.

Method

The general physics survey course for elementary education majors and the general education introductory physics course are taught with a combined lecture at Utah State University, the only difference between the two courses being that the survey course has a required laboratory component. These courses seemed particularly appropriate for an evaluation of the effectiveness of biographical material on women scientists because (1) these classes have a higher percentage of female students than the introductory physics classes for science, engineering, and other technical majors, (2) these students are generally less self-selected for a previous interest in science, and (3) a change in attitudes of future teachers is particularly important as it is likely to have a cascading effect on the attitudes of their future students.

During the Fall, Winter, and Spring quarters of the 1995-96 academic year, the combined course was taught by the one of the authors (JM). During the Fall and Winter quarters, active inclusion of biographical material on women scientists was not pursued; however, the instructor's own previous research was mentioned briefly at one point in each quarter. The presence of a female physics instructor during these quarters and her use of gender neutral language and examples (such as the use of 'he or she' and alternating male and female characters in problems) must, unfortunately, be considered as an active intervention, considering that these are not the norm in physics classes. Therefore, data were also obtained during the summer quarter for comparison. During the summer of

1995 and 1996 the course was taught by a male graduate student with no particular training in gender-neutral teaching behaviors.

During Spring quarter 1996, material on 14 women scientists (four currently engaged in research), was presented to the class during the lecture hour. A short (five-minute or less) biographical sketch on each woman was presented orally by the instructor in conjunction with the curriculum unit that best matched the woman's area of expertise. The woman's name was displayed on an overhead projector and, in all but two cases, a photograph of the woman was shown. In all cases, a connection was drawn to curriculum area currently under investigation by the students. The women were selected for the immediate applicability of their work to the curriculum and the availability of biographical material on them. The featured women are listed in Table 1, along with their areas of research and the curriculum units in which they were presented. Appendix B gives brief biographies of the featured women scientists.

Table 1

Featured Female Scientists

Scientist/Engineer	Research Area	Curriculum unit
Caroline Lewis	peculiar cosmological velocities	Motion
Mary Somerville	popularization of science, magnetism	Newton's Laws
Emmy Noether	abstract algebra, symmetry laws	Relativity
Caroline Herzenberg	nuclear emergency preparedness	Energy
Hengemeh Karimi	nuclear engineering	Energy
Inge Lehmann	geophysics, internal structure of the Earth's core	Waves
Frances Hellman	giant magnetoresistance, small-sample calorimetry	Magnetism
Edith Clarke	circuit analysis	Electric Circuits
Melissa Franklin	particle physics (top quark)	Atoms
Marie Curie[a],	radioactivity	Radiation
Irène Joliot-Curie[a]	induced radioactivity, transuranics	Radiation
Lise Meitner[a]	fission	Fission
Maria Mayer	shell model of the nucleus	Nucleus
Leona Libby	Manhattan Project	Controlled fission

(a) mentioned in text

For comparison, an equal number of male scientists (all of whom were mentioned in the text) were highlighted in the lecture over the course of the quarter, generally with a photograph. These included Aristotle, Galileo, Isaac Newton, Benjamin Franklin, James Joule, James Watt, Alessandro Volta, J.J. Thomson, Ernest Rutherford, Enrico Fermi, Albert Einstein, Louis DeBroglie, Niels Bohr, and Werner Heisenberg.

In addition, one of the featured scientists (Melissa Franklin) presented a guest lecture on the discovery of the top quark to the class during the lecture hour, and a segment from a movie on Marie Curie was shown. The material on women scientists was not, however, included in test or homework problems, with the exception that one problem on the final exam asked students to address the question of how the internal structure of protons came to be known. Particular attention was not drawn to the biographical material as related to the survey (one survey question asked students to name a famous female scientist.)

Student attitudes were measured using a researcher developed survey. The complete survey instrument is given in Appendix A. The survey was administered to all students in the combined physics classes from Summer Quarter, 1995 through Summer Quarter, 1996. Group membership was

determined by the academic quarter in which the student enrolled in the introductory physics course. Students were instructed not to research answers to questions on the surveys, but rather to record their own initial responses. All surveys were completely anonymous, allowing students latitude to express attitudes that they might feel to be at variance with those of the instructor more freely. All data were interpreted and coded by the same individual and verified by a second reader.

To assess the degree to which the biographical materials effected student awareness of women scientists, pre- and post-course survey data collected prior to the introduction of biographical materials were compared with similar data collected after the materials were introduced (Winter Quarter 1996 precourse N=124, post-course, N= 111; Spring Quarter 1996 precourse, N=93, post-course, N=89). The authors examined both between and within group differences to ascertain whether the observed change in one group could be explained by sampling error.

To assess the degree to which gender of the instructor may have influenced post-course survey results, data from the two quarters taught by the male graduate student (N=45) were compared with similar data from Fall Quarter, 1995. Survey reliability was measured for the questions which showed the largest variation in response between target and non-target groups.

Results

Several survey questions addressed students' perceptions of scientists. Question 4 asked students to describe a typical scientist, Question 6 asked students to list three famous scientists and their achievements, and Question 9 asked students to list a famous female scientist. With the introduction of the biographical materials on women scientists, one would certainly expect the number of students able to name a famous female scientist to increase, and it did. Among the control group, the number of students who could not name one female scientists actually rose from the beginning of the quarter (41.9%) to the end of the quarter (48.6%), possibly due to attrition in the class. Among the experimental group, this percentage dropped from 57% to 18% after the introduction of the biographical materials. Further, the number of students who could name a female scientist other than Marie Curie dropped slightly in the control group (16% to 14%) but rose in the experimental group (10% to 14.4%)

The response to Question 6 is perhaps more telling, in that this question asked students to name a famous scientist without specifying a gender. Responses to Question 6 indicate a substantial increase in the experimental group's listings of at least one female scientist when the question did not specify a gender. Table 2 lists frequencies of students' listing at least one female scientist in response to Question 6 at the beginning and end of the quarter for the control and experimental groups.

Table 2

Number of Students Listing at Least One Female Scientist

	Control	Experimental
Pre-Course	9 (7%)	6 (6.5%)
Post-Course	13 (10.5%)	49 (55%)

Another interesting difference in the response to Question 6 was that students in the experimental group listed more contemporary scientists as opposed to famous old scientists. In tallying the responses, Albert Einstein, Galileo, Darwin, Alexander Graham Bell, and Louis Pasteur were considered famous old scientists. Table 3 shows the frequencies of listing only members of that group vs. at least one other scientist for the control and experimental groups.

Table 3

Frequency Comparisons of Listed Famous Older Scientists Only

	Control	Experimental
Pre-Course	62 (50%)	77 (83%)
Post-Course	58 (52%)	33 (37%)

(Chi-square<.01)

Responses to Question 4 also indicated a shift in thinking about scientists. At the end of the quarter, the experimental group showed a larger change toward describing scientists in terms of their work and collaborative capabilities than did the control group (although the numbers in each case were too small for statistical analysis.)

A comparison of post-course data from sections taught by different instructors (one male, one female) to assess the degree to which the sex of the instructor effects differences in responses to survey questions indicated that it is unlikely that the sex of the instructor explains observed differences between groups (chi-square > .05). Comparison of responses sorted by gender saw no significant differences between male and female students' responses to questions discussed here.

Discussion

Results from this investigation indicate that introduction of minimal biographical materials in introductory physics may increase student knowledge of contemporary women scientists and their contributions to science and engineering. Further, the introduction of such materials, at least in this instance, appeared to change student perceptions of science as a strictly male endeavor in that they thought more often of female scientists when asked to name a scientist. The results also indicate that the gender of the instructor did not, in and of itself, explain these changes. These findings have implications for university faculty and textbook authors. If we want to associate scientific knowledge with the individuals recognized as responsible for that knowledge, we must acknowledge those contributions in an equitable fashion. Textbooks that acknowledge the importance of a scientific theory without recognition of the contributor(s) must be supplemented by the course instructor.

It is interesting to note that a significant change in student perceptions was brought about by a very minimal inclusion of material on women scientists. As a continuation of this work, we plan to investigate the effect of including copies of the biographical sketches in course notes to be distributed to all students. As stated earlier, students were not questioned on this material on homework or on exams. Perhaps, as suggested by Scantlebury (1994), a larger effect could be obtained if information on women scientists is included in homework or exam problems. In the future this will be done, and identifiers will be added to the survey so that performance (grades on exams) can be correlated with changes in attitudes.

Acknowledgments

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Appendix A: Survey Instrument

Your major________________________-
Your status: FR SO JR SR
Sex: M F
Class: 101 120
Age______________
What grade do you expect to make in Physics 101/120?______

1. Rank the following from 1(most important)-to 5 (least important) for a well-rounded citizen.
___Communication skills (reading and writing)
___Knowledge of civics and government
___Critical thinking or logic skills
___Technical knowledge (science and math)
___Knowledge of history and culture (social studies)

2. Do you consider science to be
a. not at all important
b. a little bit important
c. necessary, of substantial importance
d. critical, of extreme importance

3. Check how you feel about the following topics.

	not interested	somewhat interested	very interested
nuclear power			
space exploration			
radiation			
black holes			
time travel			
new kinds of atoms			

4. Describe a typical scientist.

5. What do you consider to be the characteristics of a good scientist?

6. List 3 famous scientists and tell what contribution each made.

7. What is the most important contribution that science has made to your world today? What is the most important problem in our world today that could be solved by science?

8. What is the biggest problem caused by science in our world today?

9. Name a famous female scientist and tell what contribution she made.

10. What percentage of students do you think should be encouraged to take advanced math classes (such as calculus and trig) and science classes (such as chemistry and physics) before they graduate from high school?

11. What do think is the most important aspect of science that an elementary school teacher can communicate to his or her students?

For those of you planning to be teachers, has Physics 101/120 changed the way you plan to teach science in your classroom or the amount of time you plan to spend teaching science?
a. Not at all
b. Perhaps slightly
c. Somewhat
d. definitely

Appendix B: Biographical Sketches

Caroline Lewis: Caroline Lewis was born in Canada, but grew up in Trinidad; she traces her interest in astronomy to "those wonderful tropical night skies." She received an undergraduate degree with

combined honors in physics and astronomy from the University of British Columbia and a Ph.D. in Physics in 1990 from the University of Texas at Austin. Her thesis work was on 'peculiar' cosmological velocities, that is, velocities of galaxies that deviate from the overall expansion of the universe by moving faster, slower, or in a different direction than prescribed by the Hubble Law. Her most recent interest turns from the cosmological to the microscopic, investigating quantum mechanical effects on the human nervous system as they relate to consciousness. She is also an avid dancer and a member of a Polynesian dance performing group. Her work was mentioned in association with a discussion of how an estimate for the age of the universe is calculated from the Hubble Constant.

Mary Fairfax Somerville (1780-1872): Although she received little formal education as a child, Mary Somerville taught herself Latin and later algebra. She and her second husband became part of a circle of amateurs and professional scientists that included some of the best-known names of the day. Although she published some of her own research into magnetism and the solar spectrum, Somerville won widest acclaim as an expositor of science for the public. She studied Newton's *Principia* and Laplace's *Mècanique Cèleste*, providing the first English translation of the latter, complete with added diagrams, explanatory notes, and details of calculations not provided by the author. With her additions, *Mechanism of the Heavens* became a standard textbook in mathematics and astronomy. Following that success, she published two additional books that became best sellers and standards*: On the Connexion of the Physical Sciences* and *Physical Geography.* Her work was highly influential, not only on the public, but on scientists of her day. It was a question she posed in *Physical Sciences* that led John Adams to compute and correctly predict the orbit of Neptune based on variations in the orbit of Uranus, leading to the discovery of the ninth planet. (Alic, 1986; Ryden, 1990)

Emmy Noether (1882-1935) :Although her father was a professor of mathematics at a university, Amalie Emmy Noether could not officially received training in science or math as a young woman in Germany. Instead, she trained to become a language instructor for girls, but at 18, she chose not to begin teaching, but to audit classes at the University of Erlangen instead. Finally, in 1903, she was allowed to take, and passed, the university entrance exam, and in 1904 she enrolled officially and began to study mathematics, eventually receiving her degree. She continued at Erlangen, working with her father, and eventually taking over his duties, unpaid. In 1916, David Hilbert and Felix Klein invited her to join them at Göttingen, where she went on to help in the mathematical formulation of Einstein's theory of general relativity. She continued at Göttingen, finally being allowed to join the faculty officially after World War I, and there she made her greatest contribution to theoretical physics: Noether's theorem, which states that if there are symmetries in the mathematics that describe a process, there will be conserved quantities, such as the total energy, that will remain constant throughout all time, and regardless of how the process evolves. The search for these symmetries occupies much of the effort of theoretical physicists today. Noether also made major contributions to mathematics, founding the entirely new discipline of abstract algebra and working in group, ring, and number theory. Unfortunately for Noether, there was little appreciation for "Jewish mathematics" or for women professors in Nazi Germany, and she was forced to leave the university in 1933, along with Edward Teller and Max Born. She continued to teach illegally from her apartment, but eventually had to flee to the US, where she taught at Bryn Mawr for two years until she died suddenly from complications from an operation. (McGrayne, 1993)

Caroline Littlejohn Herzenberg (1932-). A native of New Jersey who grew up in Oklahoma, Caroline Littlejohn received a BS in physics from MIT in 1953, and an MS (1955) and Ph.D. (1958) from the University of Chicago, where conducted her thesis research in Samuel K. Allison's laboratory, and met Maria Goeppert Mayer. Both Allison and Mayer was very supportive of the graduate students, and Mayer invited Caroline to a dinner at her house. After graduation, Littlejohn did heavy ion studies at the University of Chicago and pioneering research in the Mossbauer effect at Argonne

National Laboratory, where she works today; she later used the Mossbauer effect to analyze lunar samples in the Apollo program. In 1961 she married Leonardo Herzenberg, an engineer who worked on the development of one of the early scientific computers at the University of Chicago, and later worked with Microswitch Division at Honeywell, Inc.; they have since had two daughters. Herzenberg currently uses her nuclear physics expertise as an expert in the evaluation and analysis of environmental, energy, emergency management, technological, and institutional systems from a multi-disciplinary perspective. She specializes in radiological emergency preparedness and chemical demilitarization. In addition, Herzenberg has become an expert in the history of women scientists who worked on the Manhattan Project. She has published several books and articles on women scientists from antiquity to the present.

Hengemeh Karimi (1958-). Hengemeh Karimi was born in Iran to a family that stressed the value of education; her mother was a school principal. Growing up she loved physics, because, as she says, "You can see physics in everything: in medical applications, in the opening of a door, in the blowing of the wind." She chose to study nuclear physics in college because it had the glamour of the unknown, a gray area where everything was not yet well understood. She attended college in the US, receiving a BS from Iowa State, and an MS from the University of Washington at Seattle. She changed her emphasis from nuclear physics to nuclear engineering after a summer internship in her native Iran, where she could she a more pressing need for applied engineering knowledge as opposed to theoretical research. Her plans to help her country modernize were interrupted by the revolution in Iran, and she never returned there to work. Since graduating, she has worked in the US, specializing in environmental applications of nuclear engineering. She is currently at Southwest Research Institute in San Antonio, Texas, investigating the feasibility and safety of the proposed Yucca Mountain national nuclear waste storage site, the possibility of reclaiming waste uranium, and ways of cleaning up the reactor site at Hanford, Washington.

Inge Lehmann (1888-1993): attended the first coeducational school in Denmark, where, as she later noted, “No difference between the intellect of boys and girls was recognized, a fact that brought me disappointments later in life when I had to realize that this was not the general attitude.” She went on to graduate from the University of Copenhagen in mathematics and physical sciences in 1925. She entered the field of seismology, and, although she did not have a doctoral degree, was Chief of the Seismological Department of the Royal Danish Geodetic Institute from 1925 till 1953. In 1936, she made her most important contribution by analyzing earthquake waves to conclude that the Earth’s core actually consists of two layers, a solid inner core surrounded by a liquid outer core. She realized that the so-called P'_3 waves that reached the Copenhagen Seismological Observatory from earthquakes in the Pacific had been reflected from a sharp discontinuity (the solid-liquid boundary) within the core, whose existence had been previously determined based on waves that appeared to have been refracted or bent at the interface between the core and the mantle. (Bolt, 1982)

Frances Hellman (1956-). Inspired by a female pediatrician, as a child Frances Hellman planned to be a doctor. In high school she had summer jobs in medical labs, but then, in her junior year, she took a physics course, from a good woman teacher, that changed her mind. By this time, she was also a nationally ranked ski racer, spending much of her time in Vermont, so she also had a physics tutor, who introduced her to the some of the more exciting aspects of physics, black holes and relativity, that are usually reserved for only the more advanced courses. She went to Dartmouth, considering a career in astrophysics. When faced with the rigors of the introductory course there, she again found encouragement from a teacher, a professor who told her that she “asked all the right questions,” even if she did not have the background that other students had. In 1985, she arrived at Stanford University as a graduate student in Applied Physics, still hobbling from a sky diving accident. At Stanford, she studied thin-film superconductors, measuring their heat capacity with miniature systems, and

researching how the thin films develop on the microscopic level as they are deposited. She did postdoctoral research at Bell Labs, where she studied magnetic materials, and then took an assistant professorship at the University of California at San Diego, where she is now tenured. She is still making heat capacity measurements on small samples, only thousands of atoms thick, and is starting a project to develop a way to measure heat transfer within muscle cells. She rarely skis now, but is an avid soccer player, and holds half-season tickets for the San Diego Padres, in addition to working a 70-hour week teaching and doing research.

Edith Clarke (1883-1959). The product of a wealthy Maryland farming family, Edith Clarke was fortunate to have had an elementary school teacher who taught her algebra and geometry, so that even though girls of her class at that time were not generally educated in preparation for a career, she had an excellent mathematics background. At eighteen, she spent her inheritance on college tuition at Vassar. After graduation, she taught mathematics and for several years, and then enrolled at the University of Wisconsin in civil engineering. A summer internship as a "computer" with AT&T in New York sidetracked her and she stayed on doing laborious calculations that were done by hand (often women) in the days before electronic calculators and computers. Her major contribution to engineering would be the development of methods that simplified these calculations and allowed more advanced analysis of electrical power systems. In 1918, Clarke enrolled at MIT, completing a degree in electrical engineering, the first awarded by MIT to a woman, that same year and a masters the next. Unfortunately, with the end of World War I, the need for engineers had diminished, and Clarke was unable to find a job in her field upon graduation. She went to work at General Electric as a computer. She took a leave of absence in 1922 to travel in Europe and teach at a women's university in Constantinople. On her return, GE at last made her an engineer. In 1925, she received her first patent, for a graphical calculator. She worked at GE until her retirement in 1945, introducing analytical methods to power engineering. She became the first female fellow of the organization that became the Institute of Electrical and Electronics Engineers in 1948. She published a two-volume reference book, *Circuit Analysis of AC Power Systems*, which was widely used after World War II. She was called out of retirement in 1947 to become the first female professor of electrical engineering at the University of Texas at Austin, where she taught until 1956, when she retired again to join her nephew on his farm in Maryland. (Gusen, 1995)

Melissa Franklin: (1957-) After dropping out of high school to help found an alternative school, and then dropping out of that, Melissa Franklin wound up as a physics major at the University of Toronto. She following that with graduate school at Stanford University, postdoctoral work at the University of California at Berkeley, and a position in Harvard's Physics Department, where she became the first tenured female professor. Franklin specializes in the building and operation of detectors for high energy particle physics. She was the leader of the Harvard contingent at the Collider Detector at Fermilab, the experiment that in 1995 found the last unobserved particle in the standard model (of the construction of matter) in physics. Franklin is an experimentalist's experimentalist, who loves hardware, especially the big machines, the accelerators of high energy physics. When asked what she liked best about her work, she once responded, "Driving the fork lift." Franklin is also an accomplished jazz saxophone player and disc jockey. She has her own radio show in Canada. (Public Broadcasting System, 1995; Freedman, 1995)

Marie Sklodowska Curie (1867-1934): Almost without a doubt, Marie Curie is the most famous woman scientist. She was not only the first woman to win a Nobel Prize, and the only person to win two Nobel Prizes in physical science, but the founder of a dynasty in nuclear physics. Her daughter and son-in-law also won a joint Nobel Prize in physics. As Marya Sklodowska, she began to study physics at the University of Paris, where she met and married Pierre Curie, already a well-known physicist. In the course of her graduate work she discovered that the element thorium, like the previously known

uranium, was 'radioactive', a word she herself coined. Pierre Curie left his work on electrical properties of crystals to join her research, and they went on to discover several new elements (polonium, radium, and actinium). But it was Marie Curie who came to the all important conclusion that heralded a new age in physics, that radioactivity is a *nuclear* property, originating in the nucleus of the atom, and not a chemical one, governed by the electrical force between the nucleus and electrons, or between atoms. Although sometimes notorious in France, Marie Curie was widely popular in the United States, especially among women, due to the belief that the radiation she had discovered might hold the key to curing cancer. (McGrayne, 1993)

Irène Joliot-Curie (1897-1956): In 1914, at the age of 18, Marie and Pierre Curie's daughter Irène went to war, installing x-ray equipment in field hospitals and training military personnel to use it. At the end of World War I, she returned to Paris to become her mother's assistant at the Radium Institute. In 1925 she received her doctorate degree for a study of alpha particles (helium nuclei) emitted by polonium, an element her mother had discovered. She went on to collaborate with Frèdèric Joliot, whom she married, in an investigation of extremely energetic particles emitted by beryllium that had been bombarded with alpha particles. They mistakenly identified the energetic particles, which the Joliot-Curies were able to show to be powerful enough to eject protons from paraffin, as a new form of gamma rays, but Chadwick, at the Rutherford lab repeated their experiment and correctly identified the particles as neutrons. The Joliot-Curies missed another opportunity for a Nobel Prize when they observed, but incorrectly identified positrons. Their luck changed in 1934 when they were able to demonstrate that aluminum, normally a stable nucleus, could be made radioactive when it was bombarded by alpha particles. This result had tremendous significance because it provided an artificial source of radioactive material; previously studies of the nucleus had to be carried out with naturally radioactive materials obtained with great effort and expense. Marie Curie had worked four years to isolate less than one gram of radium from two tons of pitchblende. The discovery won the Irène and Frèdèric Joliot-Curie the Nobel Prize in 1935. Irène missed her chance at another Nobel Prize in 1938. Frèdèric having left the Radium Institute to set up his own laboratory, Irène worked with another chemist, Paul Savitch, studying the products of uranium bombarded with alpha particles. Although they correctly identified fission products, they were unable to reconcile their results with known physical laws. In Germany, Otto Hahn reached a similar impasse, but Lise Meitner was able to explain his results, and win him the Nobel Prize for the discovery of fission. After World War II, Irène continued her research, but became increasingly more involved in politics, espousing peaceful uses of nuclear energy, increased governmental support of basic research, and women's rights. (McGrayne, 1993)

Lise Meitner (1878-1968): In 1907, Lise Meitner left Vienna, where she had earned a doctorate in physics, and joined the University in Berlin, under the direction of Max Planck, one of the founders of quantum mechanics. There she began a collaboration with Otto Hahn, a chemist. In 1912, the two moved to the newly-founded Kaiser Wilhelm (now Max Planck) Institute, where Meitner received a paid assistantship. During World War I, she carried out an experiment, with the consultation of Hahn (who was away doing research on chemical weapons) that identified the parent element of actinium, a new element they called protactinium. After the war, the collaboration ended and Meitner went on to become the head of the radiophysics department. For twenty years, her lab was equal in prominence to the Curie and Rutherford laboratories. In 1934, Meitner persuaded Hahn to renew the collaboration: she wanted to explore Enrico Fermi's recent claims of having created elements larger than the largest naturally occurring element, uranium, by bombarding uranium with neutrons. Although Hahn was no longer active in nuclear physics, she needed his radio chemistry expertise in identifying the products of the interaction. Unfortunately, before the work could be completed, Meitner was forced to leave Germany, first for Denmark via the Netherlands, and finally for a position in Sweden. As a woman scientist and a Jew, she would have almost certainly been arrested had she stayed in Germany. In

Sweden, however, she had no equipment, and was essentially unable to work. She continued to direct Hahn in their experiment in Berlin, and was able to make the breakthrough that had evaded Enrico Fermi and Irène Curie. On December 30, 1938 Meitner received a letter from Hahn, stating that he had unequivocally identified barium, a nucleus smaller than that of uranium, as a product of their uranium experiment and would publish the result. Within hours Meitner came to the conclusion that the uranium nucleus had split: they were observing nuclear fission, which would be the power source for nuclear energy for the rest of the century, and the basis for the atomic bomb. Meitner performed the calculations to predict the other byproducts and published the full explanation in a paper that appeared weeks after Hahn's, which had included no explanation. Hahn would eventually receive the Nobel Prize for this work, and give little credit to Meitner. She remained in Sweden, continuing to do research, until she retired in 1960. (McGrayne, 1993; Sime, 1996)

Maria Goeppert Mayer (1906-1972): The daughter of a professor, Maria Goeppert was raised in the German university town of Göttingen, where she eventually became one of the first women to study physics at the university. With Max Born, one of the founders of quantum mechanics as her adviser, she completed a Ph.D. thesis on the probability that an electron will emit two photons, rather than one, as it jumps to a lower energy level in an atom. having married Joe Mayer, an American student in Göttingen, she returned with him to the United States in 1930, where she did the work of an unpaid professor at Johns Hopkins University. Together with Joe Mayer, she published a very popular textbook, *Statistical Mechanics*. After nine years at Johns Hopkins, Joe lost his professorship and the Mayers moved to Columbia University, where Maria was able to obtain a minor teaching position and did wartime research on an alternate method of separating fissionable from non-fissionable uranium isotopes. She also worked for a short time on the hydrogen bomb at Los Alamos. After the war, the Mayers moved to the University of Chicago, where Maria again had an unpaid position, to work with Enrico Fermi. She eventually took a part-time paid position at Argonne National Laboratory, where she worked out her shell theory of the nucleus, which won her the Nobel Prize in 1963 along with Hans Jensen, who independently developed the same idea. This theory, which describes the arrangement of nucleons (protons and neutrons) in terms of layers, or shells, similar to those of electrons orbiting the nucleus, successfully explained why some nuclei are much more stable than others. (McGrayne, 1993)

Leona Woods Libby (1919-1986) As a graduate student in chemistry, Leona Woods worked with Enrico Fermi at the University of Chicago. Upon graduation in 1942, she was called to participate in the Manhattan Project for her expertise in neutron detectors. She was present at the first controlled nuclear chain reaction at the University of Chicago stadium. In 1943 she married and became pregnant, but continued to work on the project after it moved to Argonne, measuring the neutron absorption capabilities of various materials that would be used at Los Alamos (Enrico Fermi had asked for instructions on how to deliver a baby, in case the need arose at the lab.) She and her husband, John Marshall, then moved to the Hanford reactor works in Washington, to help with the start up of the plutonium reactors there, and eventually followed Fermi to Los Alamos, where she was present for the Trinity test detonation of the atomic bomb. She and Marshall eventually divorced, and she remarried to Bill Libby, another Manhattan Project scientist. (Libby, 1979)