Seeking the Niche for Traditional Mathematics within Undergraduate Statistics and Data Science Curricula

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George Cobb's wonderful paper stimulates thought regarding the undergraduate statistics curriculum. The historical insights and the use of metaphor are illuminating. The list of references provides an entire seminar course curriculum on seminal work in statistics and how it can be taught.

In our commentary, we focus on the complex role mathematics plays in the undergraduate curriculum as it relates to the teaching of statistical science. In Section 3 of his paper, Cobb presents his case for "How we got stuck: the evolving role of mathematics." Our experiences in departments of mathematics at Cleveland State University (a comprehensive urban state university of approximately 12,000 undergraduates) and John Carroll University (a private university of approximately 3,000 undergraduates) indicate that many students get "stuck" in their quests to learn more statistics because they are limited by deficient knowledge of traditional mathematics.

At Cleveland State University, we have structured an undergraduate minor in statistics with access points for students from a variety of majors, including psychology and business. Our minor consists of a general introductory course, a second course, and separate courses in regression, design, and consulting. When non-mathematics majors become excited about statistics and wish to take additional coursework, they run into the mathematical wall. The minor at John Carroll University is similar, but differs in that students can count up to two quantitative methods courses within their home major. The statistics minor for students outside of the mathematics major does not include enough mathematical content to support graduate work in most traditional statistics programs. By this we mean programs that need students to have understanding of multivariable calculus or linear algebra in required courses at the masters or Ph.D. level.

For many students who do not take college algebra or calculus in their first year (most likely because they took a more appropriate introductory statistics course as their general education mathematics course), Cobb's summary of access to statistical ideas becomes a much longer chain of courses:

$$\text{College Algebra} \rightarrow \text{Trigonometry} \rightarrow \text{Calc I} \rightarrow \text{Calc II} \rightarrow \text{Calc III} \rightarrow \text{Probability} \rightarrow \text{Math Stat}$$

We propose a thought experiment, inspired by Cobb's three-part triage in Section 2.2 on how we work with data and clients. Whom should we allow to major in statistics (per the "Curriculum Guidelines for Undergraduate Programs in Statistical Science") or go on to graduate school in statistics?

1. Are you a third-year college student who has already taken up through multivariable calculus and linear algebra? If not, go away.

2. Are you ready, are you willing, and do you have the time before graduation to take calculus, linear algebra, real analysis, and Markov chain probability (and all the perquisites for those courses)? If not, go away.

3. Do you have the written and oral communication skills that employers repeatedly say that they really want in their employees? If not, that is okay because it is really only mathematical aptitude that matters for admittance into our programs (even though we will do little to help you acquire those needed communication skills).

To embrace Cobb's use of metaphor, we wonder if the mathematical jewels worn on the necklace around the statistician's neck have turned that jewelry into a noose that is choking access to our field.

We argue that the budget crises facing both state and private colleges and universities should make faculty aware of enrollment figures in their programs. A data-informed culture of higher education administrators is looking very closely at student enrollment data and the numbers of majors in programs. "Program prioritization" is being used across the country to help to determine where resources should flow for growth and where programs should be cut. Even state legislatures are demanding to know how established and successful universities are preparing students for immediate employment upon graduation. Statistics as a program has a tremendous opportunity to attract a great many students. Word is reaching both traditional-age and non-traditional students that there is an abundance of high-paying jobs available for those who possess data skills. Mathematics, statistics, and data science departments cannot afford to turn potential majors away. We believe that there are talented undergraduates who want to explore statistical science, but find their lack of mathematical training a hurdle that cannot be overcome in time to graduate within a reasonable window. Thus, we agree with Cobb's contention to "flatten prerequisites" at the undergraduate level, but worry that students in these courses will still be too mathematically deficient to enroll in graduate programs in statistics.

On the other hand, undergraduate mathematics programs are stocked with large numbers of mathematically talented students who need to find employment upon graduation. Inviting these students to take more statistics courses in order to broaden their skill sets will provide them with an easier path to employment and is one way to help to meet the high demand for data workers. We believe that we need to caution our mathematical colleagues that encouraging their students to go on to graduate

Online discussion of "Mere Renovation is Too Little Too Late: We Need to Rethink Our Undergraduate Curriculum From the Ground Up," by George Cobb, *The American Statistician*, 69. John P. Holcomb, Cleveland State University 2121 Euclid Avenue, Cleveland, OH 44115 (Email: j.p.holcomb@csuohio.edu). Linda Quinn, Cleveland State University - Mathematics 2121 Euclid Avenue RT 1515 Cleveland, Cleveland, OH 44115. Thomas Short, John Carroll University.

school in mathematics might be a disservice. The popular goals of becoming a community college instructor with a master's degree in pure mathematics or earning a tenure-track position at a college or university with a Ph. D. in pure mathematics are very difficult to attain. Recently, John Carroll University had approximately 500 applications for a single tenure-track position in mathematics where the area of specialization was not specified.

Statistics has the potential to help bridge this mismatch of highly talented students and employment needs in government, industry, and academia. We in statistics should advocate to our mathematical colleagues that advising students to pursue a double major in mathematics and statistics (or some major/minor combination in mathematics, statistics, and computer science) ultimately serves the students better than earning graduate degrees in mathematics. This will not be easy, as so much of personal identification is tied in up in an individual's focus of study.

We leave it to others to debate whether the undergraduate curriculum needs to be a "tear down" as Cobb suggests, but we would argue that at the very least, our statistical house needs an additional wing. We need coursework and curricula that invite students who begin in other majors (including mathematics!) to acquire data analysis skills that in turn provide an avenue to high-paying and satisfying careers.