Women and Minorities in Mathematics

Incorporating Their Mathematical Achievements Into School Classrooms

Florence Nightingale, the Passionate Statistician

Jill T. Richie
Sarah J. Greenwald
Appalachian State University
Boone, North Carolina

Most American schoolchildren are familiar with the legend of the "Lady with the Lamp." Florence Nightingale's contributions to statistics are less well-known than her nursing career, but they are still highly noteworthy (Spiegelhalter, 1999), since much of her celebrated success in nursing reform would not have been possible without them. In addition, not until the middle of the twentieth century would there be another woman statistician who achieved a similar level of recognition and influence as Florence (Salsburg, 2001). Incorporating her mathematical achievements into the classroom can be especially rewarding because, unlike many other women mathematicians, students are already familiar with Florence. Examining her mathematics in the context of her other achievements also provides a rich arena to highlight connections to other subject areas.

During the Crimean War, Florence Nightingale revolutionized the profession of nursing. She and her nurses dramatically raised standards of patient care, including sanitation and nutrition, which drastically reduced deaths from infection and disease in military hospitals. Her efforts inspired noted author Henry Wadsworth Longfellow to create a poem that cemented her image as "the lady with the lamp" (Dossey, 2000).

Florence realized that the problems she found in Crimea were not limited to wartime hospitals. Armed with statistical data she had collected, Florence turned her attention to large-scale reforms of public health. It was Florence's devotion to the systematic collection and vivid presentation of data to further social change that led her biographer Sir Edward Cook to dub her the "Passionate Statistician" (Cook, 1913).

Florence's Early Life

Florence Nightingale was born in 1820 in Florence, Italy, to wealthy British parents. The Nightingales were among the "upper ten thousand"; the economically and socially advantaged segment of society that ruled England. Both she and her sister Parthenope were thoroughly schooled in reading and writing by their governess. At seven years of age Florence was already a prolific and keenly observant letter-writer; by the age of ten she had written her own autobiography, in French. She was also noted in her family for compiling very detailed lists of nearly everything around her, many of which appeared in her journals and letters.

Beginning at age twelve, Florence was educated by her father William Nightingale. As devout Unitarian, her father rejected the contemporary philosophy that women were too fragile for the rigors of higher education. Florence studied history, politics, ethics, mathematics, philosophy, and composition. She also had a particular aptitude for languages, becoming fluent in Latin, Greek, French, German, and Italian. At the same time, young Florence learned all the manners and household skills expected of privileged Victorian girls. She was formally presented to the Queen Victoria in May 1839 (Dossey, 2000).

Florence's studies under her father were equivalent to a Cambridge college education (Dossey, 2000). At the time, only men were allowed to attend. When she was twenty, she had reached the limits of William Nightingale's mathematical ability (Diamond and Stone, 1981). Her insistence on further instruction from an outside source was met with resistance from her mother. Here Florence got support from her Aunt Mai, who located willing, educated tutors for her niece. One was James Sylvester, who is noted in mathematics for developing the theory of invariants with Arthur Cayley (Stinnett, 1990). Florence learned algebra, geometry and arithmetic, which she in turn taught to several children before starting training as a nurse (Lipsey, 1993).

Along with her mathematical tutoring, Florence conducted a self-guided course in social and health statistics. The creation of the first public register of births, deaths and marriages (when Florence was seventeen) by the General Registry Office was an unprecedented event that made social statistics a popular topic for conversation (Florence Nightingale Museum Trust, 2003). Prior to this, such records (if they existed) were usually in the hands of local church parishes. Florence also studied hospital blue books and any other data she could obtain. One of her most ambitious projects, done in 1953, was to gather her own data by sending questionnaires to hospitals regarding health administration, which she then laboriously analyzed (Diamond and Stone, 1981).

Florence the Nurse

In nineteenth century England, nursing was not considered a suitable profession for respectable women. Nonetheless, feeling called by God, Florence pursued it. When she was 29, she rejected a marriage proposal from her longtime suitor Richard Monckton Milnes. Unfortunately, despite progressive attitudes about education, her parents still felt marriage was necessary for a woman of their class, and they turned deaf ears to her request to study nursing. Two years later, a meeting with Elizabeth Blackwell, the first woman to earn a medical degree in the United States, caused Florence to reassert her position. She was finally permitted to go to Germany for training (Dossey, 2000).

Florence became the head of a charitable hospital for sick gentlewomen. Women of Florence's class were expected to perform volunteer service, and the clients of the home were women from good families. During this period her social connections let her meet and interact with doctors who were on the forefront of medical innovation. Among them was John Snow, who used the new Registry Office data and map plots of cholera deaths to establish that cholera is a water-borne illness (Dossey, 2000). Though it is not documented, one can only imagine that this effort impressed Florence, who was extremely interested in this kind of data use.

Florence was also deeply involved in the treatment of cholera patients, taking a leave of absence from her position to do so. Then, in 1954, Florence was appointed as the "Superintendent of the Female Nursing Establishment in the English General Hospitals in Turkey" by the Secretary of War. This was an unprecedented honor for a woman. With 40 volunteer nurses, she went to the military hospital at Scutari and from there into the public eye and history books.

Florence the Statistician

Florence's fascination with statistics and her desire to nurse were both present from her childhood. In Crimea she found the opportunity to meld her two passions into a single pursuit. One of her first acts was to institute uniform statistical recordkeeping to replace haphazard and contradictory military journals (Kopf, 1916). These data would form the foundation of her later work when she returned home. The Royal Commission, charged with formalizing Florence's reforms, would come to rely heavily on her statistical analyses, and it had as one of its goals the establishment of a "statistical department for the army" (Dossey, 2000). She also pressed for more uniform data collection on the civilian front, both in hospitals and in the national census. Both of these proposals were "too advanced for their time" (Dossey, 2000; Kopf, 1916) since hospitals were not used to the rigorous collection of data, and her proposals were either implemented briefly in some hospitals or not at all.

In an era where even statisticians believed that statistics should be "the driest of all readings," (Heyde and Seneta, 2001), Florence drew upon her extensive mathematical training and became an innovator in standardized data collection, tabulation and graphical displays (Stinnett, 1990). Florence thought that both visual and auditory communication was necessary to understand the real meaning of data: "the diagram which is to affect thro' the Eyes what we may fail to convey to the brains of the public through their word-proof ears" (Diamond and Stone, 1981). Her closest associate and collaborator for twenty years was medical statistician William Farr, who shared her practical view of applied statistics, though he remained rather critical of what was at the time an unconventional reliance on graphs (Diamond and Stone, 1981). She was also influenced by the Belgian statistician Adolphe Quetelet, considered to be the founder of social statistics (Dossey, 2000).

Florence's most well-known invention was the polar area chart (erroneously referred to as "coxcomb" charts in some texts), an example of which is shown in Figure 1. Very few significant precedents existed for this kind of display (Kopf, 1916).

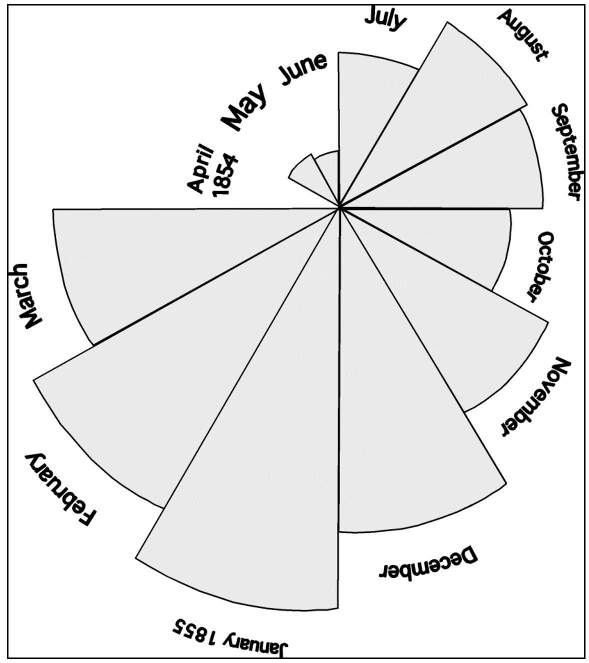

Figure 1 A partial reproduction of one of Florence's polar area charts showing military fatalities due to disease in the Crimean War.

Polar Area Charts

Polar area charts are variations on pie charts, which were first used by William Playfair in 1801 (Small, 1998). In a pie chart, the circle or "pie" has a constant radius. The total area is proportionally divided among categories to show their relative frequencies. For example, if one category has twice as many items in it as the others, then its piece in the pie chart is twice as large as any other piece.

In a polar area chart, the circle is divided into angles or "wedges" of the same size for each category. The radii of the wedges vary. Each radius is equal to the square root of the frequency for that category. The square root is used for the radius because the area of a circle is πr^2; using the square root of the frequency for radius means that the wedges in the polar area chart are still proportional to one another, like in the pie chart.

Table 1 shows the numbers of gold, silver and bronze medals the United States won in the first four modern Summer Olympic Games.

Table 1 US Olympic Medals 1896 – 1908

Olympics	Gold	Silver	Bronze
1896	11	6	2
1900	20	14	19
1904	80	86	72
1908	23	12	12

Figure 2 shows a standard pie chart for the percentages of each the three medal types the United States won in the 1896 Olympics. We would need a separate pie chart for each year if we wanted to compare all four years.

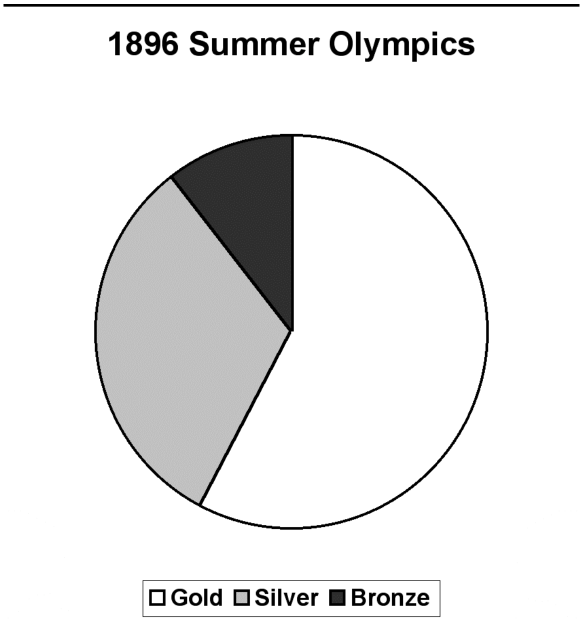

Figure 2 Pie Chart for US Medals in the 1896 Summer Olympics

Figure 3 shows a polar area chart for the same data for all four years. Each quadrant or quarter of the circle represents one Olympics. The radius of each colored slice or wedge is the square root of the gold, silver or bronze medal count, and the three slices for each year are stacked on top of each other. As in the pie chart, gold medals are shown in white, silver medals in gray and bronze medals in black.

The advantage of the polar area chart for this data is that it displays not only the relative percentages within each year, but it also gives an indication of the total number of medals won, something the pie charts do not do. In 1904, for example, the very large wedges show that far more medals were won in that year than in any of the other three years. The relative size of the wedges also shows that the U.S. won nearly equal percentages of gold, silver and bronze that year. In 1908, the totals for silver and bronze were the same, and this is represented by the striped wedge.

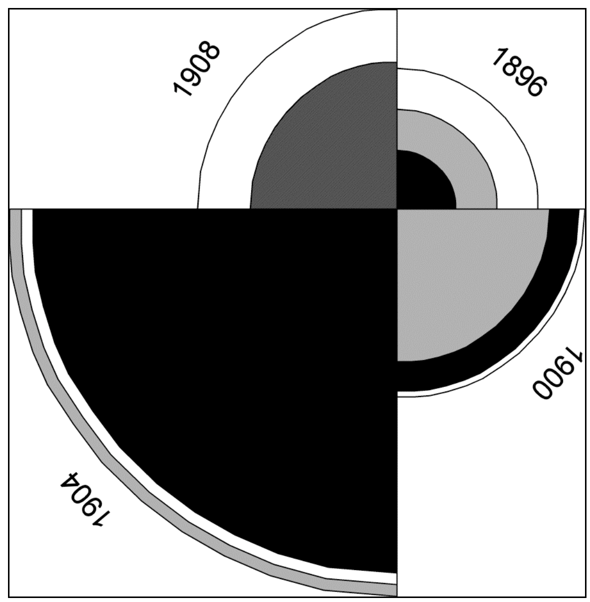

Figure 3 Polar Area Chart for US Medals in the 1896, 1900, 1904 and 1908 Summer Olympics

Though they were innovative and dramatic, polar area charts were subsequently replaced by pie or bar charts in common usage because of the laborious hand calculations that were required to find square roots in the days before calculators. Figure 3 requires 12 square root calculations. Many of Florence's diagrams representing yearly data about military deaths due to disease, wounds and other causes had 36 square roots, three for each month. Then, the charts themselves had to be drawn by hand with rulers and curved templates, making pie and bar charts more attractive options in terms of time and effort.

Technology was a common problem for statisticians of the late 19th and early 20th centuries: ideas about how to effectively summarize and visualize large amounts of data often preceded the ability to actually implement those ideas. Modern computers allow people to make a wide range of graphs with a few clicks of a mouse, so statisticians are now revisiting many of the ideas first proposed a century ago.

Florence's Legacy

Florence Nightingale was the first woman elected as a Fellow of the Royal Statistical Society, and she was also made an honorary member of the American Statistical Association. She received the St. George's Cross from Queen Victoria for her *Notes on Matters Affecting Health, Efficiency, and Hospital Administration of the British Army*, one of the first published documents that made use of her statistical data and charts (Stinnett, 1990). Karl Pearson, the developer of the Pearson product moment correlation coefficient and one of the grandfathers of modern statistics, said that Florence was a "prophetess" in the area of applied statistics (Stinnett, 1990).

In the later years of her career, Florence tried unsuccessfully to establish an Oxford professorship in applied statistics, which would have been the first position of its kind. Unfortunately, like many of her ideas, this was not fully embraced in her lifetime. Her methods are now standard practice in many fields, especially in health services auditing, quality control, epidemiology, (Spiegelhalter, 1999) and the national census of countries such as the United States (Kopf, 1916).

NCTM Standards

The activities presented address many points in the NCTM *Principles and Standards for School Mathematics*, especially with regard to the middle school curriculum. Students in sixth through eighth grades are expected to acquire a thorough grounding in algebra and geometry. Pie, bar and polar area charts all rely on geometric proportionality to display data, and comparisons of pie and polar area charts in particular can generate interesting discussions about area. For example, why do we use the square root of counts in the polar area chart rather than the counts themselves?

The NCTM middle grades standards also emphasize the ability to manipulate real-life quantitative data, including looking at how data is collected and interpreted. In grades three through five, students learn the basics of data collection and how to make simple representations such as bar charts. In the middle grades, there is increased emphasis on comparison, integration and explanation. The students must know how to manipulate not only whole numbers but fractions, percentages, exponential relationships and ratios to represent and explain quantitative relationships, all of which are necessary for the construction of pie, bar and polar area charts. As in the worksheet presented below, students need to be able to create the graphs and also explain what those displays mean, answer questions based on the data, and form conjectures about causes and relationships.

Activity Sheet: Florence Nightingale's Polar Area Diagrams

The following activity sheet gives students a chance to practice making pie and bar charts and construct Florence's polar area chart firsthand. The data provided looks at male and female athlete participation in the last eight Summer Olympics. The numbers are of a similar magnitude to those found in Florence's Scutari data. There are interesting trends in the data that require the students to draw conclusions using the related history. Participation by men dips markedly in 1980, the year that the United States boycotted the Summer Games in Moscow. Participation by women, on the other hand, shows steady increase, probably thanks to the enactment of Title IX in 1972 in the U.S. and the women's movements in many countries during the same era.

Historical information about the Summer Olympics, including for example the number of events, pictures of the posters and medals, and competition highlights can be found at the web site of the Olympic Movement (International Olympic Committee, 2004). The questions given at the end of the worksheet can be done individually or used for class discussion. These questions are designed to encourage the critical thinking and interpretation skills needed to explain the data, which is as important as the presentation.

Square Root Activity

Have your students search the internet for information about methods of finding square roots by hand, which were taught in American schools until about World War II. Ask them to use these methods to try to find the square root of a small number or a perfect square such as four, then for a larger number. Discuss with students how the invention of hand calculators and personal computers has changed the teaching, learning and practice of mathematics.

Florence Teaches Math Activity

When teaching mathematics, Florence posed the following types of questions to her students: How tall is the reindeer? Are you as tall? How tall are you? How far is the highest point of Europe from the equator? How far do you come to school? If you walked the same number of miles each day that you come to school, how long would it take you to walk to the equator? (Lipsey, 1993). Have your students solve some of these problems, either individually or in small groups. Then ask them to create other problems of their own that are similar.

Women Statisticians Activity

Have your students research the lives of other prominent female statisticians such as Gertrude Cox (who helped create the statistics department at North Carolina State University) and the very prolific Florence Nightingale David (whose parents were close friends of Florence Nightingale). Discuss their contributions to the field of statistics.

Census Activity

Suppose your students were asked to conduct a census of the students or classes at your school, similar to the U.S. decennial census. Have students research how the U.S. Census Bureau performs the census and create a standard data collection sheet for your school census that anyone can use. Discuss as a class what their census should look like and what kind of questions should be asked so that they would be able to analyze the data to make summaries and comparisons? Information and a number of free lesson plans that include large, full-color maps are available from the Census Bureau (United States Census Bureau, 2000).

Invent Your Own Graph Activity

Ask students to try to invent a new type of graph or picture-based method of displaying data. Compare these to the graphs they already know and discuss the similarities and differences.

References

American Statistical Association: Journal of Computational and Graphical Statistics (JCGS) [On-line]. Available: https://www.amstat.org/publications/jcgs/index.cfm?fuseaction=main

Cook, E. (1919). *The Life of Florence Nightingale 1820 – 1910*. London: MacMillan and Company.

Diamond, M. and Stone, M. (1981). Nightingale on Quetelet. *Journal of the Royal Statistical Society, Series A (Statistics in Society)*, 144(1), 66-79.

Dossey, B.M. (2000). *Florence Nightingale: Mystic, Visionary, Healer*. Springhouse, Pennsylvania: Springhouse Corporation.

Florence Nightingale Museum Trust (2003). Florence Nightingale Museum: The Passionate Statistician [On-line]. Available: http://www.florence-nightingale.co.uk/stats.htm

Heyde, C.C and Seneta, E. (editors). (2001). *Statisticians of the Centuries*. New York: Springer-Verlag.

Internaitonal Olympic Committee (2004). Olympic Games [On-line]. Available: http://www.olympic.org/uk/games/index_uk.asp

Kopf, E.W. (1916). Florence Nightingale as statistician. *Publications of the American Statistical Association*, 15(116), 388-404.

Lipsey, S. (1993). Mathematical Education in the Life of Florence Nightingale. *Newsletter of the Association for Women in Mathematics*, 23(4), 11-12 [Reprinted On-line]. Available: http://www.agnesscott.edu/lriddle/women/night_educ.htm

The MacTutor History of Mathematics Archive: Biography of James Joseph Sylvester [On-line]. Available: http://www-history.mcs.st-andrews.ac.uk/Mathematicians/Sylvester.html

Salzburg, D. (2001). *The Lady Tasting Tea: How Statistics Revolutionized Science in the Twentieth Century*. New York: W.H. Freeman and Company.

Small, H. (1998). Florence Nightingale's Statistical Diagrams. Presented at the Stats & Lamps Research Conference, Florence Nightingale Museum at St. Thomas' Hospital, 18 March 1998 [On-line]. Available: http://www.florence-nightingale.co.uk/small.htm

Spiegelhalter, D.J. (1999). Surgical audit: statistical lessons from Nightingale and Codman. *Journal of the Royal Statistical Society, Series A (Statistics in Society)*, 162(1), 45-58.

Stinnett, S. (1990). Women in statistics: sesquicentennial activities. *The American Statistician*, 44(2), 74-80.

United States Census Bureau (2000). Census in Schools Program [On-line]. Available: http://www.census.gov/dmd/www/teachers.html