# Broadening the Impact and Evaluating the Effectiveness of Simulation-based Curricula for Introductory Statistics

Nathan Tintle
Dordt College

Beth Chance
Cal Poly – San Luis Obispo

George Cobb
Mt. Holyoke College

Allan Rossman
Cal Poly – San Luis Obispo

Soma Roy
Cal Poly – San Luis Obispo

Todd Swanson
Hope College

Jill VanderStoep
Hope College

**Abstract** The demands for a statistically literate society are increasing, and the introductory statistics course “Stat 101” remains the primary venue for learning statistics for the majority of high school and undergraduate students. After three decades of very fruitful activity in the areas of pedagogy and assessment, but with comparatively little pressure for rethinking the content of this course, the statistics education community has recently turned its attention to focusing on simulation-based methods, including bootstrapping and permutation tests, to illustrate core concepts of statistical inference within the context of the overall statistical investigative process. This new focus presents an opportunity to address documented shortcomings in the standard Stat 101 course (e.g., seeing the big picture; improving statistical thinking over mere knowledge of procedures).

Our group has developed and implemented one of the first cohesive curricula that (a) emphasizes the core logic of inference using simulation-based methods in an intuitive, cyclical, active-learning pedagogy, and (b) emphasizes the overall process of statistical investigations, from asking questions and collecting data through making inferences and drawing conclusions. Improved conceptual understanding and retention of inference and study design that had been observed when using early versions of the curriculum at a single institution, are now being evaluated at dozens of institutions across the country with thousands of students using the fully integrated, stand-alone version of the curriculum. Encouraging preliminary results continue to be observed.

We are now leveraging the tremendous national momentum and excitement about the approach to greatly expand implementations of simulation-based curricula by offering workshops around the country to diverse sets of faculty, offering numerous online support structures including: a blog, freely available applets, free instructor materials, learning objective-based instructional videos, free instructor-focused training videos, a listserv, and peer-reviewed publications covering both rationale and assessment results.

Many hundreds of instructors have been directly impacted by our workshops and hundreds more through access to the free online materials. We are also in the midst of evaluating widespread transferability of the approach across diverse institutions, students, and learning environments and deepening our understanding of how students' attitudes and conceptual understanding develop using this approach through an assessment project involving concept and attitude inventories with over 10,000 students across 200 different instructors.

## Background

*State of the field*

The demands for a statistically literate society are increasing, and Stat 101 remains the primary statistical education venue for the majority of high school and undergraduate students. After three decades of very fruitful activity in the areas of pedagogy and assessment, but with comparatively little pressure for a complete overhaul in content, the statistics education community has recently been discussing the need for new content and focus in Stat 101. Simulation-based and computer-intensive materials for the first course constitute one major response to this need.

Before we describe the potential advantages of a simulation-based approach to inference, we briefly describe the current consensus curriculum for the Stat 101 course. This curriculum has four parts – descriptive statistics, data collection and design, probability and sampling distributions and inference[1]. Traditionally, students spend the first third of the course on descriptive statistics, and then the middle third learning about probability and sampling distributions, often disconnected from genuine "in practice" data analysis. Even if data collection issues are presented earlier in the course, statistical inference is almost always the final topic introduced in the course, after building prerequisite knowledge in design and probability. By the time students get to inferential statistics, arguably the crux of the course, they are in the closing part of the term and have often forgotten many principles of data collection and their impact on the scope of conclusions that can be drawn. With this traditional sequencing, students have often been poorly motivated to learn the probability theory they are now asked to apply and integrate with the statistical content. We have found that with this consensus curriculum, students have usually lost sight of the "big picture" by the time they reach inferential statistics. They end up in survival mode, trying to memorize the difference between a two sample *t*-test and a chi-square test, a series of conditions that need to be met to use each test, and which buttons to push on a calculator or computer to do the calculations. This gives a shallow level of understanding about the reasoning process of inferential statistics, as well as a limited appreciation for the application and impact of statistical methods, which, we argue, should be the focus.

During the three decades since 1980, when models for what was to become the consensus curriculum were first published[2,3], there have been many important changes that bear on the teaching of statistics. Chief among them is radical increases in computational power and accessibility that have dramatically changed the way we analyze and visualize data. Furthermore, statistics made its way into the K-12 curriculum, via the NCTM standards and the Advanced Placement program, a trend likely to increase further with adoption of the Common Core State Standards[4]. Many students now reach college familiar with exploratory and descriptive statistics. We have also seen enrollments in statistics courses skyrocket, from high school to college, especially in two-year colleges. Furthermore, statistics education research has come into its own[5], yielding high-quality assessment instruments and a correspondingly more sophisticated understanding of what students do and do not learn from their courses[6]. Finally, active learning through hands-on activities has come to be generally accepted as an effective way to engage students of statistics[7].

Because of the changes listed above, all of which have taken place during the thirty years that it has taken the current Stat 101 curriculum to become established, this standard curriculum now has shortcomings that have the potential to be explicitly addressed by the simulation-based approach, especially in the area where students have performed more poorly – inferential reasoning. The simulation-based approach introduces ideas of statistical inference through simulation models rather than theoretical probability models; for example, physically tossing a coin repeatedly to analyze how unusual 14 successes out of 16 attempts is, rather than developing and applying the binomial probability distribution (often for its own sake rather than within the statistical context). In fact, there is relatively little prerequisite knowledge required for students to use these methods and they can be introduced in the first week of the course. This allows a diverse set of students with varying levels of quantitative maturity to see the entire statistical process, from data collection to descriptive analysis, to inferential reasoning, to drawing conclusions, from day one. This approach provides a more direct path to the logic of statistical investigation, free from the distracting technicalities of the approach based on the asymptotic distribution of the sample mean[8]. Furthermore, the current consensus first course does not devote sufficient time or space to the connections among the method of data production, the method used to analyze the data, and the scope of inference justified by the analysis. For simulation-based methods, these connections are simple and direct. With the consensus curriculum for Stat 101, overlap with the K-12 treatment of descriptive statistics also produces inefficiencies. What once took a substantial first part of an introductory course can be integrated, as needed, into the remainder of the curriculum, as a key component of an overall statistical investigation method, and eliminated as a free-standing first unit unconnected to practice, allowing even more and continued focus on the overall statistical investigation method. Finally, the simulation-based approach utilizes best-teaching practices because of an inherent connection between student-generated (tactile and computer) simulations and the statistical topics presented in the course, as well as bringing students to a place where they can and do ask questions which lead directly to the next topic.

*State of the curriculum*

Over the last ten years, our team has been working to develop a widely available, full curriculum that revolves around simulation-based inference. After multiple versions along the way, the first edition of *Introduction to Statistical Investigations*[9] was published in January 2016. This version includes

- a full length active learning curriculum that allows instructors to utilize materials through guided discovery activities and/or interactive lectures,
- motivates all concepts through authentic published peer-reviewed research,
- has a full set of instructor and student support materials, including over 200 learning objective focused videos, instructors' manual, numerous homework exercises including full case studies and critical reading activities involving genuine research articles,
- continuous support of all learning goals through tactile experiences and a suite of over 50 freely available user-friendly javascript applets, as well as a full online homework system.

At the heart of the curriculum is the belief that student understanding of the core logic (significance and estimation) and scope (generalization and causation) of statistical inference is improved and grounded more substantively with simulation-based methods.

*What we know about student understanding*

Improved conceptual understanding and retention of concepts of inference and study design that had been observed when using early versions of the curriculum at a single institution[10,11], are now being evaluated at dozens of institutions across the country with thousands of students using the fully integrated, stand-alone version of the curriculum. Encouraging preliminary results continue to be observed[12–14].

**Expand implementations through professional development and support** As we concluded development of the first edition of the materials, we shifted increased energies to professional development and instructional support. The two primary mechanisms for providing instructional support are through intensive on-site or e-workshops and through ongoing support structures including a blog and listserv. We now briefly describe these two main approaches

*Workshops*

To date we have conducted 16 free workshops reaching over 550 faculty. Workshops have ranged in length between 2 hours and 3.5 days, with most lastly approximately 1 to 1.5 days in length. Workshops have been offered at numerous sites around the country targeting a diverse set of faculty by offering these workshops in conjunction with major statistics and mathematics conferences, conferences for two-year colleges or high school instructors specifically or by partnering with a regional host institution to target a specific regional set of schools (e.g., Chicago area). We have also offered an e-workshop (with over 200 live participants) which is archived for free viewing. Workshops include three main components. The pre-workshop preparatory component includes initial education of participants through readings and gathering preliminary information about participants. The intensive workshop walks participants through the rationale for the curricular changes, has participants play the role of student through many guided discovery tactile and computer based activities, discusses assessment and teaching tips and leaves ample time for questions. The on-going component includes providing participants with a variety of opportunities to continue to learn more and discuss topics after the workshop ends, primarily through the online learning community.

*Online learning community*

All workshop participants, as well as any other interested statistics instructors, are able to participate in a low-volume listserv where members considering using or actually using simulation-based inference materials in their classes are able to ask questions and provide dialogue about their experiences. We also use the listserv as the primary dissemination vehicle for the Simulation-Based Inference (SBI) blog. We currently have over 50 blog posts, with new content every month, arranged under a series of thematic topics relating to simulation-based inference including “Why simulation-based?” “The hardest thing about getting started with simulation-based curricula?” “Convincing/ training others to teach SBI” and many more. Blog posts are authored by simulation-based inference curriculum developers as well, increasingly, by former workshop participants who are now using the materials.

**Understand student performance** All former and upcoming workshop participants, as well as numerous other diverse statistics educators are biannually invited to participate in an ongoing assessment project to evaluate development and transferability of student conceptual learning outcomes and attitudes (whether or not they are using simulation-based inference) and to help us better understand key pedagogical and content components which impact student learning and retention. Briefly stated, the assessment project asks instructors to electronically administer a single survey, which includes a 30 question conceptual understanding multiple-choice test as well as questions from a validated ‘attitudes towards statistics’ instrument (SATS[15]) and a series of demographic questions. Surveys are administered to all students at both the beginning and end of the term in which students are taking introductory statistics. Embedded subsamples of students and instructors also received questions through the semester (as part of in-class quizzes and tests) and followed up with 4-6 months after the course ends, allowing us to better understand student learning trajectories on key concepts as well as retention. Over the last 24 months we have collected data on over 10,000 students across over 150 institutions and 200 instructors. Preliminary data analysis is ongoing but continues to show strong evidence of the benefits of using simulation-based inference on student conceptual learning outcomes and attitudes.

**Conclusions and next steps** Over the next twenty-four months we will continue to offer workshops around the country as well as through electronic formats and invite all workshop participants and other interested statistics educators to participate in the online learning community through writing and reading blog posts and participating on the listserv. As our assessment project matures our attention is during to the analysis and dissemination of our findings from the large-scale assessment project, along with developing and implementing a variety of smaller-scale follow-up studies to test particular hypotheses suggested by current data. Assessment data analysis and instructor feedback is also suggesting a variety of modifications to the core instructional materials, which we anticipate implementing in the near future. Finally, we are in the preliminary development of a curriculum using these approaches targeted directly to the high school/AP statistics market where we have experienced great demand and enthusiasm, as well as beginning to work on curricular materials for a much-needed second course in statistics that focuses on multivariable methods of data analysis using these same core pedagogical and conceptual learning goals.

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