Student Voices Note

Statistical Confusion Among Graduate Students: Sickness or Symptom?

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ABSTRACT Statistics is one of the most important yet difficult subjects for many ecology and wildlife graduate students to learn. Insufficient knowledge about how to conduct quality science and the ongoing debate about the relative value of competing statistical ideologies contribute to uncertainties among graduate students regarding which statistical tests are most appropriate. Herein, we argue that increased education of the available statistical tests alone is unlikely to ameliorate the problem. Instead, we suggest that statistical uncertainties among graduate students are a secondary symptom of a larger problem. We believe the root cause lies in the lack of education on how to conduct science as an integrated process from hypothesis creation through statistical analysis. We argue that if students are taught to think about how each step of the process will affect all other steps, many statistical uncertainties will be avoided. (JOURNAL OF WILDLIFE MANAGEMENT 72(8):1869–1871; 2008)

DOI: 10.2193/2008-138

KEY WORDS academia, experimental design, graduate education, null hypothesis statistical testing, pedagogy, statistics.

One of the biggest hurdles we face as graduate students is learning statistical techniques necessary to analyze data we collect. Unfortunately, many ecology and wildlife graduate students view the learning of statistics as a burden instead of a necessary and valuable part of the scientific process. Misunderstanding of the importance of statistics, shortcomings in statistical education, and an unresolved debate about which statistical philosophy is most appropriate can lead to confusion amongst students about how best to approach data analysis. In their recent article, Butcher et al. (2007) provide a unique, student-oriented perspective on the debate about the value of null hypothesis statistical testing (NHST) and the role of academic mentors regarding statistical analyses in wildlife management. Butcher et al. (2007) correctly assert that NHST is overemphasized in graduate education, often to the exclusion of alternative techniques, and they argue that ongoing statistical debates and cursory statistical education lead to confusion among graduate students when analyzing their own data. Our experiences have been similarly frustrating, and we appreciate a louder student voice in the discussion of how best to introduce new graduate students to statistical practices. However, we feel that statistical uncertainties may be a secondary symptom of a larger problem—namely that most new graduate students lack the knowledge and guidance of how to conduct science as an integrated process from hypothesis creation through statistical analysis.

We believe that statistical woes experienced by graduate students (Butcher et al. 2007) usually propagate from mistakes made early in the scientific process. Students are taught the importance of hypothesis testing, but instruction on the process of hypothesis creation and experimental design is lacking at some institutions. Beginning graduate students often face the daunting task of learning about hypothesis creation and experimental design by reading peer-reviewed literature or through discussions with faculty and senior graduate students. Reading and learning the literature is obviously a critical component of the maturation process. However, graduate students may have difficulty learning the initial steps of the scientific process from literature because this information is seldom explicitly discussed. Major advisers, other faculty, and senior graduate students are valuable resources, but in our experience, these topics are often glossed over in normal collegial discourse. Further, many practicing scientists take these skills for granted because most have acquired them by observing their mentors throughout their own development.

We suggest that statistical uncertainties experienced by students can be mitigated if students are taught to think about science as an integrated process rather than a series of disconnected steps. We emphasize that statistics are simply a tool, to be thought of in the larger context of hypothesis creation and experimental design. As such, development of an experimental design should include forethought of statistical tests that will eventually be used to analyze data. Below, we present our view on how this process should be taught to new graduate students. We understand that every graduate experience is different and that some students quickly learn the research practices necessary to be a successful scientist. However, we represent a wide range of

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academic backgrounds, research foci, and stages of the graduate career and we collectively feel the process we discuss is often underrepresented in graduate education.

The process of hypothesis creation begins with development of a novel question placed within the context of scientific axioms and continues with creation of biologically relevant competing hypotheses that clearly identify what is being examined. Hypothesis formulation is, in our opinion, the most important and complex step of building a research project. Ultimately, the chosen hypotheses will dictate experimental design and statistical analysis. Robust hypothesis construction requires integrating several philosophical points such as differences between strong and single inference (Platt 1964) and implications of the Quine-Duhem thesis (Gibson 1988). Relationships predicted by each hypothesis should be established and formulated into specific statistical models. Successful conversion of biological hypotheses into statistical models can greatly aid in designing experiments appropriate for conducting traditional NHST, selecting among candidate models, or parameterizing the chosen model (Hilborn and Mangel 1997). Most new students lack the statistical background to successfully convert complex biological hypotheses into statistical models; therefore, students will require assistance from graduate courses, their adviser, senior lab members, or a statistical consultant on what analytical methods are most appropriate for the question they are trying to answer. Unfortunately, many new graduate students determine what data to collect based on literature or traditions of their lab; therefore, hypotheses, predictions, and experimental design are often focused on well-flogged parameters that may not be the best measures for subsequent statistical analyses. This approach is worrisome because creativity and critical thinking may become secondary concerns resulting in studies that contribute little to scientific knowledge. After all, it is largely through development of creative and novel hypotheses that scientific progress occurs. Further, starting a project with only data collection in mind may lead to inefficient progress because research objectives and experimental design have to be continuously adjusted to fit the data collected. The absence of sufficient planning can also result in pigeon-holing data into one traditional statistical test, which may be statistically inappropriate or less powerful than alternative statistical models. If an effort is made to convert hypotheses into statistical models before the experimental design is determined, data collection can be conducted in such a way as to maximize the power and appropriateness of ensuing statistical work. Unfortunately, many graduate students fail to appreciate this process and its intricacies until later in their graduate career (although the likelihood of this varies greatly among students).

We feel that academic departments, advisers, and students are all responsible for ameliorating the confusion graduate students often have involving statistics. Additional coursework early in the graduate career may help alleviate this problem, but we doubt that additional statistical coursework per se will be the sole answer. There is considerable breadth of statistical analyses in ecology and attempting to present students with an extended list of methods without proportional instruction on how and when to implement such methods may exacerbate the problem. In our opinion, students could get just as much benefit in this regard from a large table listing all possible statistical tests, the data necessary to conduct them, and the assumptions of each test. Instead, we suggest a course focused on exploring the integration of the entire scientific process. This course would require students to think about 1) developing clear, testable, biologically relevant hypotheses, 2) converting hypotheses into statistical models (without the burden of learning the specifics of any certain statistical tests), 3) developing an experimental design that will test the hypotheses, and 4) determining the scope of inference that can be made given the experimental design and analysis techniques. Such an approach provides students with a thorough understanding of how science works and should be a precursor to more traditional statistical courses. Some of the authors have had courses similar to what we describe, but in our experiences, this type of course is far from a universal part of a graduate education.

Academic advisers cannot be expected to coddle their students, or to keep abreast of the latest statistical theory. However, we believe advisers should place more emphasis on providing guidance about how to pursue science as a holistic and integrated process. Advisers should encourage their students to develop multiple competing hypotheses and push their mathematical limits in creation of quantitative biological and statistical models. To presume that new graduate students are equipped to embark on this journey alone is unreasonable and hinders their development, productivity, and enthusiasm for the scientific process.

The impetus for our paper results from frustrations and pit-falls we have experienced during our current and previous graduate experiences. Science has matured beyond the simple scientific method and many of the statistical and philosophical intricacies required for sound scientific research made no appearance in our coursework. However, the importance of these intricacies is paramount to conducting quality scientific research, completion of a degree, publishing in high-impact journals, and being competitive in research-oriented job markets. Thus, we recommend that graduate students make discussion of the scientific process a more prominent part of their daily academic discourse, self-educate (but be willing to seek guidance) in issues surrounding experimental design and the role of statistics in science (Gibbons et al. 2007), and remember that ultimately the onus of ensuring utility of their research is theirs.

Acknowledgments

We thank J. Lesku for comments on the manuscript.

LITERATURE CITED

Butcher, J. A., J. E. Groce, C. M. Lituma, M. C. Cocimano, Y. Sánchez-Johnson, A. J. Campomizzi, T. L. Pope, K. S. Reyna, and A. C. S.

Knipps. 2007. Persistent controversy in statistical approaches in wildlife sciences: a perspective of students. Journal of Wildlife Management 71: 2142–2144.

Gibbons, J. M., N. M. J. Crout, and J. R. Healy. 2007. What role should null-hypothesis significance tests have in statistical education and hypothesis falsification? Trends in Ecology and Evolution 22:445–446.

Gibson, R. F., Jr. 1988. Enlightened Empiricism. University of South Florida Press, Tampa, Florida, USA.

Hilborn, R., and M. Mangel. 1997. The Ecological Detective: Confronting Models with Data. Princeton University Press, Princeton, New Jersey, USA.

Platt, J. R. 1964. Strong inference. Science 146:347–353.

Associate Editor: Chamberlain.