Commentary

Current Practices in Teaching Introductory Epidemiology: How We Got Here, Where to Go

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The number of students and disciplines requiring basic instruction in epidemiologic methods is growing. As a field, we now have a lexicon of epidemiologic terminology and particular methods that have developed and become canonical through the historical development of the field. Yet, many of our basic concepts remain elusive to some students, particularly those not pursuing a career in epidemiology. Further, disagreement and redundancy across basic terms limit their utility in teaching epidemiology. Many approaches to teaching epidemiology generally start with labeling key concepts and then move on to explain them. We submit that an approach grounded not in labels but in foundational concepts may offer a useful adjunct to introductory epidemiology education. We propose 7 foundational steps in conducting an epidemiologic study and provide examples of how these steps can be operationalized, using simple graphics that articulate how populations are defined, samples are selected, and individuals are followed to count cases. A reorganization of introductory epidemiology around core first principles may be an effective way forward for educating the next generation of public health scientists.

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Editor’s note: An invited commentary on this article appears on page 669.

How do we teach introductory epidemiology?

Introductory instruction in basic epidemiologic methods is a requirement for all students of public health and, increasingly, many related disciplines (1). In addition, 2 trends suggest an ever greater need for introductory epidemiologic training that is accessible to a broad range of trainees. First, the growing and dominant health challenges of the 21st century (obesity, diabetes, and emerging infections, among others) will require a new generation of public health professionals trained in the basics of epidemiologic science in order to study and control these health threats. Second, job growth in the health sector is projected to increase in the next decade, including medical research, and jobs requiring a master’s degree are projected to be especially in demand (2). Epidemiology training is a requirement for many people employed in this sector.

The field of epidemiology has both consolidated and grown substantially during the past 25 years. We now have a lexicon of epidemiologic terminology and particular methods that are well-established in the discipline. Our understanding of study design, disease causation, measures of disease occurrence, bias, interaction, and confounding has advanced in deep and nuanced ways yet needs to be explained in a simple way for a large audience of students beyond those training specifically in epidemiology (3).

Commensurate with this growth in the field, a variety of introductory textbooks for epidemiology are now available, from basic guides to study design and analysis for the general public health student (4–6) to more theory- and methods-driven guides for the student interested in pursuing epidemiology as a career (7, 8). These introductory textbooks are remarkably similar in architecture. In particular, the ordering of information is relatively similar across existing textbooks and has remained fairly constant over the past 25 years. In Figure 1 we show the distribution of major introductory topics in epidemiology among 14 introductory epidemiology textbooks currently available for purchase (7, 9–21), with publication dates ranging from 2002 to 2011. These books were selected to represent the
majority of textbooks being used by schools of public health and those that are foundational to the field, based on discussions with a broad range of colleagues across the Americas and Europe. While other introductory epidemiology textbooks are available, they are less widely used, in our estimation. The textbooks included are those by Aschengrau and Seage (9), Bhopal (14), Bonita et al. (15), Carneiro and Howard (16), Carr et al. (17), Friis (18), Gerstman (12), Gordis (10), Kestenbaum (13), Merrill (19), Rothman (7), Saracci (20), Webb et al. (21), and Wassertheil-Smoller (11). Squares in Figure 1 become darker as the number of textbooks with the concept "X" in proportionate book position "Y" becomes larger. For example, the dark square associated with "<10th Percentile" for "Definition/history" indicates that the vast majority (more than 80%) of introductory epidemiology textbooks introduce definitions and epidemiologic history in the first 10% of the book.

While there is some variation in the proportionate position of major epidemiologic concepts, with few exceptions these texts generally present epidemiologic concepts in the following order. First, textbooks present basic measures of disease occurrence such as prevalence and incidence, risks and rates, etc., and an overview of surveillance and descriptive epidemiology. Second, textbooks present major epidemiologic study designs, including cohort studies, case-control studies, and (though there is more variability here) randomized trials. Some texts include a chapter on cross-sectional studies and/or "ecological" studies. Third, textbooks present introductory concepts in bias and confounding, and some textbooks cover basics of interaction. Causal inference is often included, although there is more variability in placement; some textbooks introduce causal inference at the beginning of the text (7), some at the end of the text (9, 10). While there is wide
variation in the vocabulary and amount of space devoted to each concept, almost all textbooks cover these concepts to some degree.

How did our current educational paradigm emerge?

The current paradigm for teaching introductory epidemiology grew through the development of the discipline itself. As public health crises arose across the 19th and 20th centuries, too did design and analysis techniques aimed at isolating and explaining the causes of disease, and commensurately we have added, largely sequentially, to the list of topics we teach in introductory epidemiology courses.

For example, the roots of epidemiology as a population health science can be traced to the 17th century as John Graunt pioneered approaches to tabulating population health and mortality, presenting rates, ratios, and proportions for various causes of mortality. Epidemiology grew further in the 18th and 19th centuries as public health scientists such as William Farr developed more sophisticated life-table approaches to understanding the force and burden of mortality and formally separated risks and rates, and pioneers such as John Snow used epidemiologic group comparisons to understand the mode of dissemination of the London, United Kingdom, cholera epidemic. The basic measures of disease frequency and occurrence were developed and applied to the prevailing public health problems of the 19th century. Correspondingly, most introductory textbooks in epidemiology today begin by instructing students in the very descriptive epidemiology and measures of disease occurrence developed centuries prior (see Figure 1).

With the advent and development of large-scale prospective studies, methods were needed to account for differential follow-up periods, exposure time, time-varying exposures, and competing risks. A look through historical epidemiology textbooks indicates that concepts such as person-time appeared as early as 1937 in Hill’s text (22) and started receiving substantial attention in textbooks starting with MacMahon et al.’s seminal text in 1970 (4). Paneth (23) notes that the first mention of the term “case-control” in a biomedical paper appeared in 1967, and the term did not appear with frequency until the 1980s. The central principles of case-control studies that comprise our rich understanding today, such as sampling controls from the same source population as cases and selecting subjects independently of exposure, were articulated by early scholars (e.g., Lilienfeld (24) and Cornfield (25)) and gained substantially more attention with the advent of “modern” epidemiology through Miettinen’s methodological work (26), as well as that of Rothman (7, 27). Echoing this historical timeline, most epidemiology textbooks today present study designs, particularly cohort and then case-control studies, in sequence, following their introductory presentation of descriptive epidemiology and measures of disease occurrence. Histories of formalized assessments of bias, confounding, and interaction are still under development as methodologists continue to uncover insights about the nature and magnitude of bias in our studies (3), and as such these topics tend to be covered towards the end of epidemiologic texts.

In summary, historically the concepts of descriptive epidemiology, cohort studies, case-control studies, experiments, bias, and confounding have developed separately, arising from different intellectual traditions, and different methodologists have made key contributions to the development of a rich body of knowledge.

What are the limitations of the dominant approaches?

The consistency of the concepts taught, and of the sequence in which we teach them, across a wide range of books of varying depth and scope would seem to suggest that we have consensus as a field about how epidemiology should be taught, and that this consensus is reflected in the relative similarity in outline in the major epidemiologic textbooks and consequently in most introductory epidemiology courses. However, epidemiology remains a difficult subject for some students of public health. Indeed, the need for improved accessibility in the teaching of quantitative foundations was identified by the Institute of Medicine as a critical tool for the next generation of public health professionals more than 20 years ago (28) and was reinforced in more recent Institute of Medicine recommendations (29).

Core quantitative competencies have been developed by public health agencies and established by major schools of public health in order to implement these improvements (30, 31).

Our experience as teachers and at least 1 study of public health graduate students indicates that a substantial proportion of public health students have difficulty grasping the core competencies that are foundational to our science (32). Certainly, population-level thinking is not easy, and epidemiology is a rigorous science. A proportion of students will struggle with the concepts regardless of how they are taught. However, we wonder whether the approach taken in our introductory texts, which is by-and-large consistent, is in some ways contributing to the difficulty that remains among our students in mastering basic concepts. At the very least, the contrast between the certainty we seem to evince through the consistency in our textbooks and the proportion of students who have difficulty mastering our concepts is a gap worth evaluating.

We suggest that 3 central challenges underlie the difficulty in successful introductory epidemiology instruction.

First, with few exceptions, existing approaches to teaching epidemiology build a sequence of concepts, whether intentionally or not, based on their historical evolution in our field. Intentionally or not, we are asking students to memorize terms in a particular sequence determined, in large part, by historical accident, and are asking students to do so often without making connections with the fundamental principles that underlie population science. Certainly, there is nothing inherently problematic in teaching a discipline through the historical way in which its methods arose, and such an approach can be quite effective. In many introductory texts, however, the historical grounding and sequence of methodological instruction is not explicitly articulated, and the concepts are sometimes presented in discrete ways that do not allow the student to see connections and grasp redundancies across topics. By and large, introductory textbooks adopt an approach that labels concepts and then attempts to explain them. Students memorize the rules and labels in order to understand the appropriate ways to conduct a study and draw inference. Each epidemiologic concept that we introduce to
students can be conceptualized as 1 piece of a new cognitive schema (33) that we hope to impart to students by the time they finish their epidemiology training. Many of our current approaches teach students about specific concepts, such as “When would you conduct a case-control study rather than a cohort study?,” “How do we control confounding by stratified analysis?,” and “Is recall bias differential or nondifferential misclassification in this particular study?” as distinct pieces of information. We ensure that students are competent with regard to each piece of information, requiring students to memorize lists of study strengths and limitations, rules for assessing confounding, and the definitions of concepts like misclassification. While these are important assets for students to come away from an introductory epidemiology class with, this approach runs the risk of confusing students about the way in which concepts work together to build a complete whole for conducting epidemiologic science. By way of illustration, labeling a “case-control study,” describing its attributes, contrasting it and comparing it with experiments and cohort studies, and articulating its strengths and weaknesses runs the risk of eliding the fundamental commonalities of these approaches.

Second, disciplinary arguments over definitions and terms have led to a great diversity in how basic epidemiologic concepts are defined in introductory books. While most in the field would agree that, for example, “selection bias” is an important concept to teach in introductory epidemiology, available texts vary considerably in how it is described, how it is defined, the weight given to the concept, and the relationship between selection bias and concepts such as confounding and generalizability. Similar incongruence emerges for many other concepts, such as “rate” and “confounder,” and even for concepts that we might consider to be at the core of epidemiology, such as the definition of a population. In addition, our particular choice of terminology distances us from natural allies such as biostatisticians, who themselves have different definitions for confounding and bias. Further, within textbooks (although of course there are exceptions), these concepts are often presented in discrete and unconnected ways, leaving redundancy between some terms (e.g., selection bias and confounding) and gaps in the description of other core concepts (e.g., in our opinion, representative sampling).

Third, a related yet more fundamental struggle: While we have, as a field, articulated many discrete concepts that are important for students to learn, there is no connecting overarching set of first principles that guide the field’s general approach to teaching introductory epidemiology. Such an articulation would not necessarily provide different content to the field in terms of the core epidemiologic concepts, but it would provide a difference in terms of approach, guiding the student through from first principles to the more complex methods that we handle. The economics field is a nice illustration of a discipline that has been able to reduce itself to core canonical concepts, which are cast as “laws.” When a complex discipline is distilled into a core set of principles, these principles can guide the teaching of the discipline to new students and provide common grounding for the field.

Succinctly, a maturing and ever more relevant discipline is distilled into a core set of principles, which are cast as fundamental arguments about teaching epidemiology still hold even if we disagree or agree with the 7 steps we have outlined, the central arguments about teaching epidemiology still hold—the need to start from first principles and the necessity of articulating those principles.

Could we generate first principles for epidemiology?

We argue that the foundational concepts in epidemiology could be taught in a way that begins with the problems that generated the formation of certain concepts, follows through with the connections among various concepts, and in the end labels each concept after students fully understand the theory and rationale behind the method or methods in question. Students may be most successful in learning the fundamentals of epidemiology when seemingly discrete pieces of information regarding population health sciences are transmitted in ways that explicitly illustrate the connections from which these concepts flow (34).

In thinking through the need for a set of first principles for the field, we suggest an approach that focuses the teaching of introductory epidemiology on 7 steps (Appendix Table 1). We consider these steps to be the foundational building blocks of conducting an epidemiologic study, and we focus our approach to teaching epidemiology around the articulation of these steps. Broadly, these steps involve defining a population of interest; identifying and developing measures of key health indicators and their potential determinants; taking a sample; estimating measures of health indicator occurrence, frequency, and association; and rigorously assessing internal validity, interactions, and the generalizability of the observed associations. An entire textbook could be devoted to each one of these steps, but these are the steps that we consider to be the foundational principles underlying our definitions and the concepts most important for introductory public health students. Our purpose in explicating these steps is to concretize the basics of conducting an epidemiologic study, providing introductory students with a broad framework for understanding the basics of our science by focusing on foundational concepts.

These steps are neither new nor novel; we recalculate and reorganize material that many in the field have presented for years. We also do not anticipate that the field will agree that these foundational principles are the best for every context or student body. For example, we did not include infectious disease modeling or screening in our foundational principles. Another epidemiologist might include one of these concepts. However, for us, to provide an integrated, problem-focused, overarching schema for understanding the basics of epidemiologic science, we have found that these 7 steps provide a solid grounding for students in a way that makes all concepts connected. Regardless of whether some in our field would agree or disagree with the 7 steps we have outlined, the central arguments about teaching epidemiology still hold—the need to start from first principles and the necessity of articulating those principles.

Articulating epidemiologic concepts from first principles

Starting epidemiologic instruction from a set of first principles introduces new opportunities for an epidemiologic...
pedagogic vocabulary that can tie together core concepts underlying the discipline. In particular, for each of these core first principles, we can provide a combination of instruction that bridges verbal and mathematical material, perhaps given cohesion through the judicious use of graphical illustrations. An example of our approach to instructing students on how to select a study sample is found in Figure 2. At its very core, epidemiologic science involves watching groups of individuals develop health outcomes over time. In these groups, some persons are exposed and some are unexposed, and some of both the exposed and the unexposed have disease. How can we tell whether the exposure causes the disease? We take a sample of individuals, follow them forward, and count cases. In Figure 2 we present the basis for setting up an epidemiologic study. We begin by defining the population of interest (top left); we then take a sample of that population (bottom left), define and measure exposure (top right; exposed persons in black), and measure and count cases of disease (bottom right). Through this simple panel, we can illustrate the concept of incidence, risk differences, and risk ratios.

After articulating these basic principles about watching a sample and counting cases, we can forge ahead to other concepts, such as the way in which noncausal associations arise in our data and what to do about them. The principle is introduced with step 5 of our 7-step approach (Appendix Table 1), when we rigorously evaluate whether an observed association suggests a causal relationship. We do not separate concepts like loss to follow-up, misclassification, and classical “confounding”—they are all ways in which the association one observes may arise from a noncausal process. Therefore, we address them all together, without labels. We thus introduce ideas of bias and confounding from an intuitive standpoint rather than through technical definitions and criteria.

As an example of our approach to operationalizing the problem of noncausal associations, we present here our approach to teaching the impact on measures of association of losing people along the way during the study, due to either dropout or death. In Figure 3 we illustrate 4 follow-up periods in our mini-person population, with black squares indicating loss from the cohort. We demonstrate 3 ways to sample a
Figure 3. Three ways to sample a dynamic population.

Figure 4. Selection of a matched-pair sample in a population with 2 exposures of interest: exposure A (black figures vs. gray figures) and exposure B (spotted figures vs. nonspotted figures).
dynamic population. The top panel shows a dynamic population over 4 time points. Individuals enter and leave the population across time, visually illustrating the dynamic nature of the population. If at any point we take a sample of exposed and unexposed people without disease, we could follow them forward and conduct a cohort study. Such a sample is taken at time 1 in Figure 2. If at any point we take a random sample of the population and count exposure and disease statuses, we conduct a cross-sectional study. Such a sample is taken at time 3. Finally, if at any point we take a sample of diseased and nondiseased persons and then assess exposure status, we conduct a case-control study. From this simple graphical description, we can then construct $2 \times 2$ tables within each time period and intuitively demonstrate the need for conditional probability survival analysis to properly account for cohort loss. In this way, we connect basic principles such as methods of accounting for loss to follow-up to the design, conduct, and evaluation of epidemiologic studies in an integrated manner.

Once we introduce the processes through which these noncausal associations arise, we can then introduce some mechanisms to mitigate against noncausal associations in the design and analysis of the study. Again, we are still operationalizing step 5 of the 7-step approach. Consider the series shown in Figure 4. We have now added another differentiator to our mini-populations. Some people have dots and some do not. Students can easily grasp that the dots may be more common among persons with some exposures than among others (e.g., smoking may be more common among persons of lower socioeconomic status). In Figure 4 we show how we can match participants on a variable that is not an exposure of interest. The figure here shows a sample in which there is an exposure (denoted with black figures vs. white figures), an outcome (“X”), and a third variable of interest (denoted by dots or no dots). If we are interested in matching on dots, we will choose (i.e., match) persons matched only on the presence or absence of dots, irrespective of their status on the exposure or their disease status. Thus, as shown in the matched figures to the right, we can have matched pairs that are discordant with regard to the exposure and with regard to disease status, as long as they are concordant with respect to their dot status—that is, a matched pair either has B or does not have B. From these panels and with real-world examples, we can then illustrate core concepts in controlling confounding in observational epidemiology.

In conclusion

We suggest here that an approach to introductory epidemiologic instruction that rests on the articulation of core principles and guides students to an understanding of the foundational building blocks of population health may be a useful adjunct to model contemporary pedagogic approaches in the field. We do not intend to suggest that the pedagogic approach we illustrate here is necessarily the best or only approach to presenting epidemiologic material. However, we suggest that this approach corresponds more closely to generating a set of material that flows from first principles and is organized around intuitive concepts rather than canonical terms. As the field continues to refine its approaches to the teaching of epidemiology, we suggest that a focus on a logical sequence of how health and disease arise in populations, an explanation of the foundations of how we measure and count health and disease, and at the very end an application of labels that are conventional in the field can be useful in helping our students classify and comprehend these concepts. We argue that this approach can lead the next generation of public health, medical, and other professionals to a better understanding of our field and a richer understanding of the study designs and concepts that guide us towards identification of causes and ultimately prevention of illness.

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REFERENCES


**Appendix Table 1.** Seven foundational steps in conducting an epidemiologic study

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<tr>
<th>Step 1</th>
<th>Define the population of interest.</th>
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<tr>
<td>Step 2</td>
<td>Conceptualize and create measures of exposures and health indicators.</td>
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<td>Step 3</td>
<td>Take a sample of the population.</td>
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<td>Step 4</td>
<td>Estimate measures of association between exposures and health indicators of interest.</td>
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<td>Step 5</td>
<td>Rigorously evaluate whether the association observed suggests a causal association.</td>
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<td>Step 6</td>
<td>Assess the evidence for causes working together.</td>
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<td>Step 7</td>
<td>Assess the extent to which the result matters—is externally valid—to other populations.</td>
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