ABSTRACT
Understanding Koch's postulates, including how they are used to study the spread of disease within a population, is central to the teaching of microbiology. These concepts are often presented and discussed with little or no historical background, and as a result students fail to appreciate how the field has developed from past to present. We designed a lesson based on the story of Typhoid Mary to engage students in the learning and application of Koch's postulates in the field of epidemiology and provide insight into the interplay between scientists and the public as illustrated by this episode. The lesson uses an interrupted story technique in which students watch a documentary about Typhoid Mary, with pauses to discuss the events and engage in a role-play to reenact Mary's trial. The purpose is to improve student understanding of central concepts and to foster a deeper understanding of issues associated with the nature of science (NOS), such as how the process of science is influenced by culture and society (and vice versa). This lesson plan was created for a college-level microbiology course for non-majors, but can be easily modified for use in high school settings.

Key Words: history of science; microbiology education; nature of science (NOS); Koch's postulates; Typhoid Mary; epidemiology.

Introduction
Those who study and participate in the field of science have an awareness of how it impacts the world in which they live. As instructors and students of science, we have come to appreciate how the advances of science impact society as a whole, and how the cultural norms of that society can also influence what is studied within that particular field. However, as educators we also have noticed that students are often unaware of these cultural impacts. Understanding how science impacts society (and vice versa) is an important aspect of the nature of science (NOS) (DeBoer, 1991). We have found student unfamiliarity of these impacts is particularly striking in the context of medical science. Students do not recognize doctors as scientists who investigate the cause of disease and search for a suitable treatment, nor do they seem to be aware of how medical practitioners work with other scientists and other professionals to prevent future outbreaks. To help students appreciate and understand the mutual impact of science on society and culture, and vice-versa, we constructed a lesson plan with reference to a well-known episode in the history of science, the case of Mary Mallon, aka “Typhoid Mary.” Our lesson plan, using a documentary and a court case reenactment, shares the cultural context of the time and how Mary's experience shaped our understanding of how disease is spread as well as future epidemiological practices. Our approach embodies a contextualized historical approach to the teaching of NOS in order to help students develop deeper understandings (Matthews, 1994). Studies have shown that the use of an explicit and reflective approach (cf. Abd-El-Khalick & Lederman, 2000) to teaching NOS through the use of contextualized historical narratives can help the students foster a deeper understanding of NOS (Rudge & Howe, 2009; Williams & Rudge, 2016).

Our specific lesson plan was designed using a narrative approach to guide the students’ understanding by showing them how scientists tracked down Mary as the cause of the disease outbreak.
after watching half of the documentary gives students the opportunity to decide how Mary’s case should have been handled before finding out the verdict. In this way, they must consider Mary’s social and cultural standing as an Irish female immigrant trained as a domestic servant for the wealthy. The historical reenactment also gives students the opportunity to consider the position of scientists trying to protect society from further spread of the disease.

The design of this lesson plan is motivated by Next Generation Science Standards with particular attention to the nature of science as well as Project 2061, both acting as guides in helping design curriculum to further engage students in scientific literacy, which is a key aspect of the multifaceted nature of science. Please refer to Table 1, which outlines the specific learning objectives and how the lesson intends to meet each particular objective.

Historical Basis: The Story of Mary Mallon

Typhoid fever is an enteric disease characterized by the onset of high fever, headache, and severe diarrhea (Tortora et al., 2010). This particular disease has been endemic within the human population for centuries. Initially, it was believed that typhoid fever was spread by contaminated food and water. It wasn’t until the work of the English doctor William Budd in the mid-nineteenth century that it was understood that the disease could also be spread person-to-person. Budd’s observations and vigilant study of enteric diseases led him to conclude not only that typhoid fever was spread due to poor sanitation, but also that it could also be spread by individuals who were stricken with the disease (Moorhead, 2002).

It was not until 1880 that Budd’s hypothesis was confirmed through the work of Karl Joseph Eberth (and later verified by Robert Koch), who first isolated and cultured in a laboratory setting the microorganism responsible for typhoid fever (Marinelli et al., 2013). The microbe responsible for causing typhoid fever was identified as Salmonella typhi. The historical narrative of Mary Mallon, a woman who infected over fifty people with typhoid fever but never contracted the illness herself, is often used to introduce students both to how microbes are transmitted and to the concept of someone being a “carrier” for a disease without showing symptoms.

In 1906, the Warner family hired Mary Mallon as their head cook while they were on summer holiday in a portion of Long Island known as Oyster Bay. During this time, six out of ten members of the household became ill with typhoid fever. Not long after this incident, Mary changed jobs. To determine the source of the outbreak, George Soper, a civil engineer who worked in sanitation...
and was well known for his epidemiological investigations, was hired to track the source of the outbreak. After several months of searching, Soper finally tracked Mary down to the residence of her current employer on Park Avenue in New York City. Soper was keen to finding Mary because he believed her to be a healthy carrier of typhoid fever, which he had read could occur in an article published by the German physician Robert Koch (Soper, 1939). Mary did not believe him and became aggressive and uncooperative. Her behavior and her carrier state led her to be arrested and sent into quarantine on North Brother’s Island. After years of isolation and a court ruling against her, Mary was finally released only to be again quarantined five years later—this time for the rest of her life.

The story of Mary Mallon (writ broadly to include the roles of the numerous people she infected, the medical and scientific professionals who studied her case, and the consequences for health policy surrounding contagious diseases) holds importance for how modern epidemiological practices are conducted today. By understanding Koch’s postulates and applying them in practice, scientists were able to determine not only the cause of the disease, but also that Mary was the one (unknowingly) behind the outbreaks. Koch’s postulates paved the way for modern epidemiology by giving scientists a guide to improve their understanding of how to determine what causes a disease and how diseases are spread. Koch was also able to see the limitations of his own postulates (his initial false assumption that anyone with the suspected pathogen must exhibit symptoms of the disease), which in turn led George Soper to recognize that even though Mary did not show signs or symptoms of the disease, she could still be a healthy carrier and infect other people.

**Learning Objectives**

This lesson plan was designed with learning objectives taken from both the Next Generation Science Standards (NGSS) and Project 2061. The NGSS is comprised of learning domains consisting of crosscutting concepts, science practices, and core ideas. These three domains work in conjunction to help the student develop a deeper understanding of science generally as well as how the various fields of science are related to each other. This lesson plan was designed with the crosscutting concepts of “Science as a Human Endeavor” and “Science Addresses Questions about the Natural and Material World,” and the science practice concept of “Scientific Knowledge is based on Empirical Evidence.” All three of these NGSS concepts are designed to help students develop a deeper understanding of NOS. Therefore, this lesson was designed to explicitly address these concepts through in-class discussion facilitated by the handouts, the handshaking activity, and the court case reenactment. These activities give the students hands-on experience with important NOS ideas found in the Next Generation Science Standards (see Table 1 for more details).

Project 2061 provides benchmarks for scientific literacy within the classroom. These benchmarks are statements that act as goals of learning within the classroom, which are based on student grade level. The specific Project 2061 benchmark covered by this lesson is The Scientific Enterprise: “Scientists can bring information, insights, and analytical skills to bear on matters of public concern. Acting in their areas of expertise, scientists can help people understand the likely causes of events and estimate their possible effects. 1C/H6ab.” This benchmark objective will be accomplished through students working on Handouts 1–3 (see Appendix) as well as through in-class discussions and the court case reenactment. In this way, students learn about Mary’s story, think about and discuss how she was treated, and make a decision on how they felt her case should be handled through the court case reenactment—all before learning what was decided as the final verdict. These benchmarks are not new curriculum, but rather act as a tool to aid in curriculum reform, and because of this, these benchmarks dovetail nicely with the Next Generation Science Standards. The following lesson plan was designed with both Project 2061 and NGSS core disciplinary ideas and NOS crosscutting concepts (see Table 1) in mind in order to help students gain a deeper understanding of NOS through an interactive and hands-on learning experience.

With regard to teacher preferences, this lesson plan can also simultaneously incorporate science content objectives covering the major concepts of epidemiology, Koch’s postulates, disease transmission, eukaryotic vs. prokaryotic cells, differences between various single-celled organisms (i.e., viruses, bacteria, protozoans, and fungi), and control/prevention of disease outbreaks. During this lesson students will explore why the Center for Disease Control and Prevention (CDC) tracks certain types of diseases and how they do this, and learn how Typhoid Mary’s story impacted the field of epidemiology at the levels of both science and policy.

**Assessment**

Students will be assessed for their understanding of the nature of science learning objectives through sharing their understanding as well as expressing views and opinions during the in-class discussions and on the handouts. The questions on the handouts are specifically geared to help students reflect upon how scientists and their work can affect the public view and can even have an impact on legal and political outcomes (which can be seen in Mary’s continued incarceration). With regard to teacher preferences, students can also be assessed for their understanding of basic epidemiological concepts through the questions asked in class, the handouts, and through questions asked on exams.

**Typhoid Mary Lesson Plan**

This four-day lesson plan was designed to be implemented in a college-level nursing microbiology course, but can also be used in both a non-majors college course and even in a high school setting. It can also be modified based on the requirements of different courses or classroom needs. Ideas for modification are provided at the end of this article.

**Materials**

- A computer with projector to show the Powerpoint presentation and the NOVA documentary, *The Most Dangerous Woman in America* (Porter, 2004)
- Glo Germ™ and a UV wand for Day 1
- Handout 1 with discussion questions for Day 2
- Handout 2 with discussion questions for Day 3
- Handout 3 with discussion questions for Day 4
Preparation
We created this lesson plan to engage students in how disease can be transmitted from one host to another as well as key aspects of NOS through the historical story of Typhoid Mary. The class is given background information on Koch’s postulates and epidemiology, and is then introduced to the history through the 52-minute NOVA documentary entitled The Most Dangerous Woman in America (Porter, 2004), which was produced for PBS (Public Broadcasting Services) by WBGH. The video can be found on the NOVA website. The video describes the steps taken by key characters not only to find Mary Mallon, but to also determine that she was indeed a carrier of the disease, which in turn shows how epidemiologists work in the field. We believe that the documentary, used as an interrupted story, will engage students in an epidemiologist’s process to find the source of disease. The lesson plan also utilizes a court case reenactment in which students have the opportunity to determine Mary Mallon’s sentence before learning the actual historical verdict. During the court case, students will consider Mary’s social and cultural standing as an Irish female immigrant trained as a household servant for the wealthy. The historical reenactment also gives students the opportunity to take the position of the scientists trying to protect society from further spread of the disease. In this way, students may develop a deeper connection, which in turn may help them better understand the cultural context of that particular historical episode.

Procedure: Day 1
During the first class, the students will be introduced to an activity in which each will be given a plastic container, each container showing a different number. Inside each container will be powdered sugar, except one will contain the powder called Glo Germ™. Students will be asked to coat their right hands with the powder in their containers, and will then be guided by the instructor through a series of hand-shaking rounds. The students will be asked to keep track of the order in which they shake other students’ hands, and in between each round, their hand will be tested under a low-power UV lamp to see if it glows. The glow will indicate that they are infected with the germ.

When the glow germ activity is over, students will try to determine who was the initial infected person who started the spread of disease. The students, whether they realize it or not, will work backward to figure this out. This opportunity can then be used to discuss how epidemiologists also work backward to find “patient zero.” Following the in-class discussion, a review of basic epidemiological terms and an introduction to Koch’s postulates (and their limitations) should take place to familiarize the students with the science as well as the language used, which will aid in future discussions during this lesson plan. At this time, the major differences between prokaryotic and eukaryotic cells can be discussed, as well as the different types of single-celled organism such as viruses, bacteria, protozoans, and fungi. It can also be discussed how some of these types can cause illness. During this discussion, it should also be brought to the attention of the students how scientific studies may effect public understanding of certain issues. Students should also reflect on how they think scientists have provided the public with insight into topics (such as disease), and should be asked if they can think of any particular instances (either past or current) where scientists have provided information and insight to the public for better understanding.

The students’ attention should also be drawn to the fact that this is a facet of the nature of science and part of the responsibilities of the scientist.

Procedure: Day 2
This class will begin with the NOVA film entitled, The Most Dangerous Woman in America (Porter, 2004). Students should be asked to talk notes of during the course of this film. This documentary will be used as an interrupted story, which means that at various points the film will be paused so different topics can be discussed or so that an activity relating to the story can be done in class. At time 26:30, pause the film and discuss Koch’s postulates in terms of Mary’s samples that are being tested in the lab, and discuss how scientists are offering the public insights into how the disease is being spread, as well as how further spread can be stopped and prevented (see Handout 1). Following the conclusion of the discussion the film should be resumed. At time 36:32, pause the film again and divide students into six groups of five students each (in a class of thirty students total).

- **Group One**: Mary and her defense team—This group is responsible for planning and justifying why Mary Mallon should be released from quarantine.
- **Group Two**: New York Department of Health and the prosecution team—This group is responsible for planning and justifying why Mary Mallon should remain in quarantine.
- **Group Three**: The Supreme Court Judges—This group is responsible for listening to the prosecution, defense, and after listening to the verdict of the jury, deciding upon the sentence to be carried out.
- **Group Four**: The Jury—This group is responsible for listening to the prosecution, defense, and witnesses during the trial. After the trial, this group will discuss their verdict and report it to the judges.
- **Group Five**: The Witnesses—Various members will be asked to act as witnesses for either the defense or prosecution. Various witness characters may include: George Soper, Josephine Baker, Mary’s unnamed boyfriend, Mary’s former employer(s).

Procedure: Day 3
During this class session, students will reenact Mary’s court case before they know the actual verdict. Students should be given the first 20 minutes of class to plan their portion of the court case. The remainder of the class will be devoted to the students acting out their court defenses, the jury delivering the verdict, and judges delivering the sentence. The instructor should only be an observer, but available to answer questions from students pertaining to how they should run the court; however, the instructor should not answer anything in terms of how the actual court case of Mary Mallon took place. The instructor’s interaction should be kept to a minimum in order to allow students to be as creative as they want to be. At the conclusion of the court case role play, Handout 2 will be given to the students to begin a follow-up discussion of the nature of science objective chosen for this lesson plan. If not enough time remains for discussion, then this discussion will be continued in the following class session (Day 4).
**Procedure: Day 4**

At the beginning of the class, the students will be reminded of their court verdict from the last class. The remainder of the film will then be shown revealing Mary’s actual verdict as well as the rest of her story. At the conclusion of the film, students will be asked to discuss the ethics of what happened to Mary as well as the nature of science objective through the use of Handout 3.

**Activity Modifications**

The following are recommended modifications to the above lesson plan that may better suit the instructor and class needs:

- The lesson plan can be easily condensed into two days. Students can work in groups when answering questions on the worksheets, review PowerPoint presentations before coming to class, and even finish questions on the worksheet as homework.
- Students could read George Soper’s first-hand account of the historical episode (Soper, 1939).

○ **Conclusions**

This lesson has been used in the college-level classroom with both non-majors and pre-professional health students. Based on the anecdotal feedback from the instructor, the students responded positively to this lesson plan. According to the instructor, with particular emphasis on the court case reenactment, students were active participants in the learning process and were engaged not only with one another, but with the material as well. The instructor reported an excitement in her students during the court case reenactment that she had not seen before during a lecture class. The instructor has reported that students seemed to be interested in the NOS concept and seemed to have a deeper understanding of NOS based on the answers given on the in class worksheets.

○ **Resources**

Powerpoint slides will be made available upon request.

**Handout 1**

1. Being familiar with various biochemical tests and staining techniques, what tests and stains would you use to identify the bacterial cultures in Mary’s fecal sample?
2. How would you apply Koch’s postulates to Mary’s fecal sample?
3. If Mary does have typhoid fever, why is she not sick herself? Do Koch’s postulates still apply?
4. What are scientists and public officials doing currently to inform the public of the disease outbreak?

**Handout 2**

1. What techniques did George Soper and the Department of Health use to determine that Mary was the cause of the typhoid fever outbreaks? How does this relate to current epidemiological practices?
2. How did scientists and public officials handle Mary’s particular case? How did this effect the public’s view of Mary and the disease of typhoid fever?

3. In what other ways have scientists affected the outcomes of public understanding? Does the public always listen to the scientists? Why or why not?

**Handout 3**

1. Why do you think George Soper tried so hard to get Mary to cooperate?
2. Why do you think Mary refused to cooperate? Would the outcome have been different if she had?
3. Did the newspaper reports hurt or help Mary’s cause? Should the Department of Health have stepped in to help ease the public view of the outbreak?
4. Do you think the verdict was fair? If yes, then explain. If no, then offer an alternative sentence and plan for Mary.
5. In the nature of science, it is often scientists’ responsibility to provide insight into areas of public concern. How did the scientists do that with Mary’s case? How do they continue to do that today?

**Notes**

1. A German physician who studied the transmission of disease and is best known for his postulates (Koch’s postulates), which are still used today as a basis for the diagnosis of disease.
2. This product can be ordered from this website: https://www.teachersource.com/product/glo-germ/biology-life-science.

**References**


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