Using Simulations to Foster Students' Understanding of Statistical and Probability Concepts: A Commentary

Pfannkuch, Maxine
The University of Auckland, Department of Statistics
38 Princes St
Auckland 1, New Zealand
E-mail: m.pfannkuch@auckland.ac.nz

Budgett, Stephanie
The University of Auckland, Department of Statistics
38 Princes St
Auckland 1, New Zealand
E-mail: s.budgett@auckland.ac.nz

We are delighted to have the opportunity to comment on three stimulating papers. Despite the fact that each paper is brief, they succeed in conveying two major challenges currently faced by statistics educators. The first challenge is the dissonance between students living in an interactive technology-driven environment and students learning in a paper and listening teaching environment. The second challenge is breaking the reliance on classical mathematical arguments to embrace empirical, exploratory approaches to understand statistical and probability concepts. Two articles describe preliminary research on undergraduate students' understanding of concepts through the use of simulations, with neither article presenting any definitive results at this stage, while the third article addresses the rationale for teaching statistical inference using the bootstrap method. In these comments we will discuss issues arising from each paper and then close with some general comments on simulations.

Christou, Dinov, and Sanchez present a preliminary evaluation of their interactive simulation applets in terms of students' achievement. However, it is uncertain about whether there were differences in performance between treatment and control groups. A premise of this research appears to be that preferred learning styles, attitudes, prior knowledge and demographics may impact on the effectiveness of simulations for conceptual understanding. Consideration could be given to other factors, such as the teacher, the learning culture and educational environment set up by the teacher, and the simulation task design. For example, the three sample activities presented appear to be implicitly stating that students can build conceptual understanding with coin tossing analogies or context-free distributions. Do students' concepts of the Central Limit Theorem simulated through context-free distributions transfer to contextually-based distributions? Many researchers (e.g., Watson, 2006) believe students should experience sampling reasoning in many different contexts. Should students, for example, simulate drawing random samples of different sizes from actual light bulb lifetime data or shoe size data as well?

Zieffler and Garfield, on the other hand, describe nine simulation activities that are a mixture of social context and gambling-type problems. In the Cola Taste Test activity an experiment is conducted physically by the students and then simulation software is used to conceptually understand whether experimental results were surprising or not. Zieffler and Garfield's implicit premise appears to be that effective use of simulations requires presenting students with a contextually-based problem, involving students in a hands-on physical activity or hands-on simulation, and then from that understanding move students to the computer simulation. Notably this premise is not applied to the Central Limit Theorem and Confidence Intervals activities and a question is why not? Another question is whether Zieffler and Garfield's main approach to students using simulations is more effective than students using solely computer simulations.

The simulations described by both articles require the predominant use of visuo-analytical reasoning where students experience and reason from dynamic diagram shapes requiring a visual analysis with some summary statistics displayed. When students see these simulations what facets do they attend to or notice? Is their attention on the visual display with their reasoning focused on shapes and colors or is it on the statistical summaries? How do they cognitively integrate both types of information? Furthermore, does the design of the presentation on screen facilitate or hinder conceptual development? Did these authors take into account research on screen perception (e.g. Sweller, 1988)? Simulations provide powerful ways of comprehending statistical concepts but how can we be sure that students really understand what they perceive on the screen?

Engel promotes the idea that bootstrap or resampling methods have the potential to change the way students are introduced to inferential statistics. Since the core concept of inferential statistics is the sampling distribution, he argues that resampling methods allow the learner to experience and visualize how such a distribution evolves. Since the 1970s Julian Simon (e.g., Simon, Atkinson, & Shevokas, 1976) has been a major proponent of using resampling methods with tertiary and secondary students as his research suggests students obtain a better understanding of statistical principles. Other statisticians, such as Scheaffer (2000), support this view and believe that such methods should be introduced to students learning statistics. Statistics education packages such as Fathom (Key Curriculum Press Technologies, 2000) now exist so that teachers have access to resampling methods as a way of introducing students to inferential reasoning. Resampling methods may be common tools for professional statisticians but how should they be taught to teachers enmeshed in a traditional mathematical approach? Based on our limited experience we conjecture that teachers may approach resampling methods, for example, as a formulaic method to set up hypotheses and obtain *P*-values. We believe that the challenge will be to enculturate teachers into the way of reasoning and talking about the inferential ideas present in resampling methods.

Based on these three articles there is no doubt that the statistics classroom of the future will incorporate interactive computer simulations and be more closely aligned to how students intuitively learn new technologies presented in their everyday lives. Exploration, experience, statistical ways of thinking and reasoning are at the heart of simulations. Simulations offer new approaches to understanding the conceptual underpinnings of statistical methodology, one that should be embraced, as the statistics discipline releases its reliance on a mathematical approach and reclaims its roots as an empirical science.

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