Epidemiology and Education: Using Public Health for Teaching Mathematics and Science

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Scientific and technological advances of the modern world bring clear benefits to society, especially improvements in health. At the same time, creation of opportunities to enable all students to reach their full potential for education is a high priority.[1] Indeed, in the 2006 State of the Union Address, the President of the United States emphasized the importance of education in mathematics and science.[2] Nonetheless, recent critiques of K–12 education have noted that U.S. school systems produce students with inadequate skills and knowledge in science and mathematics. For example, many students perceive that the health and science courses they take are unrelated to decisions they make in their daily lives.[3] Because teachers are often trained inadequately in math and science, they might be uncomfortable teaching these subjects.[4] Less time is spent on science nationwide than on instruction in any other subject, and that time most often focuses on passive learning of facts rather than science as a way of asking questions or testing hypotheses.[3] Perhaps, as a result, the majority of children elect to stop studying science as soon as they are allowed that option.[5] To address this gap and motivate change, the Educational Testing Service (Princeton, New Jersey) is piloting an information literacy test geared toward high school seniors that provides colleges and universities with a tool for assessing the science and technology skills of entering freshmen.[6]

In addition, foreign advances in science now rival or exceed those of the United States.[7] In 2000, Asian universities accounted for approximately 1.2 million of the world's science and math degrees. European universities graduated 850,000 in science and math, but North American universities (in the U.S. and Canada) accounted for only 500,000.[8] The European Union and Asia Pacific nations have steadily increased their world share of the journal literature in the physical sciences, now surpassing the United States in output of papers in physics, chemistry, and materials science.[9] Although this imbalance might have resulted from an increase in the number of foreign journals since 1983, it is reasonable that the number of American scientists publishing exclusively in foreign journals is offset by the number of foreign scientists publishing in American journals, making this an underestimate of the imbalance. Clearly, the

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U.S. is at a crossroads in regard to leading the world in science and mathematics expertise and innovation.

Epidemiology, the basic science of public health,[10] provides a compelling and relevant context for teaching science and mathematics. Successful application of epidemiology among populations for comprehensive health protection and promotion requires interdisciplinary links among medicine, statistics, and other public health sciences (e.g., laboratory, behavioral, social, and genetic). Thus, integration of epidemiologic applications in existing frameworks for math and science teaching both fosters an opportunity for multidisciplinary learning around specific problems and is an avenue for enabling students to grasp the relevance of the real-world application of mathematics and science.

A compelling argument can be made for developing epidemiology as an undergraduate (college) field of study. The Institute of Medicine (IOM) of the National Academies of Science has recommended that education in public health be available to all undergraduate students.[11] Notable examples of undergraduate public health curricula exist, primarily at larger research universities with associated schools of public health (Figure 1). However, the undergraduate curriculum in the majority of colleges and universities does not contain any public health education. Although individual professors have noted the benefit of undergraduate training in epidemiology,[12,13] the lack of curriculum standards and available materials can limit applicability and sustainability when individual professors retire or relocate.

Figure 1. Characteristics of selected examples of undergraduate applications of epidemiology—United States, 2006

Number of institutions offering at least one course	38
Number of institutions offering degrees	22
Areas of concentration[a]	
Community health/health promotion	11
Environmental health	7
Health-care administration	4
Biology	4
Pre-professional/rehab	4
Mathematics/biostatistics	3
Nutrition	3
Informatics/geographic information systems	3
Health policy	2
Aging	2
Other (substance abuse, health communication, social science, school health)	5
Faculty source	
Associated school of public health	7
Medical school	3
Health department	3

[a]Because some institutions offer an undergraduate degree in epidemiology in several concentrations, totals are more than 22.

This article argues that the public health community has an integral role to play in increasing the quality of mathematics and science education in the U.S. and that epidemiology can form the cornerstone of that role. These efforts should improve the quality of math and science education (K–16), integrate science and math education with other curricula, increase students' interest in studying science and mathematics, and inform the public about public health.[14,15] At the same time, this development can help develop and recruit a qualified public health workforce and, ultimately, enhance public health.

EXPERIENCE AT THE K–12 LEVEL

We conducted a literature review to determine existing resources for use of epidemiology in education. We searched the National Library of Medicine's PubMed database, ERIC, Google Scholar, and PsychNet (from 1966 to 2006) using the Medical Subject Heading (MeSH) terms "epidemiology, public health, education, teaching," and 228 articles were returned. Of those, 204 were excluded because they dealt with teaching epidemiology in specific clinical contexts or with the role of educators in addressing specific public health problems (e.g., acquired immunodeficiency syndrome [AIDS]).[16] Of the 24 articles remaining, 10 presented discrete exercises for use in classrooms. For example, Cronin[17] describes a teaching unit that simulates an outbreak of cholera to teach the scientific method. McEachron and Finegold[12] describe use of epidemiology with eighth-grade students and with undergraduate business majors. Sahai and Reesal[18] argue that introducing applications of probability and statistics in the context of epidemiology can motivate students with limited initial interest to become comfortable with mathematical tools; they then illustrate selected common applications of probability and statistics in epidemiology (e.g., risk estimates and screening accuracy).

We found no documentation of programs that disseminated materials beyond the publication or offered an evaluation of the program's effectiveness. In this article, we present examples of successful programs to integrate epidemiology into K–12 and undergraduate college education.

The Centers for Disease Control and Prevention (CDC) has developed teaching tools (Excellence in Curriculum Integration through Teaching Epidemiology [EXCITE]) to introduce middle and high school students to epidemiology.[19] EXCITE materials include:

- background for teachers on epidemiology and outbreak investigations;
- student exercises based on actual public health investigations;
- preparatory material for CDC's events in the annual National Science Olympiad;
- profiles of practicing epidemiologists; and
- a glossary and links to other Internet-based resources.

These instructional modules enable teachers to provide students with quantitative and reasoning skills to interpret risks, engage in comparative reasoning, illustrate math and science concepts and methods through real-life case studies and exercises, and engage in lifestyle decision-making. In addition, the modules provide students with examples of multiple career paths.

We analyzed these epidemiology materials in terms of their ability to address math and science content standards and vetted this analysis with teachers and curriculum experts. For example, the majority of the standards for grades 5–8 are covered in depth by these materials (Figures 2 and 3). In addition, this curriculum aligns with the National Science Education Standards' fundamental abilities in "science as inquiry"[20] and attributes of scientific literacy.[21]

These materials have been disseminated widely and used successfully in multiple settings for K–12 education. For example, Emory University (Atlanta, Georgia) adapted the curriculum for Emory Science Education Partners,[22] a program to enhance science teaching at the elementary level in the Atlanta Public School system, by providing science materials and helping kindergarten through fifth-grade teachers use inquiry-based instruction. Emory's program is also used in the Georgia Governor's Honors Program, a six-week summer instructional program designed to provide intellectually gifted and artistically talented high school students with challenging and enriching educational opportunities not usually available during the regular school year. The curriculum developed for middle school (grades 6–8) has been distributed to more than 3,500 teachers. In addition, professors at Montclair State University (Upper Montclair, New Jersey) have developed Detectives in the Classroom, a curriculum to prepare middle school students to make

Figure 2. Science content standards, grades 5–8[a]

Standards	*Degree of coverage*	*How supported*
Unifying concepts and processes		
Evidence, models, and explanation	OOO	Students use epidemiologic study models to gather, analyze, and evaluate data regarding public health problems and to form conclusions and recommendations.
Change, constancy, and measurement	OOO	Students statistically evaluate and compare groups over time to measure differences in risk and disease.
Evolution and equilibrium	O	Students learn about the development, transmission, prevention, and control of disease through the fundamentals of agent, source, and host relationships.
Form and function	O	Students explore the biomechanics of injury and injury prevention and control.
Science as inquiry		
Abilities necessary to do scientific inquiry	OOO	Students learn to collect and analyze data; develop, evaluate, refine, and reevaluate hypotheses; form conclusions; and communicate findings.
Understanding scientific inquiry	OOO	Students conduct outbreak investigations based on epidemiologic principles and practice.
		Students use statistical analysis to evaluate and support their hypotheses.
		Students learn about scientists who use technology to collect data, perform diagnostic evaluations, and communicate with other scientists and with the public.

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Figure 2 (continued). Science content standards, grades 5–8[a]

Standards	*Degree of coverage*	*How supported*
Life science		
Structure and function among living systems	O	Students study disease and disease organisms and how they interact with and affect individual people and populations.
Reproduction and heredity	OO	Students learn that genetics and heredity affect an organism's susceptibility to diseases.
Regulation and behavior	OOO	Students learn how health problems can be prevented through lifestyle choices, good hygiene, safety measures, and other means.
Populations and ecosystems	O	Students learn how agent, source, and host interact to create health problems among populations and how to prevent and control these problems.
Diversity and adaptations of organisms	OO	Students learn about the life cycle of parasitic organisms through the chain of disease transmission.
Science and technology		
Understanding science and technology	OO	Students learn how technology is used to track, investigate, and solve health problems.
Science in personal and social perspectives		
Personal health	OOO	Students learn about factors that affect wellness and the public health institutions that promote personal wellness.
Populations, resources, and environments	OOO	Students learn how elements of the natural environment affect the health of populations and how they can interact with the environment to improve health.
Natural hazards	OO	Students learn of natural hazards that cause disease and injury and how communities can respond to these hazards.
Risks and benefits	OOO	Students learn about different factors that affect wellness and how to analyze risk through attack rates and other measures.
Science and technology in society	OOO	Students learn about how scientists use technology to identify and address health problems in populations.
History and nature of science		
Science as a human endeavor	OOO	Students are introduced to different roles of scientific practitioners active in the field of public health.
Nature of science	OOO	Students learn that the scientific method is a process of observation, analysis, evaluation, and debate with other scientists.
History of science	OOO	Students learn about the development of modern epidemiology by contrasting it with early attempts at outbreak control and prevention. They also learn about the impact of disease and epidemiologic inquiry on human history.
Understanding scientific inquiry	OOO	Students conduct outbreak investigations based on epidemiologic principles and practice.
		Students use statistical analysis to evaluate and support their hypotheses.
		Students learn about scientists who use technology to collect data, perform diagnostic evaluations, and communicate with other scientists.

[a]http://www.nap.edu/html/uses

OOO Covers the standard in depth.

OO Covers the standard.

O Touches on the standard.

Figure 3. Data analysis content standards, grades 6–8

Standards	*Degree of coverage*	*How supported*
Formulate questions that can be addressed with data and collect, organize, and display relevant data		
Formulate questions, design studies, and collect data about a characteristic shared by two populations or different characteristics within one population	OOO	Students use study designs to gather, analyze, and evaluate data regarding why one group of people might experience a health problem, whereas a similar group does not.
Select, create, and use appropriate graphical representations of data	OOO	Students create epi curves (histograms) from reported disease data. Box plots are used to examine descriptive characteristics of populations. Scatter plots are used to evaluate associations between variables.
Select and use appropriate statistical methods to analyze data		
Find, use, and interpret measures of central tendency and spread, including mean and interquartile range	OOO	Students calculate measures of central tendency and spread to characterize populations and compare two populations (e.g., age of ill and well groups).
Discuss and understand the correspondence between datasets and their graphical representations, especially histograms, stem-and-leaf plots, box plots, and scatter plots	OOO	Students conduct outbreak investigations based on epidemiologic principles and practice. Students use these graphical presentations to evaluate and support their hypotheses. Students learn about scientists who use these representations to perform diagnostic evaluations and to communicate with other scientists and the public.
Develop and evaluate inferences and predictions that are based on data		
Use observations about differences between two or more samples to make conjectures about the populations from which the samples were taken	OOO	Students study disease and disease organisms and how they interact with and affect individual people and populations. Students use data about ill and well populations to derive hypotheses about risk and prevention.
Make conjectures about possible associations between two characteristics of a sample on the basis of scatter plots of the data and approximate lines of fit	OO	Students use scatter plots and lines of fit to assess associations between risk factors and illness.
Use conjectures about possible associations between two characteristics of a sample on the basis of scatter plots of the data and approximate lines of fit	OOO	Students learn how to generate hypotheses between characteristics of a population (e.g., weight and serum cholesterol).
Understand and apply basic concepts of probability		
Understand and use appropriate terminology to describe complementary and mutually exclusive events	OOO	Students learn how investigation of public health problems involves classification of people into four complementary and mutually exclusive groups on the basis of their illness status (ill vs. well) and whether or not they have been exposed to a risk factor (exposed vs. unexposed).
Use proportionality and a basic understanding of probability to make and test conjectures about the results of experiments and simulations	OOO	Students learn to calculate risk estimates on the basis of probabilities and use these estimates to test hypotheses about what causes health problems.
Compute probabilities for simple compound events by using such methods as organized lists, tree diagrams, and area models	OO	Students use the distribution of disease to calculate time-to-event data and assess mode of transmission.

OOO Covers the standard in depth.

OO Covers the standard.

O Touches on the standard.

personal and collective evidence-based, health-related decisions.[14]

Further, since 1999, the National Science Olympiad has included a Disease Detectives event in state and national competitions.[23] The Science Olympiad is an international nonprofit organization devoted to improving the quality of science education, increasing student interest in science, and providing recognition for achievement in science education by both students and teachers. These goals are accomplished through integrating National Science Olympiad topics into science classroom activities and training workshops. District, regional, state, and national tournaments are rigorous academic interscholastic competitions that consist of a series of individual and team events for which students prepare during the entire academic year. Each year, more than 14,000 K–12 schools participate from all 50 states and Ontario, Canada.

The Disease Detectives event presents students with an actual outbreak or other public health problem (e.g., injuries or tobacco use); the students use data presented to evaluate risks, hypothesize etiology, and design appropriate control or intervention measures. Only 34 events are in each tournament, and events are evaluated each year. No new event can be added until an existing event is discontinued. The continuation of Disease Detectives in 2006 for its seventh year is evidence of its value for science instruction.

To further extend its outreach to science teachers, CDC has developed the Science Ambassador Program.[24] This collaboration between the education community and public health scientists allows teachers to develop science lesson plans based on epidemiologic concepts, particularly birth defects, developmental disabilities, disability and health, genomics, and chronic disease topics. These lesson plans are disseminated nationally.

Building on this development of available curriculum materials, the Robert Wood Johnson Foundation has developed the Young Epidemiology Scholars (YES) competition to interest students in careers dedicated to improving the health of the public, while simultaneously raising the general level of awareness about factors important to health. The student award program is coupled with teacher awards for recognizing outstanding contributions to curricula or mentoring.[25]

EVALUATION OF K-12 MATERIALS

The Georgia Governor's Honors Program used an evaluation that included a pre- and post-test that examined students' awareness of math and science concepts as used in the epidemiologic case study. Scores on the post-test were significantly higher (using a t-test) for all students (77.5 vs. 61.4; $p=0.04$), as well as for subgroups by sex (male post-test = 76.6 vs. male pre-test = 59.6 [$p=0.03$]; female post-test = 78.8 vs. female pretest = 61.9 [$p=0.04$]). Evaluation of the simulated outbreak investigation indicated that only 10% responded that they knew much of the information before the instruction; however, 80% reported that the curriculum provided the information needed to successfully complete the exercise.

The impact of the modules developed at Montclair State University was assessed by measuring students' abilities to meet National Science Education Standards and students' interest in science in a controlled pre-test/post-test comparison.[26] The prototype modules were refined further on the basis of field-testing experiences, results of students' assessments, and students' feedback.[27]

THE EXPERIENCE AT THE UNDERGRADUATE LEVEL

When examining the prevalence of epidemiology at the undergraduate college level, results are mixed. Certain institutions with schools of public health offer coursework in epidemiology and public health at the undergraduate level,[28] ranging from a single course[29] to an undergraduate major.[30,31] In addition, programs are often taught within other fields (e.g., physical education or nutrition) and may not be aggregated in a manner for students to access them easily as part of a math and science concentration (Figure 1).

Riegelman et al.[28] articulate a rationale for undergraduate public health curricula. First, the public is more aware of public health activities, in large part as a result of terrorism and natural disasters. Second, medical and graduate schools value an undergraduate education that is broader than traditional science. Third, public health provides a context for interdisciplinary undergraduate education. Fourth, public health provides a foundation for postgraduate study in selected fields (e.g., business, law, and international affairs). Fifth, the skills taught in undergraduate public health education equip graduates for immediate careers in local public health, health information systems, or human services.

One problem that Riegelman et al. cited in 2002 was the lack of preparation of entering college students for this curriculum. We now have an answer to that problem, in part, through the K–12 curriculum development efforts discussed previously. In addition, excellent teaching resources suitable for the undergraduate level have been published.[32,33]

One of us (Stroup) developed a course in epidemiology that satisfied the science requirement at a liberal arts college. We used a pre- and post-test design and a validated rubric to assess knowledge of epidemiologic concepts and critical thinking skills of students (Figure 4).[34] Scores on epidemiologic knowledge increased significantly during the course (68% to 87%, standard error = 4.8). Three items were used to measure critical thinking skills (Figure 5); these items were selected by the Director of Assessment at the college on the basis of the validated rubric. On a scale of 1–4, mean responses for the three items were 3.9, 3.8, and 3.6. Of particular note, a student's score on the critical thinking rubric was strongly predictive of her grade in the course, regardless of the student's overall grade point average or choice of major.

Figure 5. Items used to assess critical thinking skills

1. In the outbreak of Brazilian Pupuric Fever discussed in call, the disease detective used a "blinded" analysis in providing the samples to the laboratory for testing. Why was it important to use a blinded analysis? What would be the possible result of not using a blinded analysis in this situation? Is blinding always possible in epidemiologic studies? Why or why not?
2. In the spring of 2005, the *Journal of the American Medical Association* published a study from the Women's Health Initiative reporting on low-fat dietary pattern and the risk of invasive breast cancer (Prentice RL, Caan B, Chleowski RT, Patterson R, Kuller LH, Ockene JK, et al. Low-fat dietary pattern and risk of invasive breast cancer: the Women's Health Initiative Randomized Controlled Dietary Modification Trial. JAMA 2006;295:629-42). List at least three characteristics of this study you would need to know about in order to assess the validity of these results.
3. Using criteria defined for making a condition a priority for women's health, explain whether diabetes is a women's health concern. Be specific in your answer, citing data where relevant.

DISCUSSION

The idea of a government agency with a robust education component is not new. For approximately 50 years, the National Aeronautics and Space Administration (NASA) has been a presence in the nation's school system.[35] Dedicated to scientific research and to stimulating public interest in aerospace exploration, as well as science and technology in general, NASA offers well-developed resources for students and teachers in grades K–12, in college, and in graduate school. The resultant knowledge of NASA and space exploration has produced a well-informed public, as well as a future NASA workforce. To meet the requirements of the Government Performance and Results Act of 1993,[36] NASA developed the NASA Education Evaluation Information System to demonstrate outcomes of educational performance goals, which are defined in the categories of NASA's education programs, reflecting the unique role of NASA as a federal mission agency as well as NASA's agency-wide vision and strategic objectives. The online system[37] provides the number of students reached, participants' ratings, and other outcome information. Data from this system are used when NASA scientists testify on educational programs before U.S. Congressional committees and the White House Office of Management and Budget.

Figure 4. Holistic critical thinking rubric[a]

- Accurately interprets evidence, statements, graphics, and questions.
- Identifies the salient arguments (reasons and claims) pro and con.
- Thoughtfully analyzes and evaluates major alternative points of view.
- Draws warranted judicious, nonfallacious conclusions.
- Justifies key results and procedures, explains assumptions and reasons.
- Fair-mindedly follows where evidence and reasons lead.

[a]Facione and Facione 1994, used with permission.

Numerous forces argue that this is indeed the time for comparable attention to epidemiology as part of education. Teachers report difficulties in getting students to think about the evidence that supports conclusions when solving problems.[38] Quantitative literacy and interdisciplinary teachings are becoming more important in education. As previously noted, The Educational Testing Service has developed a new information literacy test for high school students to provide colleges and universities a tool for assessing quantitative and technological skills of entering freshmen, allowing admissions departments to make determinations about readiness for college-level work.

In addition, the Association of Schools of Public Health has convened an expert committee to develop standards for an undergraduate course in public health.[39] The Education Development Center, Inc. (associated with the Agency for Internal Development) has launched a major initiative to seek more effective methods for teaching to improve health and well-being on every continent.[38]

Epidemiologists and public health professionals can play a part in ensuring recognition and support for public health in education. Epidemiologists and the larger public health community can partner with K–12 and undergraduate education to develop and promulgate appropriate curriculum materials and to assess the impact of these materials on students' interest and ability in math and science. Indeed, epidemiologic methods have great potential for increasing the effectiveness of education beyond math and science.[40] For example, global AIDS prevention efforts have tremendous ramifications on the political economy, and explanations for underutilization of preventive health screenings among minority populations have roots in cultural and anthropologic constructs.

The public health community can partner in new ways with education to increase public health literacy, contribute to a future public health workforce, and ultimately enhance the health of communities—providing curriculum materials, internship experiences, evaluation expertise, and research opportunities. The result will be a cadre of high school and college graduates who understand the concept of risk that underlies critical thinking skills. These people will understand the pervasive influence of public health activities beyond health care for indigent populations to injury prevention, safe air and water, health behaviors, and preparedness. They will be informed community members when public health policy is under discussion and able to influence effective allocation of scarce resources. And they may contribute to a pipeline of careers in public health. To ignore this challenge would be to admit that epidemiology is the purview of a select few who manage to find their way into the work of protecting and preserving the health of communities and to relegate public health to a lower rung among the sciences.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention.

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