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Incorporating Quantitative Reasoning in Common Core Courses: Mathematics for *The Ghost Map*

John R. Jungck
Beloit College, jungck@beloit.edu

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Abstract

How can mathematics be integrated into multi-section interdisciplinary courses to enhance thematic understandings and shared common readings? As an example, four forms of quantitative reasoning are used to understand and critique one such common reading: Steven Berlin Johnson's "The Ghost Map: The Story of London's Most Terrifying Epidemic - and How it Changed Science, Cities and the Modern World" (Riverhead Books, 2006). Geometry, statistics, modeling, and networks are featured in this essay as the means of depicting, understanding, elaborating, and critiquing the public health issues raised in Johnson's book. Specific pedagogical examples and resources are included to illustrate applications and opportunities for generalization beyond this specific example. Quantitative reasoning provides a robust, yet often neglected, lens for doing literary and historical analyses in interdisciplinary education.

Keywords

quantitative reasoning, interdisciplinary courses, common readings, public health issues

Cover Page Footnote

John R. Jungck is Professor of Biology and Mead Family Professor of Sciences at Beloit College. He co-founded (1986) the BioQUEST Curriculum Consortium, recipient of the 2010 Bruce Alberts Award for Excellence in Science Education from the American Society of Cell Biology. His specialties are molecular evolution and bioinformatics. He is a fellow of the American Association for the Advancement of Science and served (2006) on the NNN committee that shaped this journal.

Introduction

A common challenge on many campuses is the inclusion of quantitative reasoning in all-campus courses intended to introduce incoming students to college and university expectations of academic scholarship. How can mathematics be integrated into such multi-section, interdisciplinary courses to enhance thematic understandings and shared common readings? Steven Berlin Johnson's (2006) *The Ghost Map: The Story of London's Most Terrifying Epidemic - and How it Changed Science, Cities and the Modern World* is a book that has been chosen for one of these courses. Four forms of quantitative reasoning are described and used to understand and critique this common text: (1) Geometry, (2) Statistics, (3) Modeling, and (4) Networks. Each is featured here as the means of depicting, understanding, elaborating, and critiquing the public-health issues raised in Johnson's book. Specific pedagogical examples and resources are included to illustrate applications and opportunities for generalization beyond this specific example. Quantitative reasoning provides a robust, yet often neglected, lens for doing literary and historical analyses in interdisciplinary education.

Interdisciplinary education affords numerous opportunities for addressing contemporary issues, curricular innovation, team teaching, and extending our own education. "Developing interdisciplinary knowledge requires a collaborative effort and a commitment to process learning. Moreover, this process forces both students and teachers to engage in a continuous effort to invent new knowledge" (Mayberry and Rees 1999). The development of trust, credibility, and respect in such explorations frequently differs from our experience in offering classes within our own disciplinary perspective. How can "numeracy" advocates contribute effectively to interdisciplinary educational initiatives in such a way that students acquire an appreciation for the power of our analyses, data, and methodologies in addressing a pressing problem or develop a deeper contextualization of a historical era or achievement?

C. P. Snow's (1960) classic essay on *The Two Cultures* argued for the formation of a unified third culture. Despite this clarion call being over a half-century old, we still have an enormous need to promote dialogue between the sciences and humanities.

> The attempts at interdisciplinary education that seem to be most successful are those that address the polarity question in a different way. The question here isn't whether we should teach the classics (though that is a question worthy of genuine discussion); rather we are considering a larger point: No matter what the content, we can design active linkages between fields of knowledge. … Integrated curriculum attempts should not be seen as interesting diversion but more as a more effective means of presenting the curriculum.… The curriculum becomes more relevant when there are connections between subjects rather than strict isolation (Jacobs 1989).

The micro-specialization of professors' education and the housing of faculty in well-separated silos and off-campus sites have made face-to-face conversation even more difficult than in C. P. Snow's era (Krauss 2009). Students who pursue a balanced or liberal arts education have the challenge of going from disparate classes with varying cultural assumptions, epistemologies for knowledge construction and validation, and pedagogical practices.

Creative Interdisciplinary Opportunities

There are ways to address these challenges. At Beloit College, and I presume at other colleges and universities as well, we have a requirement that, on average, one-sixth of the course load of each professor should be devoted to all-college courses in interdisciplinary education, first-year initiatives, and writing-to-learn or learning-to-write courses. Each offers an opportunity for the inclusion of quantitative reasoning into the curriculum. In the Fall of 2011, Steven Berlin Johnson's (2006) *The Ghost Map: The Story of London's Most Terrifying Epidemic - and How it Changed Science, Cities and the Modern World* was adopted as a common reading for our incoming students. Students must matriculate in one of an interdisciplinary series of orientation courses entitled the First Year Initiative. Since this was also the first year of a new "Quantitative Reasoning" requirement, I decided that *The Ghost Map* offers an excellent case study to combine the two. I adopted four forms of quantitative reasoning mentioned, though not elaborated, by Johnson in this text. By providing a mathematical elaboration and analysis of some of Johnson's claims, I hope that I raise issues for mutual consideration by both the sciences and humanities.

Context of *The Ghost Map*

Four major revolutionary maps from Great Britain in the nineteen century transformed much of science and public health: First, William Smith's geological map of the British Isles transformed our sense of time. Second, Charles Darwin's world map of the distribution of coral reefs, colored according to whether they were rising or subsiding, transformed our sense of the global dynamism of our planet. Third, Florence Nightingale's rosette plots led to careful record keeping of morbidity and mortality in all hospitals so that accurate statistical data could be compiled. She revolutionized health care for wounded soldiers, which tremendously increased survival in the Crimean War and every war since. Fourth, and the subject of this review, John Snow's map of the cholera outbreak in London in 1854 transformed our sense of disease transmission and is usually heralded as the origin of modern epidemiology. Fortunately for the course, Johnson's *The Ghost Map* has been extensively reviewed (including one by a

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distinguished cholera researcher: Richard A. Finkelstein, Curators' Professor and Millsap Distinguished Professor Emeritus, Department of Molecular Microbiology and Immunology, School of Medicine, University of Missouri-Columbia)[1] and a series of sixteen discussion questions (unfortunately none drawing on mathematics) are available online.[2] Additionally, Johnson has received numerous awards; for example, he was named a Distinguished Writer in Residence at New York University's Department of Journalism. Therefore, I decided to take a fresh approach to using Johnson's highly readable piece on scientific sleuthing and revisionist history of science by using features of these other contemporaries of Snow.

Johnson argues for four mathematical principles that I will use to organize a set of activities that could be deployed to conduct a "Quantitative Reasoning" analysis of this book. Namely, Johnson emphasizes: (1) Geometry, (2) Statistics, (3) Modeling, and (4) Networks. The following activities and easily available resources exemplify how we can enhance our understanding of disease distributions, prevention of epidemics, and extended applications to contemporary public-health issues.

Geometry of *The Ghost Map*: Voronoi Tessellations

The Ghost Map celebrates the importance of mapping as a fundamental tool of public health. Visit the Center for Disease Control's website or the National Cancer Institute's website for numerous instances of maps that range from the spread of West Nile Virus from its initial introduction in the U.S. to its spread across the whole nation to the incidence of lung cancer by county level. Johnson states his support for mapping unequivocally: "When the next great epidemic does come, maps will be as crucial as vaccines in our fight against the disease" (p. 219). And,

> The second is to commit ourselves anew to the kinds of public-health systems that developed in the wake of the Broad Street outbreak, both in the developed world and the developing: clean water supplies, sanitary waste-removal, and recycling systems, early vaccination programs, disease detection and mapping programs. (p.255)

However, the construction of a map is insufficient in and of itself. Prior to Snow, other scientists had constructed maps that illustrated the outbreak of cholera in this section of London (Brody et al. 2000; Newsom 2006). Brody et al. (2000) argue that the usual mythology about Snow's map creates several misconceptions on the nature of scientific progress and that "other observers

[1] http://www.theghostmap.com/ (see full web site on the book containing snippets from many reviews) (This and all other links in text were accessed 10 Dec. 2010 – Ed.)
[2] http://us.penguingroup.com/static/rguides/us/ghost_map.html

looked at even more detailed and accurate maps … [and] yet came to different conclusions about the cause of the cholera outbreak" and that [Snow's] "map did not give rise to the insight, but rather it tended to confirm theories already held by the various investigators" (p. 64). In a further challenge of the Snow myth, McLeod (2000) raises three specific questions: (1) "What happens to the meaning of our story when the determinative use of the map is challenged? … (2) What happens to the meaning of the myth when the causal connection between the pump's disengagement and the end of the outbreak is examined? (3) With the drama of the pump handle being questioned and the map, our artifact, occupying a more illustrative than central role, what is our sense of Snow?" Furthermore, in a follow-up, Koch and Denike (2009) ask two hypothetical questions: "And yet, Snow's work did not satisfy most of his contemporaries who considered his proof of a solely waterborne cholera interesting but unconvincing. Uniquely, this paper asks whether the caution of Snow's contemporaries was reasonable, and secondly, whether Snow might have been more convincing within the science of the day." While Vandenbroucke (1998; Vandenbroucke, Rooda, and Beukers 1991; Vandenbroucke, Plaut, and Morens 2000) all disagreed with some aspects of Brody et al.'s analyses, they emphasize that "Snow's study should be understood in the context of its times, including the Sanitary Movement, the growing acceptance of a germ theory, the belief that causes of diseases such as cholera could at last be understood by epidemiology, and the cumulative effects of those who influenced Snow …." Tulodziecki (2011) continues the debate by asserting that Snow's "epistemic superiority" deserved to defeat the miasmatists.

Hypotheses that propose causal mechanisms for the observed distribution of disease must be tested on the map. In the particular case of *The Ghost Map,* Johnson makes the claim (p. 174) that the fundamental insight for Snow was the construction of a Voronoi tessellation of the cholera-infected region by using the pumps as generator points and then observing the much greater concentration of cholera-associated deaths in the Voronoi cell containing the Broad Street Pump compared to cells surrounding it (see Fig. 1).

> To solve this problem, Snow (1855) drew upon a centuries-old mathematical tool that would later be termed the Voronoi diagram. (It is unlikely that Snow knew anything of the device's history, though he was certainly the first to apply it to disease mapping.) … What Snow set out to do with his second map was to create a Voronoi diagram using the 13 pumps as points. (p. 195)

John Snow's map centerpiece is a mathematical construction, namely a Voronoi tessellation; yet its construction and visualization are not shared in the book. This absence of computational geometry, along with an inadequate appreciation of the revolution in statistics co-occurring with Snow's investigations, afford a second opportunity to share another component of quantitative reasoning that affects policy formation, identification of the source of an epidemic, and improvement of public health. Because John Snow is revered as the founder of modern epidemiology (Cameron and Jones 1983; Frerichs, n.d.; Vinten-Johanssen, n.d.) and because Johnson discusses the importance of our interconnected modern cities, modeling and networks are two more mathematical approaches introduced to understand public-health issues. These entrees to quantitative reasoning not only inform our dialogue with our humanities and social science colleagues, but provide an opportunity for our biology students to participate in discussions of contemporary issues and to contribute to the mediation of policy.

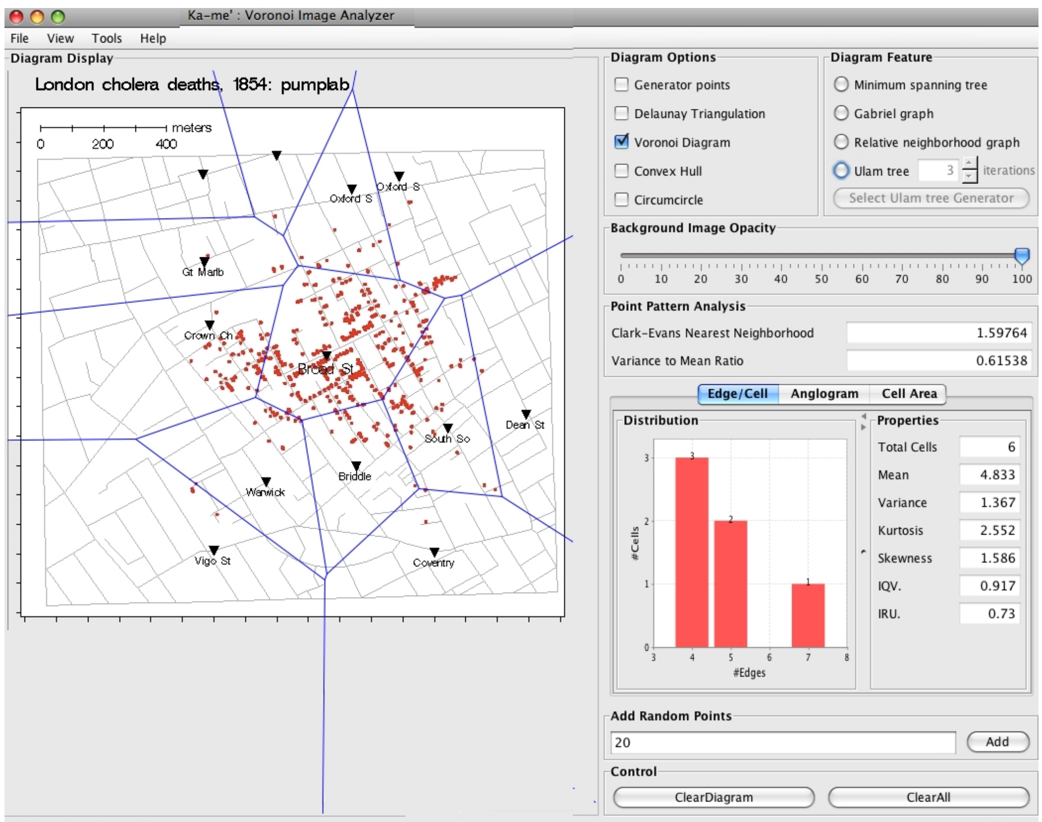

Figure 1. A Voronoi tessellation of Snow's map of the location of thirteen pumps that served as sources of fresh water for this London neighborhood and his red dots indicating where deaths due to cholera had occurred. The blue lines generated in the software package Ka-me (Khiripet, Khantuwan, and Jungck, submitted) indicate the perpendicular bisectors between the location of each of the pumps used as a generator. The Broad Street pump Voronoi cell clearly has the greatest density of red compared to its neighboring cells. While he did not reprint any map of this explicit kind, Johnson drew special attention to some cells with no deaths at all (p.193).

However, while Johnson maintains a website which supplements his book with resources, neither here, nor in the text, nor in his end notes does Johnson provide an explanation of Voronoi tessellations. Other sites and articles have done so. For example, Mathematica's site on Voronoi tessellation uses Snow's map explicitly as its practical example.[3] A popularization of Voronoi tessellations appeared in the TV show *NUMB3RS* during the 2005 episode "Bones of Contention" for the regions served by fast food restaurants and again in the fourth season (2007–2008) in the "Black Swan" (see the Danish website maintained by Professor Lisbeth Fajstrupon on the math behind each episode,[4] the popular book by Devlin and Lorden (2007), and the student activities developed by Professor Tom Butts, University of Texas Dallas for Texas Instruments Incorporated for the earlier episode of NUMB3RS[5]). An even more interesting site is by John Burkhardt from Virginia Tech who gives a lecture entitled "The Death Map: Discovering Nature's Geometry" wherein he shows that if Snow had chosen a more conventional geographic subdivision of this local London region, two such maps[6] would not have even shown any overt concentration of deaths around the Broad Street pump. For my fellow biologists, Voronoi tessellations have received considerable attention since Hsiao Honda's wonderful 1978 paper on epithelial cell patterns and cells grown in monolayers in tissue culture (Honda 1978) and most recently by Bock et al. (2010). I got so excited by Honda's original and ensuing papers that I have taught about them ever since and have developed (with Thai colleagues) computer software for analyzing cellular epithelia (Khiripet, Khantuwan, and Jungck 2011, submitted).

To turn Snow's approach into a contemporary activity, students may appreciate both contemporary applications and a variety of methods appropriate to their talents, interests, and mathematical backgrounds. Recently, microbiologists and hydrologists have collaborated in investigating viral populations in ground water in community wells used as sources of fresh water. Just as Snow found that *Vibrio cholera* (although he didn't know yet about bacteria or the germ theory of disease) traveled from the sewage of an infected house into the well drawn up by the Broad Street pump, these scientists used quantitative PCR (polymerase chair reaction) to identify enteric viruses in Madison, Wisconsin's water supplies (Borchardt et al. 2007) that have been contaminated by surface sewage.

Numerous algorithms have been developed by mathematicians and computer scientists to generate Voronoi tessellations such as: (1) Method of Half Planes; (2) Byer's Method; (3) Fortune's Method; (4) Contour Method; (5) Sampling Method; and (6) Pixel Method (see Okabe et al. 2000). However, I suggest here that students try one or more of the following much more elementary constructions after downloading a map of interest.

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[3] http://mathworld.wolfram.com/VoronoiDiagram.html
[4] http://numb3rs.math.aau.dk/wordpress/?s=Voronoi
[5] http://teach.fcps.net/trt3/Act2_VoronoiDiagrams_BonesofContention_final.pdf
[6] http://people.sc.fsu.edu/~jburkardt/latex/clustering_voronoi/different_maps.png

- Origami: poke holes through points of interest (pumps, wells, hospitals, cities, etc.) in a paper copy of a map – superimpose the centermost hole with its nearest neighboring hole, crease the paper sharply along the fold; iterate until creases exist between every pair of adjacent points. The origami lines that represent a convex polygon around each generator point then can be highlighted with a pen.
- Construct the perpendicular bisectors by using a compass and straight-edge; i.e., draw circles around each generator point sufficiently large that adjacent circles overlap such that the straight edge can be used to connect the two intersecting arcs. Complete as in #1.
- Alternatively, instead of using a physical compass and straight-edge, use a geometry package such as Geometer's Sketchpad, GeoGebra, or Cinderella for a visual, interactive environment.
- Use a protractor and ruler to construct the perpendicular bisectors by first constructing a Delaunay triangulation (triangles formed by connecting every set of three nearest neighbors) for all of the Voronoi generator points, measuring the mid-point of each Delaunay edge, and then drawing a line that intersects the Delaunay edges at 90 degrees.
- Find circumcenters. A circumcenter is a point equally distant from three other points in a plane. Find all of the (x,y) coordinates of three neighboring generator points $((x_1,y_1), (x_2,y_2), (x_3, y_3))$ and substitute the values into these equations (this is a nice example of the utility of a spreadsheet or a computer algebra package) to find the circumcenters (x_c, y_c) of Y-junctions in the Voronoi tessellation:

$$y_c = \frac{\{(x_3^2 - x_2^2) + (y_3^2 - y_2^2)\}(x_1 - x_2) + (x_2 - x_3)\{(y_1^2 - y_2^2) + (x_1^2 - x_2^2)\}}{2(x_1 - x_2)(y_3 - y_2) + 2(x_3 - x_2)(y_2 - y_1)}$$

and $$x_c = \frac{(y_1^2 - y_2^2) + (x_1^2 - x_2^2) + 2(y_2^2 - y_1^2)y_c}{2(x_1 - x_2)}.$$

  Then join the circumcenters with a straight-edge to complete the construction.
- Import the map into Ka-me[7] to generate the Voronoi tessellation, calculate the area of each Voronoi cell, and investigate other geometrical, topological, and spatial statistical properties. Remember to interpret the construction in terms of the hypothesis that you're testing. As Johnson noted:

[7] http://bioquest.org/downloads/kame_1.0.rar

> But as exacting as Cooper's map was, it ultimately had too much detail to make sense of the story. The connection between the Broad Street pump and the surrounding deaths was lost under the sheer mass of data that Cooper had charted. For a map to explain the true cause behind the Broad Street outbreak, it needed to show less, not more. … (p. 193)

As an alternative contemporary activity, consider Frerichs,[8] who provides an excellent background to current outbreaks of cholera *per se* in Haiti and Nepal that could be used as resources for developing "investigative case-based learning" modules (Waterman and Stanley 2008). In 2009, Doctors Without Borders (MSF: Medicine Sans Frontiers) highlighted the massive outbreak of cholera in Zimbabwe – over 88,000 cases by March of that year and discussed how the political and economic meltdown contributed to the massive disaster. Or, if your interest is to explore a different quantitative question, Johnson discusses the actual paths that people would have walked along the streets rather than cut across blocks as the eagle flies. This is equivalent to using a Manhattan metric ("taxi-cab geometry") rather than a Euclidean metric and the resulting Voronoi tessellation will generate curvilinear edges instead of straight edges for the individual Voronoi cells.

Such maps "may affect the way people grasp" a theory and its importance for public health:

> Graphical representations such as maps and diagrams play an important role in everyday communication settings by serving as an effective means of exchanging information. In such communication, graphical representations work not only as "windows" through which we can see the target situations the graphics describe, but also serve as information processing "sites" because we can take advantage of their handiness. Though the final aim of speakers is to exchange information about the target situation, graphical representations are so deeply a part of information processing that they may affect the way people grasp the target situations. (Umata, Katagiri, and Shimojima 2008).

Statistics

While Johnson presents Florence Nightingale as an opponent of John Snow, Nightingale foreshadowed just how important statistics can be in contemporary health research as well as leading a revolution in health care in her own time. Kopf (1916) paid testimony to the significance of her work: "In hospital care of the sick, as an instance, Miss Nightingale replaced the astigmatic viewpoint with one embodying a grasp of total situations. This is one function of statistics."

Johnson critiques Florence Nightingale's support of the airborne ("miasma theory") cause of cholera rather than John Snow's water borne hypothesis (p. 123–124) in an introduction to a wonderful pair of questions on how do we distinguish between these alternative hypotheses.

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[8] http://www.ph.ucla.edu/epi/snow/origin_cholera_haiti_epilogue.html

> All of which begs the central question: Why was the miasma theory so persuasive? Why did so many brilliant minds cling to it, despite the mounting evidence suggesting it was false? (p. 126)

Unfortunately, Johnson commits the popular misconception of *datum anthropomorphum* by not offering students the opportunity to explore the rhetorical imperialism of such phrases as “data suggest,” “results indicate,” “research tells us,” “experiments show.” Such phrases silence any alternative interpretations of the data that might be drawn by the readers (Carver 2007; Jungck 1996; Wild and Pfannkuch 1997). “They are not given the opportunity to question or suppose that science could be anything other than the natural order of what is truth. — ‘Truth is supposed to emerge unambiguously from experiment’ (Scalon, Murphy, Thomas and Whitelegg 2004, p.4)” (Wilkins 2008). Johnson avoids the role of controversy in scientific progress, but instead asserts that those who got it wrong were blinded by ideology, social prejudice, convention, conceptual limitations, failures of imagination and analysis (p. 126). However, recent research in science education (Bell and Linn 2000; Osborne 2010; Witte 2008; Witte et al. 1989; Toulmin 1958) posits that when students learn to argue scientific concepts, hypotheses, and interpretations and to probe their own ignorance, they also develop their own scientific reasoning:

> Argument and debate are common in science, yet they are virtually absent from science education. Recent research shows, however, that opportunities for students to engage in collaborative discourse and argumentation offer a means of enhancing student conceptual understanding and students’ skills and capabilities with scientific reasoning. As one of the hallmarks of the scientist is critical, rational skepticism, the lack of opportunities to develop the ability to reason and argue scientifically would appear to be a significant weakness in contemporary educational practice. In short, knowing what is wrong matters as much as knowing what is right. (Osborne 2010).[9]

In addition to the pedagogical value of controversy in helping students learn science, Donna Armstrong (1999) argues that controversy can help illuminate the role of social inequalities which are usually excluded in “conventional epidemiological debates of causality:”

> Social inequalities relate not only to disparities in health but also are the social context for theories of disease causality being legitimized or denied. In the discipline of epidemiology, conventional discussions on whether or not a given exposure “causes” a specific disease are framed almost exclusively as debates of validity and whether there is sufficient accumulation of evidence to satisfy “Hill's Causal Criteria.” However, the way in which the conceptualization of disease processes is restricted to conform to the current causal paradigm, which is based on socially determined ideas of individualism, reductionism, monocausality and the legitimacy of social inequalities, can be identified as a fundamental assumption underlying conventional epidemiological debates of causality.

[9] http://icampus.mit.edu/projects/POSIT.shtml (An MIT project, POSIT (developing Public Opinions on Science using Information Technology)

> Any argument that social inequalities are an important determinant of poor public health must also explicitly critique the current causal paradigm, which disallows epidemiologists from conceptualizing social relationships as causal of poor health in populations.

Andrew Ward (2007) states his concern more simply: "S. Leonard Syme makes this point by writing that just "as bad water and food may be harmful to our health, unhealthful forces in our society may be detrimental to our capacity to make choices and to form opinions" conducive to health and well-being." Karhausen (2000) even takes on the whole notion of causality in epidemiology: "There are no known sufficient causes in epidemiology. We merely observe tendencies toward sufficiency or tendencies toward necessity: cohort studies evaluate the first tendencies, and case-control studies the latter. In applied sciences, such as medicine and epidemiology, causes are intrinsically connected with goals and effective strategies: they are recipes which have a potential harmful or successful use."

Thus, Johnson's diminution of the role of controversy about causes of cholera in Snow's time as legitimate may deflect students from perceiving the helpful role of controversy in evaluating claims of various theories and their correspondence with alternative inferences drawn from data. If the cause of cholera in London is reduced to a population of a particular bacterium, *Vibrio cholerae*, does that mean that the squalid living conditions of the poor were not a causative agent (Winkelstein 1958)? What should the goals of public health be?

Snow himself was dependent upon pioneers like Florence Nightingale who had led a campaign to collect better statistics from every health care provider and institution. Without the work of these public-health statistics pioneers, it is highly unlikely that Snow could have put together such a strong case for his water borne hypothesis for the transmission of cholera. In particular, Johnson heralds the incredibly detailed records of Snow's contemporary William Farr and his *Weekly Returns of Births and Deaths*.

> Farr … went on to revolutionize the use of statistics in public health in the following decade. Farr went on to track the elemental of demographic trends: the number of births, deaths, and marriages in England and Wales. Over time, though, he had refined the statistics to track more subtle patterns in the population. … But Farr recognized that these surveys could be far more valuable to science if they included additional variables. He waged a long campaign to persuade physicians and surgeons to report a cause of death wherever possible, drawing upon a list of twenty-seven fatal diseases. … Farr was a man of science, and shared Snow's belief in the power of statistics to shed light on medical riddles (p. 100–101).

Despite his respect for Farr's contribution, Johnson assails Farr, on the criteria above, because of his support for the miasma theory. Nightingale deployed (some give her credit for inventing) polar graphical plots, referred to as coxcombs or "Nightingale's rose" (Lewi 2006; Maindonald and Richardson 2004) in order to persuade Parliament of the importance of good nursing practices (and poor practices of military surgeons).[10] Below (Figure 2) I illustrate four different plots of Nightingale's data from the Crimean War. Which one do you feel best illustrates her point? From these graphs, when do you think that Nightingale arrived with her new nursing practices? How does this correspond with the historical record?

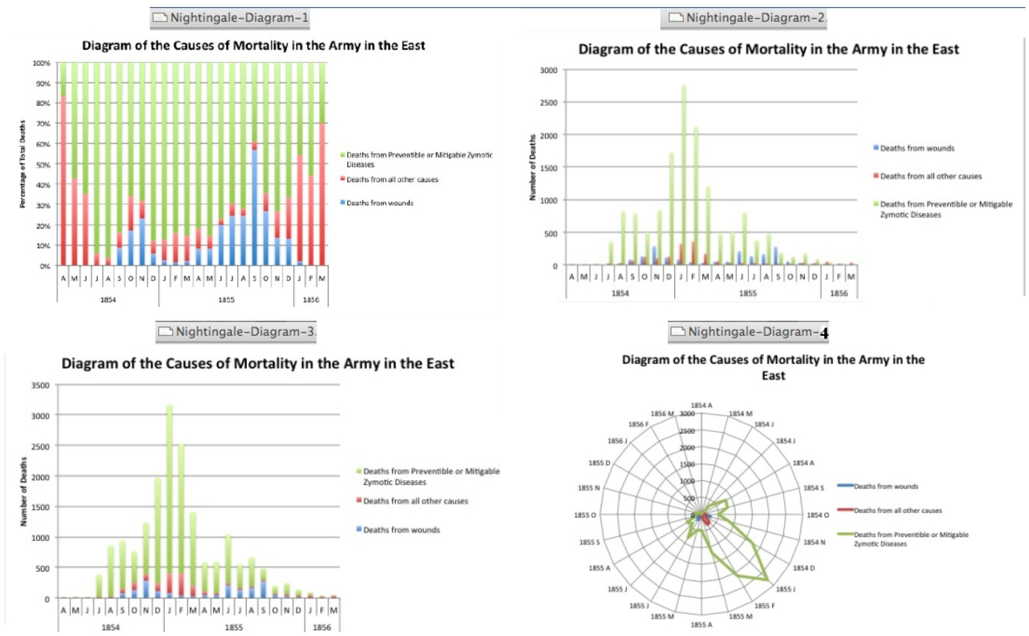

Figure 2. Four different Excel graphs of Nightingale's original data from her analysis of deaths of British soldiers in the Crimean War from 1854-1856 (the same time as the cholera outbreak that Snow was analyzing in London). (a) A stacked histogram of all deaths proportional to 100%. (b) Side-by-side histograms of actual numbers of deaths of the three categories of deaths. (c) A stacked histogram of actual numbers of deaths of the three categories of deaths. (d) A polar stacked histogram of actual numbers of deaths of the three categories of deaths. I simply assert that this polar graph built in Excel™ does not function as well as any of Nightingale's original three roses or coxcombs or bat wings (see Fig, 3a).

For three movies of dynamic representations of Nightingale's original data see Julie Rehmeyer's 2008 *Science News* blog: "Florence Nightingale: The passionate statistician." [11] She explores correcting Nightingale's original roses visually by representing proportions of deaths by the areas of pie wedges rather than the lengths of radii. Then, Rehmeyer states:

[10] http://www.york.ac.uk/depts/maths/histstat/passionate_stat.htm
[11] http://www.sciencenews.org/view/generic/id/38937/title/Math_Trek__Florence_Nightingale_The_passionate_statistician

> The conventional way of presenting this information would have been a bar graph, which William Playfair had created a few decades earlier. Nightingale may have preferred the coxcomb graphic to the bar graph because it places the same month in different years in the same position on the circle, allowing for easy comparison across seasons. It also makes for an arresting image. She said her coxcomb graph was designed "to affect thro' the Eyes what we fail to convey to the public through their word-proof ears."
>
> Some argue that a bar graph would have made her point more dramatically, though. One of the peculiarities of Nightingale's circular presentation is that the deaths are proportional to the area, not the radius. Since the area of a circle is πr^2, the area is proportional to the square of the radius rather than to the radius itself. This difference tends to de-emphasize the contrast between the small areas and the large ones. (In an early version of this diagram, Nightingale didn't catch this distinction and drew the graphic incorrectly, with the radii proportional to the deaths. She quickly corrected her mistake.)
>
> Her report and commission had an enormous impact, leading to systematic changes in the design and practices of hospitals. By the end of the century, Army mortality was lower than civilian mortality.
>
> Furthermore, statistics has become a powerful tool for reform. And powerful graphics like Nightingale's have spared the eyes of many more than just Queen Victoria's from glazing over.

To further amplify my point of the popular misconception of *datum anthropomorphum* and the importance of interpretation of data, especially graphed data, consult the excellent elaboration by Henry Woodbury in his critique of the magazine's *Economist*'s interpretation of graphical data wherein it praised Nightingale's Rose as one of three of "history's best"[12] and said: "Nightingale's diagram, often referred to as Nightingale's Rose or Nightingale's Coxcomb, represents one of the inherent risks in visual explanation. An image may be so visually interesting — so iconic (a rose, a coxcomb) — that we assume its conclusions without examining its data." What could be more dangerous?

Let us look at two other diagrams that highlight the revolutionary impact of Nightingale's intervention in Crimea and her later political advocacy for public health (Figure 3).

Better public sanitation, wider use of vaccination, safer and more nutritious food, the use of antiseptic techniques and sterilization of instruments in surgery, prenatal and neonatal care that lowered infant and maternal mortality, and other strides improved longevity and reduced mortality significantly shortly after the work of Snow, Nightingale, Farr, Lister, Chatwick and others. By 1866 the British Parliament adopted legislation enforcing many public-health measures on sewage, water supplies, housing, factory work conditions, childhood labor, hospital accommodations, and food adulteration.

[12] http://dd.dynamicdiagrams.com/2008/01/nightingales-rose/

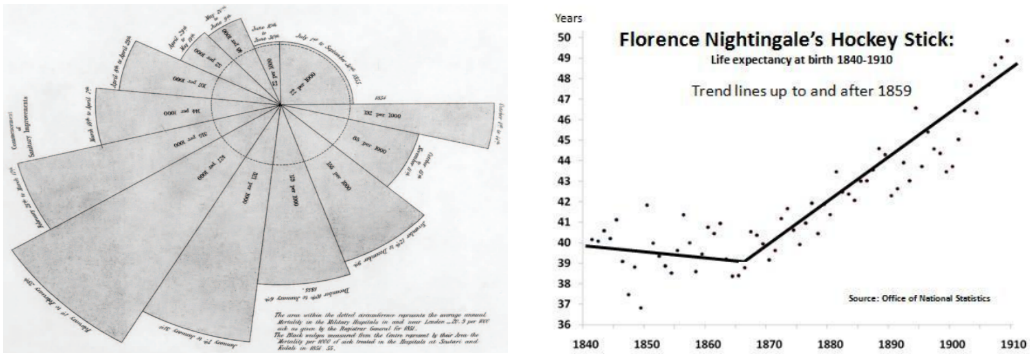

Figure 3. (a) Nightingale's third rose diagram of the mortality rate of soldiers in army hospitals at Scutari and Kulali (near modern Constantinople/Istanbul) during the Crimean War over the period from October 1854 to September 1855. Nightingale's team instituted sanitary improvements, better nutrition, and nursing attention to soldiers soon after her arrival in March 1855. The mortality rate is adjusted in this graph on the basis of the number of deaths per thousand patients on an annual basis. Note that Nightingale's team, despite the harshness of the war environment, was able to reduce the death rate to a comparable value for patients in hospitals in London (the inner circle) (Brasseur 2005). While most of Nightingale's biographers celebrate the first two of her rose diagrams, I like Brasseur's highlighting the positive message of the third rose because it focuses on the solution (improving the health of soldiers) rather than either the high mortality rate or the causes of death in the first two roses. Modern computer software for generating such 'stacked polar bar charts [that] allow comparison of multiple sets of data on polar axes" are available from Golden Software.[13] (b) *The Real Message of her Rose Diagram* by Hugh Small (Presented at the Royal Statistical Society, London, 7 October 2010)[1415] dramatically portrays the political significance of Nightingale's advocacy for better public health and medical care. The data are from the United Kingdom's Office of National Statistics. Despite Small's advocacy for Nightingale, did not Snow's work also contribute to the dramatic change at that time?

Vere-Jones (1995) argues that Nightingale's work is crucial to a "democratization of mathematics" because "it breaks away from the vision of mathematics as a male-oriented subject." It is in this sense that I see statistics as a key part of his more general process of the "democratisation of mathematics". In particular, he returns to our heroine: "From the time of Florence Nightingale onwards, statistics has enjoyed the support of some very forceful and outspoken women -- not least, perhaps, because it provided them with ammunition for their own campaigns. Traditional mathematics teaching formed part of an education programme which acted to perpetuate a tradition of male dominance. Statistics does not carry the same historical loading and can encourage girls to continue with mathematical subjects, reinforcing social and educational changes already at

[13] http://www.goldensoftware.com/grapher-9/polar-graphs.shtml
[14] http://www.mrc-bsu.cam.ac.uk/NewsandEvents/Images%20&%20attachments/16461170_FN%20programme%20for%20web.pdf
[15] http://www.florence-nightingale-avenging-angel.co.uk/Nightingale_Hockey_Stick.pdf

work in the schools." These aspects may be even more important in interdisciplinary courses where students may have alternative conceptions of the role of mathematicians/statisticians in society. In the field of public health, often women hold the majority of the professional positions that specialize on statistics. For example, Jane Gentleman, is the Director of the Division of Health Interview Statistics at the National Center for Health Statistics (NCHS) and the society: Caucus for Women in Statistics just celebrated its fortieth anniversary[16].

As noted before, Johnson stated: "Farr … went on to revolutionize the use of statistics in public health in the following decade … Farr was a man of science, and shared Snow's belief in the power of statistics to shed light on medical riddles" (pp. 100-101). However, Johnson does not contextualize the revolution in statistics that Snow and Farr were depending upon. Both Nightingale and Farr were deeply influenced by the Belgian mathematician Lambert Adolphe Jacques Quetelet's (1796-1874) pioneering work in statistics (Quetelet 1842, reprinted 1969). Just before the London cholera outbreak, Quetelet had organized the first international statistics conference in 1853, helped found the Statistical Society of London, and the Statistical Section of the British Association for the Advancement of Science. In 1874, he stated: "The more progress physical sciences make, the more they tend to enter the domain of mathematics, which is a kind of centre to which they all converge. We may even judge the degree of perfection to which a science has arrived by the facility with which it may be submitted to calculation." Furthermore, his most notable statistical quote is: "Since absolute certainty is impossible, and we can speak only of the probability of the fulfillment of a scientific expectation, a study of this theory should be a part of very man's education." Quetelet was also the first foreign member of the American Statistical Association and was described by an American historian of science as the "patriarch of statistics." As the Dutch mathematician, mathematics education pioneer, and historian Hans Freudenthal (1975) stated:

> With Quetelet's work of 1835 a new era in statistics began. It presented a new technique of statistics, or, rather, the first technique at all. The material was thoughtfully elaborated, arranged according to certain pre-established principles, and made comparable. There were not very many statistical figures in the book, but each figure reported made sense. For every number, Quetelet tried to find the determining influences, its natural causes, and the perturbations caused by man. The work gave a description of the average man as both a static and dynamic phenomenon.

Thus, the statistical work of Snow fell at a propitious moment because: (1) the quality of data was better than before; (2) the amount of data was much greater; and, (3) the belief that inferences based upon new statistical techniques could be employed objectively to draw conclusions from such extensive

[16] http://www.caucusforwomeninstatistics.com/wp-content/uploads/2010/05/CaucNewsletter11-Fall-2011.pdf

DOI: http://dx.doi.org/10.5038/1936-4660.5.1.7

quantitative data. Therefore, Johnson's analysis of the Broad Street cholera outbreak and what it means to us today, was not just dependent upon the individual genius of Dr. John Snow (who created *The Ghost Map* of the cholera cases) and/or his colleague the Reverend Henry Whitehead ("whose extensive knowledge of the local community helped determine the initial cause of the outbreak"), but on the shoulders of a community of scientists and civil servants.

Such statistical work continues to make massive differences in terms of saving lives. The 100,000 lives project and the 5 Million Lives Campaign are recent initiatives of the Institute for Healthcare Improvement.[17] Its founder, Dan Berwick, has collected statistics on how small attempts to improve hygienic procedures such as by using hand sanitizer before entering and after leaving every room in a hospital and to prevent medical errors such as by giving nurses a check-list of every instrument used in surgery and the power to stop a physician if something is missing, can lead to massive changes in morbidity and mortality as well as diminishing the overuse of antibiotics. The campaign's slogan "Some Is Not A Number, Soon Is Not A Time" has been highlighted in *Supercrunchers: Why Thinking-by-Numbers Is the New Way to Be Smart* by Ian Ayres (2007, p. 85). Ayres celebrates: "this is statistics on steroids. Berwick succeeded in scaling his campaign to impact two out of every three hospital beds in the country. And the sheer speed of the statistical influence is staggering: saving 100,000 lives in little more than 500 days" (p. 87). Statistics save lives!

Students might want to explore with contemporary questions based on Johnson's assertion that the construction of maps with statistics are as fundamental to public health today as in London in 1854 by using Schloman's (2001) paper and hyperlinked website[18] which provides one of the best list of links to contemporary health data statistics; she directly credits the availability of all this statistical data as due to "Nightingale's Legacy." They might also want to use GIS software (some freely available or inexpensive for educational purposes are: GRASS, MapWindow, MyWorld GIS, Quantum GIS (QGIS), ArcGIS Explorer Desktop, and DIVA-GIS) with these statistics to explore the location of hospitals with respect to some factor such as poverty, ethnicity, incidence of a particular type of cancer or infectious disease, or occupational injuries (see Radinsky et al. 2006). Two cases of particular interest are "Studying Schistosomiasis in the Philippines" and "AgriSecurity: Containing Hoof and

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[17] http://www.ihi.org/offerings/Initiatives/PastStrategicInitiatives/5MillionLivesCampaign/Pages/default.aspx

[18] Schloman, B. (August 31, 2001). Information Resources Column: "Using Health Statistics: A Nightingale Legacy." *Online Journal of Issues in Nursing*. Available: www.nursingworld.org/MainMenuCategories/ANAMarketplace/ANAPeriodicals/OJIN/TableofContents/Volume62001/No3Sept01/UsingHealthStatistics.aspx

Mouth Disease" available from ESRI; a third start might be on low birth weight and childhood lead poisoning (Krieger et al. 2006); and, a fourth lead on infant mortality is discussed in Richards et al. (1999). Riner et al. (2004) lay out a strategy for developing GIS public-health education modules and argue that: "GIS technology can assist in groups to present a strong policy argument for why new resources should be allocated or there should be a re-distribution of existing resources for treating and preventing diseases or illnesses." Pearce, Witten, and Bartie (2006) illustrate such approaches to "Evidence Based Public Health Policy" for the country of New Zealand and how it particularly affects Maori populations. For non-statistics educators, Wild and Pfannkuch (1995) have developed "A 4-dimensional framework for statistical thinking in empirical enquiry" for beginners which nicely develops a series of steps to take students through: (1) an investigative cycle, (2) types of statistical thinking, (3) an interrogative cycle, and (4) a set of dispositions. They hope that their procedures (such as "Read/see/hear + Translate + Internally summarize + Compare + Connect") stimulate students to be open, to seek deeper meaning, and to take a position based upon analysis of empirical data. Thus, students might be given a social justice assignment (Lesser 2007; Kwako 2011) to follow in Snow's and Nightingale's shoes by using their analyses to "influence public opinion." In particular, I would encourage students to consider that while we celebrate both individuals as pioneers in massively transforming health care, why didn't their quantitative reasoning convince one another? Florence Nightingale never accepted John Snow's ideas even though she lived for another fifty years. Nightingale wrote:

> What does contagion mean? It implies communication of disease from person to person contact. It presupposes the existence of certain germs like the sporules of fungi, which can be bottled up and conveyed any distance attached to clothing, merchandise … There is no end to the absurdities connected with this doctrine. Suffice it to say that in the ordinary sense of the word, there is no proof such as would be admitted in any scientific enquiry that there is any such thing as contagion. (Hempel 2007, page 278).

Models in *The Ghost Map*:

In 2001, a massive foot and mouth epidemic in England led to the destruction of numerous livestock. Further spread was finally prevented by the recommendations of mathematical modelers. While Johnson does not describe such modeling, his analysis does describe the analysis of assumptions similar to the process of modeling *per se*. For example, on page 243, Johnson states: "Traditional bombs obviously grow more deadly as the populations they target increase in size, but the upward slope in that case is linear. With epidemics, the deadliness grows exponentially."

DOI: http://dx.doi.org/10.5038/1936-4660.5.1.7

Elsewhere we (Jungck, Gaff, and Weisstein 2010) described two activities using beads in cups and marbles in troughs. These manipulative activities help students develop a kinesthetic and intuitive sense of the process of building models with standard finite difference equations and ordinary differential equations known as S-I-R (susceptible-infected-recovered) that have been used in epidemiology for over half a century. We encourage readers to explore a variety of our S-I-R computer models in our BioQUEST Library, Microbes Count!, and ESTEEM projects available at[19] (see Figure 4). Johnson identifies a variety of public-health interventions that you might consider modeling with these packages by thinking about which parameters they would affect: quarantining, vaccination, early detection combined with antibiotic treatment and re-hydration therapy, clean water, sanitary waste removal, etc. (pages 251 and 255).

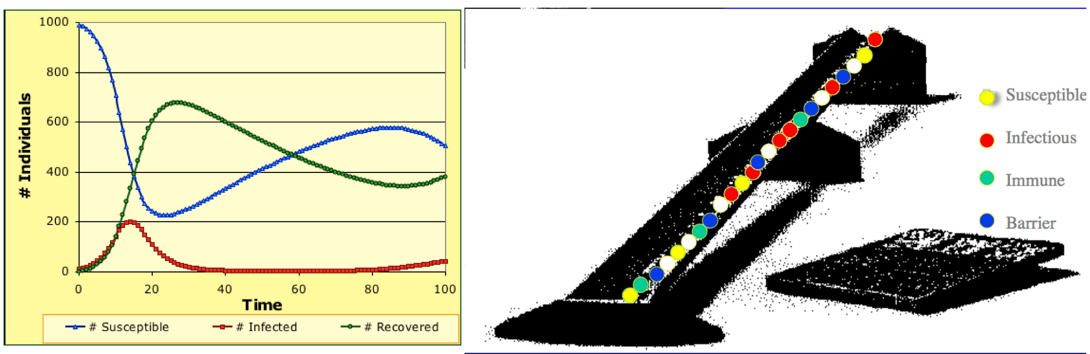

Figure 4. Two models of standard Susceptible-Infected-Recovered epidemiological populations. (a) Screenshot of an interactive spreadsheet S-I-R model in the Biological ESTEEM Project (Anton Weisstein, Truman State University[20]). (b) Students can model S-I-R relationships with marbles on an inclined trough by starting with different amounts of each of the three S, I, and R populations, a fourth population of B marbles to vary the probability that the S, I, R individuals interact, and a set of rules for the spread of a disease (such as an S marble adjacent to an I marble gets replaced by an I marble or that an I marble between two B marbles gets replaced by an R marble). (Reed-Frost model of S-I-R developed by Joan Aron, Johns Hopkins University School of Public Health).

I believe that the use of such interactive models can go far towards Johnson's wish for "making visible patterns in the daily flow of lives and deaths that constitute the metabolism of a city, the rising and falling fortunes of the sick and the healthy" (p. 252).

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[19] http://bioquest.org
[20] http://bioquest.org/esteem

Networks in *The Ghost Map*:

Interestingly, *The Ghost Map* has been published with two different subtitles: (1) *The Story of London's Most Terrifying Epidemic- And How it Changed Cities, Science, and The Modern World* and (2) *A Street, A City, An Epidemic and the Hidden Power of Urban Networks*. While I don't know why either the publisher or the author chose one title or the other for different audiences or editions, I appreciate that Johnson felt at least once that "networks" were so important to his analysis as to appear in the title on the book's cover. My suspicion is the difference lies between the cultural expectations of British and American reading publics.

In either case, the contents of the book seem identical. Johnson uses multiple contexts for networks, but fundamentally I suggest that they fall into only two domains. The first is equivalent to the popular notion of "Small World Theory" in that all of us are connected by a chain of connections such as in the aphorism: "six degrees of separation" (Watts and Strogatz 1998). The second is a physical one: "the elaborate network of sensors sniffing the air for potential threats in urban centers, or hospital first responders reporting unusual symptoms in their patients, or public water facilities scanning for signs of contamination" (Johnson, p.252).

In Johnson's first sense, contemporary graph theory models of the individual to individual, house to house, business or school to home modes of transmission or social network analyses (Lieb, Harding, and Webster 1996) lend themselves to modeling the sleuthing that Johnson so appreciates about Snow's colleague, the Reverend Henry Whitehead, who knew and interviewed each of the families who survived and who had lost members of their families to the cholera outbreak. The network traced by Whitehead was instrumental in convincing others that they had found the famous index case:

> But Whitehead's investigations in 1855 were ultimately as decisive as Snow's in solving the Broad Street mystery. His "conversion experience" reading Snow's monograph set him off in search of the index case, eventually leading him to the baby Lewis. The discovery of baby Lewis led to York's excavation of the pump, which confirmed a direct connection between the pump and the cesspool at 40 Broad. (p. 199)
>
> Snow's map – with Whitehead's local knowledge animating it - … is also an emblem of a certain kind of community – the densely intertwined lives of a metropolitan neighborhood – an emblem that, paradoxically, was made possible by a savage attack on that community. (p. 198)

Follow the dots and lines to the index case.

A recent example of an international effort to identify an index case using graph theory was the SARS outbreak in China. Gerberding (2003) reported that: "Severe acute respiratory syndrome (SARS) was diagnosed in more than 1800 patients in 17 countries (including the United States and Canada) between

February 1 and March 31, 2003. During this two-month period, the World Health Organization (WHO) coordinated an international investigation that has produced unprecedented scientific and epidemiologic discoveries with unprecedented speed. On March 12, the WHO issued a global alert about SARS. On March 14, the Centers for Disease Control and Prevention (CDC) activated its emergency operations center to support the response of the WHO to this global threat." While numerous animals and places were initially suspected as being the vectors and sources of the infection in the first human case, careful detective work traced the first case to a farmer who was treated in the First People's Hospital of Foshan in Nov 2002, and the possible animal source to caged palm civets as amplification hosts and ultimately to Chinese horseshoe bats. In addition, Meyers et al. (2005) have applied network modeling explicitly to SARS (Figure 5). Nishiura, Cook, and Cowling (2011) actually develop three graph theoretic models of the extinction of H1N1 flu that emanated from a single child index case such as occurred in London with the contamination of the Broad Street pump.

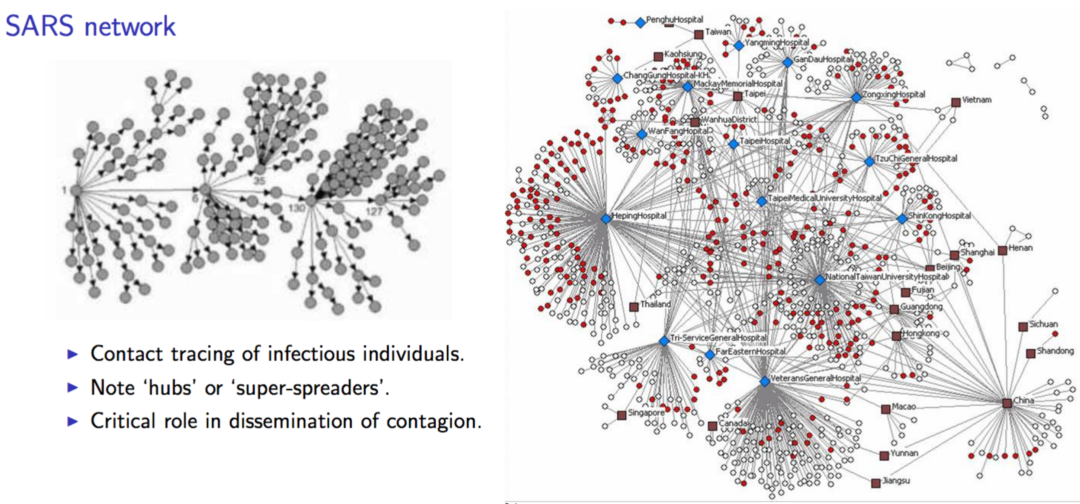

Figure 5. (a). A SARS outbreak in Singapore[21] illustrated as a graph with vertices representing infected individuals and edges representing the infection of another individual. In the case of SARS, while the graph looks like a graph for a sexually transmitted disease where the behavior of "superspreaders" is well known, we do not understand why some SARS infected individuals are so successful in spreading their infection. Lloyd-Smith et al. (2005) note that if an infectious disease has superspreaders then "disease extinction [is] more likely and outbreaks rarer but more explosive." (b). A graph of the strains of SARS related to one another in Chinese hospital cases.[22] Note that which many connections exist similar to the Singapore graph, but that in this case, each vertex in the graph represents a population (of infected hospital patients) rather than infected individuals.

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[21] http://reality.media.mit.edu/epidemiology.php Epidemiology and Information Dissemination: MIT Media Lab's Reality Mining Project
[22] http://ai.arizona.edu/research/bioportal/images/SNA-SARS.jpg

Tracking diseases to their source is a potential source of tremendous controversy. For example, the search for the origin of HIV blamed numerous agencies, researchers, NGO's, etc. before the primate source of SIV that jumped the species barrier was finally identified. Heymann (2006) argues that as a major outcome of the international search for a source for SARS was "A Challenge to Place Global Solidarity above National Sovereignty" and "it is no longer the exclusive privilege of countries to report and respond to infectious diseases occurring in their own territories." Thus, in a "Flat World," global connectedness may transform many conventional assumptions about the responsibility for public health. Graph-theoretic diagrams help make some of these challenges explicit by illustrating how rapidly diseases spread across the world because of air travel of adults rather than most infectious diseases being primarily spread locally by young children.

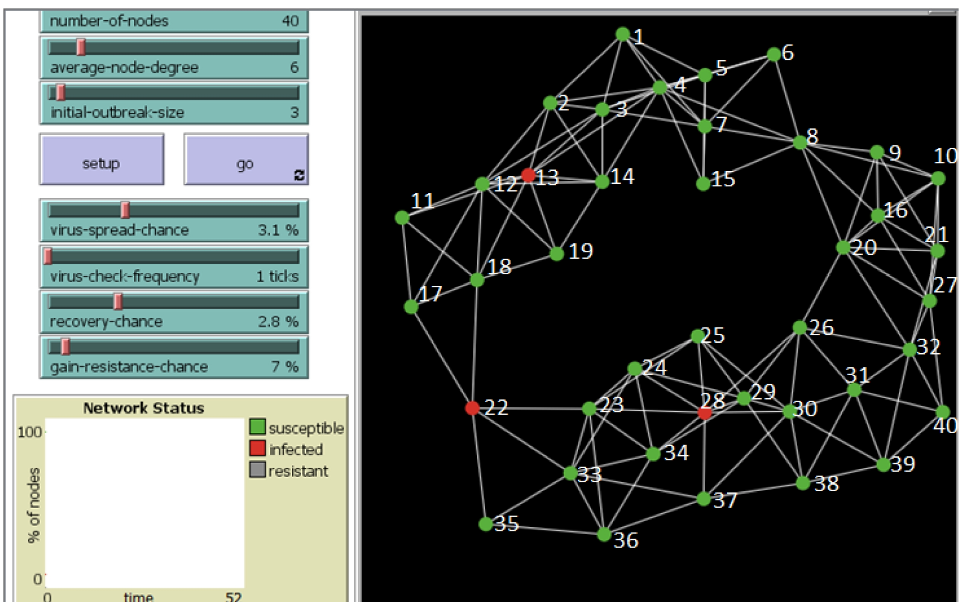

Figure 6. Interactive StarLogo Simulation[23] of a viral infection. Students can set seven different parameters. Most notably, in this graph theory context, students can set the total number of vertices, the initial number of infected vertices, and the average degree of each vertex, as well as relativity infectivity, acquisition of resistance by mutation, and degree of recovery.

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23 http://ccl.northwestern.edu/netlogo/models/SmallWorlds. Bakshy, Eytan, and Lada Adamic. 2005. NetLogo Small Worlds model. Also consider running related modules entitled: AIDS, Virus, and Disease Solo. In U. Wilensky, editor, NetLogo Models Library, Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

A nice model for students to explore has been developed by Professor Uri Wilensky's StarLogo group at Northwestern University (Figure 6). It aptly lets students construct dynamic graphs of the evolution of an infection from an index case to a population-wide epidemic. As Johnson so aptly noted: "Cholera demonstrated that the nineteenth-century world was more connected than ever before; that local public-health problems could quickly reverberate around the globe. In an age of megacities and jet travel, that connectedness is even more pronounced, for better and for worse" (p. 255). For a nice review of the difference between this graph-theoretic approach to looking at the spread of diseases versus the Voronoi tessellation method or "patch" method of John Snow, please see Riley (2007).

Thus, Johnson's final conclusion emphasizes the "small world" hypothesis of network theory and its impact for our public health.

Conclusion

The artificial barriers of departmentalized curricula need not prevent us from fruitful exploration of issues from multiple vantage points. To reiterate Heidi Hayes Jacobs' point:

> No matter what the content, we can design active linkages between fields of knowledge. … Integrated curriculum attempts should not be seen as interesting diversion but more as a more effective means of presenting the curriculum. … The curriculum becomes more relevant when there are connections between subjects rather than strict isolation. (Jacobs 1989)

Thus, an interdisciplinary exploration of Steven Berlin Johnson's (2006) *The Ghost Map: The Story of London's Most Terrifying Epidemic - and How it Changed Science, Cities and the Modern World* has potential for integrating many perspectives simultaneously. The issue of social justice in addressing the spread and control of an infectious disease affords a "commons" wherein multiple lenses such as the humanities, social sciences, sciences, engineering, and mathematics can all contribute to a deep reading and greater mutual understanding.

Cavalli-Sforza, Weiner, and Lesgold (1994) assert that we must "assist students in conducting dialectical activities of constructing, comparing, and evaluating arguments for competing scientific theories." By using mathematics, four specific examples have been demonstrated that are intended to help students explore claims about the consequences of certain actions:

- Maps are constructed with specific purposes in mind and their analysis is dependent upon the active processes of partitioning, classifying, and finding patterns. To appreciate the role of theory as a lens, multiple maps had been constructed before John Snow focused on his water borne theory of the spread of cholera and the pumps as the source of water and their proximity to deaths. The map was not the source of the theory, but the illustration of the theory in order to analyze and develop a pattern consistent with the theory.

- We need to balance the frequent calls for "we need more data," "data suggest," "data-based decision making," "data literacy," and "democratizing data" with the knowledge that statistical evaluation is an active process of *interpretation*, testing hypotheses, and examining *a priori* and *a posteriori* probabilities, possibilities, and plausibilities not a mere *description* of means, medians, modes, and variance. The consequences of the collection of high-quality data and their interpretation for public health in terms of disease prevention are an opportunity for multiple alternative analyses and visualizations.
- Modeling with partial differential equations, a series of finite-difference equations, or with mathematical manipulatives such as beads in a cup or marbles in a trough can help students explore the limitations of "false models" that purposefully have simplified what is happening in the world while simultaneously experiencing the explanatory power of a simple model for prediction, control, and understanding the dynamics of disease spread.
- Small-world theory makes assumptions about the web structure of our relationships and the spread of disease in a social network. By using graph theory, the spread of disease by people with many more connections than others (hubs) is compared with isolated or barely connected individuals. Discussions of strategies such as vaccination, sanitation, and quarantining are easily visualized and can be explored interactively.

Throughout, mathematics has been emphasized as having a role at the interdisciplinary table when rhetorical assertions and historical claims are being made. We as scientists can join our humanities and social science colleagues in fruitful explorations of complex issues and explorations of popular texts chosen to promote just such dialogue. Hopefully, by using our tools of analysis, we can contribute some clarity, caution, humility, and perseverance in our scholarly examination of contemporary issues. For this, we have much to thank Johnson who has popularized science so well in *The Ghost Map* for he concludes his book with two pleas:

> The first is to embrace – as a matter of philosophy and public policy – the insights of science, in particular the fields that descend from the great Darwinian revolution that began only a few years after Snow's death: genetics, evolutionary theory, environmental science. Our safety depends on being able to predict the evolutionary path that viruses

and bacteria will take in the coming decades, just as safety in Snow's day depended upon the rational application of the scientific method to public-health matters. Superstition, then and now, is not just a threat to the truth. It's also a threat to national security.

The second is to commit ourselves anew to the kinds of public-health systems that developed in the wake of the Broad street out-break, both in the developed world and the developing world: clean water supplies, sanitary waste-removal and recycling systems, early vaccination programs, disease detection and mapping programs. (p. 254-255)

Epilogue

I feel it is only fitting to amplify Johnson's call for more biology and mapping to leave the reader with a 21st century map and graph to interpret (Figure 7).

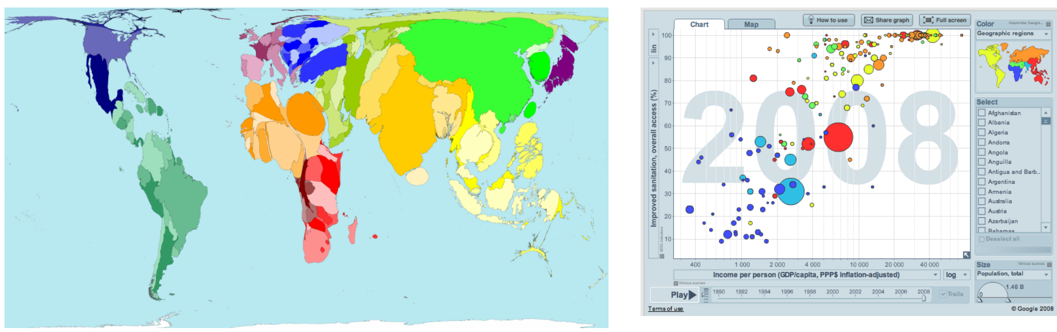

Figure 7. (a) "WorldMapper Territory size shows the proportion of people living with access to basic sanitation that live there. Basic sanitation includes pit latrines and toilets with cesspits, but not those linked to main sewerage systems. … 'Are we to decide the importance of issues by asking how fashionable or glamorous they are? Or by asking how seriously they affect how many?' Nelson Mandela, 2002."[24] (b) A Gapminder plot of the relationship of income to improved sanitation. It can be generated as a movie to illustrate how different countries have changed over recent decades.[25]

My own area of expertise is a combination of molecular evolution and bioinformatics. If I were teaching about cholera, I would draw upon two sub-areas: phylogenetic systematics and phylogeography, because these tools allow us to reconstruct the evolutionary history of *Vibrio cholera*, the bacterium that causes cholera, as strains mutate during their movement around the world and to see the concomitant structural changes in the cholera toxin (Figure 8). We (BioQUEST) have a variety of tools for students to learn the mathematics behind

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[24] http://www.worldmapper.org/display.php?selected=184

[25] http://www.gapminder.org/world/#$majorMode=chart$is;shi=t;ly=2003;lb=f;il=t;fs=11;al=30;stl=t;st=t;nsl=t;se=t$wst;tts=C$ts;sp=5.59290322580644;ti=2008$zpv;v=0$inc_x;mmid=XCOORDS;iid=phAwcNAVuyj1jiMAkmq1iMg;by=ind$inc_y;mmid=YCOORDS;iid=0ArfEDsV3bBwCdE4tekJPYkR4WmJqYTRPWjc3OTl4WUE;by=ind$inc_s;uniValue=8.21;iid=phAwcNAVuyj0XOoBL_n5tAQ;by=ind$inc_c;uniValue=255;gid=CATID0;by=grp$map_x;scale=log;dataMin=295;dataMax=79210$map_y;scale=lin;dataMin=4;dataMax=100$map_s;sma=49;smi=2.65$cd;bd=0$inds

these constructions, so this affords another opportunity for introducing quantitative reasoning in a relevant context.

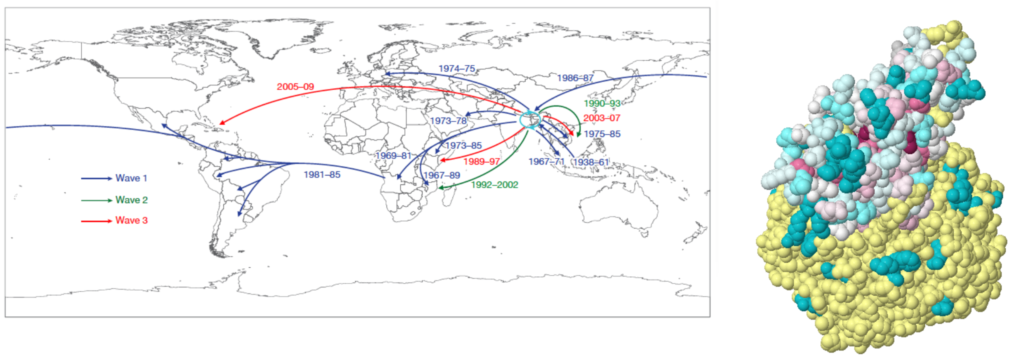

Figure 8. World map of the spread of cholera strains as identified by phylogenetic systematics after the outbreaks from Southeast Asia of new strains in 1961, 1982, and 1992.[26] Three dimensional structure of cholera toxin[27] with most conserved residues in red and most variable residues in green.

Why have these new forms of mapping and graphing health data grabbed our interest? What advantages and disadvantages do they have for possibly influencing the development of policy? Can they even contribute to a deeper interdisciplinary discussion?

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Given my own lack of knowledge of epidemiology, I am deeply grateful to my colleagues Holly Gaff, Old Dominion University, Carlos Castillo-Chavez, Arizona State University, and Anton Weisstein, Truman State University for sharing their expertise and demonstrating tolerance for my ignorance. While recently editing a special issue of *Biology International* entitled "Global Health Has No Borders," authors Marion Field Fass, Beloit College, Ethel Stanley, BioQUEST Curriculum Consortium, Margaret Waterman, Southeast Missouri State University, and Julie Seiter, Oakland Community College, sensitized me to a whole range of issues that influenced me greatly. Also, I personally want to thank Len Vacher, Editor, *Numeracy*, for encouraging me to submit this manuscript and to five reviewers who contributed so many wonderful suggestions for significantly improving the manuscript. Sue Risseeuw, BioQUEST Curriculum Consortium, and Susan Jungck, National-Louis University, toiled to make this article readable, but the responsibility is mine for not taking all of their suggestions to heart.

[26] http://sitemaker.umich.edu/macepid/files/keim_reading_1.pdf
[27] http://www.proteopedia.org/wiki/index.php/1xtc

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