How to Make Engineering Statistics More Appealing to Millennial Students

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Abstract

A one-semester calculus-based course in Engineering Statistics is taught in almost all engineering colleges, and is viewed as a "tools" course versus courses focused on engineering concepts and principles. Most current engineering faculty members were undergrads in 1970-2010 and graduate students 1975-2015. We argue that the way many of us learned probability and statistics, even as graduate students, does not support engagement and appeal to Millennial students. The purpose of this paper is to recommend adapting new pedagogical methods to the accepted topics in an introductory probability and statistics course for engineering undergraduates—methods that better match the learning characteristics of Millennial students in our courses. In a nutshell, those characteristics may be summarized as: (1) They want **relevance** to their major, and future engineering career; (2) They want **rationale** (for the textbook selected, and for specific course policies and assignments); (3) They **revel in technology** (to collect data, compute, communicate, and multi-task); (4) They want a **relaxed, hands-on environment;** (5) They prefer instructors who **rotate among several classroom delivery methods.**

Considering the "Five R's" learning characteristics of Millennial students, and recommendations of highly respected engineering statistics educators, we suggest a modification of the introductory probability and statistics course for engineers, adapted as follows: (1) Use textbooks that have a plethora of examples and exercises from the students' major fields; (2) Establish student rapport and respect for experience of the textbook author and the instructor while avoiding authoritarian style; (3) Use a statistical package integrated into the textbook, with in-class tutorials and homework solutions that require use of the package; (4) Use of the Quincunx and Stat-a-pult® training devices, for in-class demonstrations; (5) Alternate between lecture, problem solving, software tutorial, and physical demonstration.

There is a long history of articles similar to this one attempting to identify best practices in teaching probability and statistics to engineering students, who are often mixed together in sections with more than one major. Sixteen articles or books from the past 40 years are referenced to provide the foundation to support the course concept we recommend. Through review of the well-documented learning characteristics of today's Millennial students, the observations of well-known engineering educators, and our own experiences teaching engineering statistics courses the past 30 years, we have recommended a multi-faceted approach to modernize the introductory engineering statistics course. Hopefully other instructors, whether new or seasoned, can benefit from these recommendations.

Introduction

Statistics has been called "the art and science of collecting and analyzing data", Bisgaard [1]. So, naturally a one-semester calculus-based course in Engineering Statistics is taught in almost all engineering colleges, and is “viewed as a ‘tools’ course versus those focused on engineering concepts and methods”, Wilson [2], required in some B.S. programs, such as industrial and civil engineering; an elective in most others. Including such a course in a degree program is responsive to several ABET EAC general criteria, including those that concern problem-solving, application of mathematics, experimentation and data analysis, and communication of results.

Standard topics in a one-semester course are:

- Overview and Descriptive Statistics
- Probability
- Discrete Random Variables
- Continuous Random Variables and Probability Distributions
- Joint Probability Distributions and Random Samples
- Point Estimation
- Statistical Intervals Based on a Single Sample
- Introduction to Statistical Hypothesis Testing
- Simple Linear Regression and Correlation

A second course with more advanced topics may follow, either at the B.S. or M.S. level:

- Inferences Based on Two Samples
- The Analysis of Variance
- Multifactor Experimental Design and Analysis of Variance
- Nonlinear and Multiple Regression
- Response Surface Methods
- Evolutionary Operation Method
- Taguchi (Robust Design) Method
- Quality Control Methods
- Special Topics: Time Series Forecasting, Monte Carlo Simulation, Others

For the past 30 years there have been articles in the statistics and engineering education literature about what to teach (topics, emphasis) and how to teach it to undergraduate engineers. See, for example, in chronological order--Hogg [3], Joiner [4], Godfrey [5], Bisgaard [1], and Wilson [2]. Most current engineering faculty members were undergrads in 1970-2010 and graduate students 1975-2015. We argue below that the way many of us learned probability and statistics, even as graduate students, does not support engagement and appeal to millennial students.

The purpose of this paper is to recommend adapting new pedagogical methods to the accepted topics in an introductory probability and statistics course for engineering undergraduates—methods that better match the learning characteristics of Millennial students in our courses.

Learning Characteristics of Millennial Students

Bart [6] identified “Five R’s” that describe the learning characteristics of Millennial students:

- They want **relevance** to their major, and future engineering career
- They want **rationale** (for specific course policies and assignments)
- They want a **relaxed, hands-on environment**
- They **revel in technology** (to collect data, compute, communicate, multi-task, etc.)
- They prefer instructors who **rotate among several classroom delivery methods** (alternating among lecture, tutorial, and problem-solving);

These five characteristics have been noted in one form or another by other researchers in a variety of disciplines (psychology, educational methods, English as a Second Language, etc.). Concerning relevance, Novotney [7] states "Millennial students are more likely to perform better when professors connect their lessons to real life…humor and use of current examples also help engage students." Martz [8] observed that Millennials dislike authoritarian approaches, and want to know "why? Explain your rationale." Price [9] has determined that Millennial students prefer a relaxed learning environment that allows them to interact informally with the professor and fellow students, and experience/observe phenomena rather than just read or be told about it. Grover and Groscurth [10] review how Millennials "have been enculturated into a society that is increasingly comfortable with and dependent on digital technologies" and "are more adept at responding to technological change and more creative in using technology". They instinctively use technology to compute, communicate and multi-task in their engineering work. Price [9] has determined that Millennials want more variety in class (meaning mix up the methods), stating "This is a culture that has been inundated with multimedia and they're huge multitaskers, so to just sit and listen to a talking head is often not engaging enough for them."

As engineering faculty and administrators, the reason to adapt our pedagogy to the students we now have were well-expressed in Romero et al [11]:

- What matters is not what is taught, but what the majority of the students can learn…the process must focus on the student more than the teacher
- What students actually learn is what they are able to apply in their jobs ten years later
- Technological knowledge is acquired mainly by "doing" and seeing what others do
- The learning process is basically a personal task, where the protagonist is not the teacher but the student
- The teacher must be a generator of resources and learning contexts, but the student is the person who is learning.
- This requires the student to actively participate in all steps of the process, particularly in the classroom.

They conclude: "Basic knowledge (of probability and statistics) is important, but not more important than creating in the student a positive attitude toward statistical methods…The only way to succeed in this is through the formulation and solution of real, or at least realistic, problems of direct interest to the students. This must be done using the scientific method and sharing the teacher's experience in real projects."

Joiner [4] lamented "most people who teach statistics have never practiced statistics." We believe that engineering statistics should be taught by those who have practical experience applying it—be it in research, development, production/construction operations, quality control, or field reliability and maintenance.

What Others Have Said About Teaching Statistics to Engineering Students

Two experienced engineering statistics instructors, Richard J. Wilson (University of Queensland) and Soren Bisgaard (University of Wisconsin) have insights and experiences that are highly informative and impacted the manner in which we modified the Engineering Statistics courses at The University of Alabama (UA). First, here are three excerpts from Wilson [2]:

Students find engineering statistics courses difficult and do not learn the concepts and methods, and staff find the experience frustrating and try to avoid being allocated such courses whenever possible. This paper…is not intended to imply that there is only one way of teaching applied statistics to engineering students but rather to suggest some approaches which others may not have tried.

Engineering students have a grasp of deterministic systems and seem to believe that "error" in measurement is precisely that, an error, and not due to unpredictability in the measured variable. Consequently, dealing with uncertainty seems superfluous and random models incomprehensible…So, the first obstacle in teaching engineering statistics to engineering students can be the negative attitude to the material before the course commences.

By the time engineering students are introduced to statistical modeling, they are often fixed in their choice of field of engineering. As a consequence, they only wish to see material which related to that field and tend to be inattentive whenever examples from other fields are used. Hence some subgroups of a lecture group may be disinterested at times and so be disruptive. The issue of catering for students with diverse backgrounds in currently gaining more attention and is difficult to handle…One useful approach is to commence with case studies for each field of engineering of students in the course. Another is to select textbooks that specifically guarantee examples and exercises that match the engineering fields represented in each course section.

Other observations from Wilson about engineering students:

- Engineering students typically learn through action, that is, they learn best by doing something while being taught and often find it difficult to learn by listening and reading.
- Engineering students also tend to have reasonable visualization skills…This is also one of the key skills required of a statistician—much of statistics involves being able to recognize patterns in data.
- Students' mathematical skills are often underdeveloped (at the time they take engineering statistics).

Observations from Wilson about engineering statistics courses:

- Courses use a considerable amount of subject specific language (jargon) and introduce alien concepts (randomness and ways of describing it). These are obstacles to the students.
- Simple examples—the traditional and unfortunate coins, cards, dice, and balls in urn—are not seen as relevant or interesting to the students. Alternative examples in engineering contexts are much better received.
- Applied statistics courses involve a reasonable amount of computational work, usually achieved through at statistical package. As there are usually time limitations, there is not time teach the use of the package in any detail.

Next, here are six excerpts from Bisgaard [1]:

Engineering statistics has traditionally been regarded as a separate topic, almost “orthogonal” to engineering. Instead, it should be an integral part of engineering. Statistical methods are not an adjunct to, but are an inseparable part of, how engineers solve engineering problems…Whether or not engineers have learned statistics, they *will do statistics*.

Engineering educators have not been very conscious about how much experimentation is in fact a part of an engineer’s daily work. Yet, design of experiments has usually been tucked away in the back of the textbook and hence has not been covered in a one-semester course. (It appears in a second course, whether at the undergraduate level or the graduate level.)

Every one of these (physical and chemical laws) originated from an extensive series of experiments in an interactive process of induction and deduction. (See Figure 1, Bisgaard [1], which originated with Box in [12] and appeared later in textbooks co-authored by Box, such as [13]). Yet, the only type experiment students have been involved in, if any, are often demonstration experiments of already known phenomena.

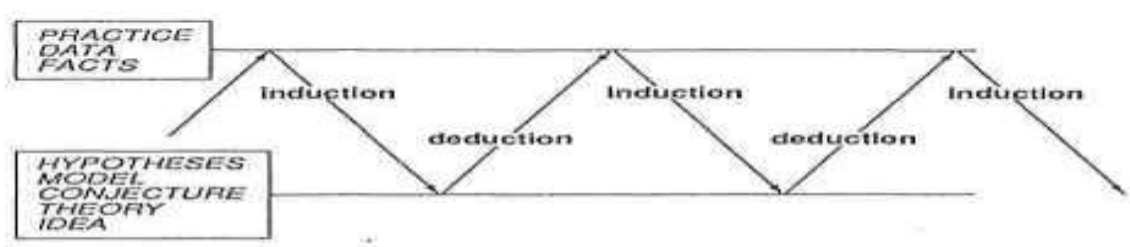

Figure 1. Learning as Iteration Between Theory and Facts (Bisgaard [1])

With rapidly developing new technologies, materials, and processes, it is today even more important that engineers learn how to learn basic facts, as illustrated in Figure 1. Learning how to learn is the only invariant in today’s rapidly changing world.

As a science, statistics is more appropriately considered the science of inductive reasoning and experimentation. What we emphasize and teach to engineers should be to that end. Most engineering education is presented almost exclusively as a deductive development…It gives students the false impression, however, that science and scientific thinking are synonymous with deductive reasoning only…It is important that we introduce statistics not as a separate topic, but as an integral component in the scientific learning process of induction and deduction (Figure 1). The introductory statistics course should be used to assure that students learn how to generate fundamental *new knowledge* through induction and experimentation.

Real statistical work involves a lot of practical considerations that I think can only be learned by *doing* statistics…I do not see how I could teach statistics without the experience that consulting gives me. In courses we teach (at U. of Wisconsin), we always start with a problem, rather than focusing on techniques. (This resonates with a teaching method recommended by Mosteller [14], the Particular-General-Particular (PGP) strategy: A particular problem stimulates the presentation of a theory/method to solve the problem, which then proves immediately useful in another problem of a similar structure… note that this is the opposite of how math instructors will typically introduce a theorem, then an application.

Adapting Pedagogical Methods to Millennial Student Learning Styles

Considering the "Five R's" learning characteristics of Millennial students, and the above recommendations of two highly respected engineering statistics educators, we recommend the introductory probability and statistics course for engineers be revised as outlined in Table 1. An explanation of each adaptation follows.

Table 1. Matching Pedagogical Adaptations to Millennial's Learning Characteristics

Learning Characteristic	**Pedagogical Adaptation**
Provide a Rationale	Establish student rapport and respect for experience of the textbook author and the instructor; avoid authoritarian style
Make it Relevant	Use textbooks that have a plethora of examples and exercises from the students' major fields
Revel in Technology	Use a statistical package integrated into the textbook, with in-class tutorials and homework solutions that require use of the package
Prefer Relaxed and Experiential	Use of the Quincunx and Stat-a-pult® training devices, for in-class demonstrations
Rotate among Delivery Methods	Alternate between lecture, problem solving, software tutorial, and physical demonstration (if feasible)

Provide a Rationale On the first day of class, the instructor should take time to discuss the qualifications of the textbook author, why this particular text was chosen, and how it has evolved through editions he/she is aware of. Also, the instructor could go ahead and mention how long he has been using statistics—mentioning educational experiences and situations in his practice of engineering where applied statistics was used. Personally, this author expresses empathy for the students in his sophomore-level Engineering Statistics courses at The University of Alabama by stating "I can still recall the difficulty I experienced in transitioning from a purely deterministic understanding of science and engineering—for me (at least) it took several courses to get comfortable with probability and statistics to the point where I felt competent to apply it." The opening remarks should include a reminder of how the scientific method works, and that both induction and deduction are aided by statistical thinking and methodology. Then carefully explain why the course is required, or at least elective, in the various majors represented. One can refer to ABET general and program criteria, for instance discussing collection and analysis of data, planning and conducting experiments, engineering problem solving, and communication of results/recommendations within ones organization or to customers—using the language of probability and statistics to professionally address the strength of findings, and the extent of uncertainty in the information transmitted. In the case at our institution, we have a mix of civil, construction, and environmental engineering majors in the course, along with all the computer science majors; most have just completed Calculus II and are therefore sophomores, with mathematics, natural science, and introductory engineering, graphics, and programming courses behind them. The instructor should assure the curious students that many of the perhaps 100 examples in the course material will appeal to them at this stage in their education, and the homework exercises from several hundred provided in chapters covered will be selected specifically for the engineering majors represented in this semester's enrollees.

Make it Relevant As previously mentioned, a textbook for a course on Engineering Statistics, whether introductory or advanced, should provide a plethora of examples and exercises from the engineering disciplines represented in the course. As an example, two textbooks we have used at UA satisfy this criterion: *Applied Statistics and Probability for Engineers*, Montgomery and Runger [15]; *Probability and Statistics for Engineering and the Sciences*, Devore [16]. Both of these offer hundreds of examples and exercises from every field of engineering and science, are in at least their sixth edition—meaning they have been around for a couple of decades— and include examples throughout the text of solution via the statistical package Minitab. Devore includes many examples and exercises with data sets from engineering journal articles, which are identified just as they would be in the literature. Either of these example texts can be bundled with Minitab, and provide a good fit of topics for the first and second courses in engineering statistics alluded to in the Introduction section. There are of course many other textbooks that could meet the criterion of relevance to students in multiple engineering majors.

Revel in Technology As explained earlier, Millennial students have grown up with digital tools they use in educational, recreational, and social situations. They can quickly gain skills in menu-driven software tools embodied in any statistical software package (in-class demonstrations certainly help and provide the opportunity to ask questions) and realize the significant productivity gains achieved in computation and graphing required—first in homework assignments, and later in other courses, senior projects, and the practice of engineering. With bundling, students obtain access to a one-semester download of Minitab for their particular operating system. Some universities (ours included) provide Minitab on a campus-wide or college network, for free use by any enrolled student. Still, rather than jockey for seats in a computer lab, most students prefer to have access anywhere, anytime, on their personal machine.

Relaxed and Experiential Even those of us who were undergraduates in the 1970s recall the value of "platform" demonstrations in our science and engineering courses. These physical demonstrations provide opportunity for the students to see the instructor in a less formal, and sometime humorous, situation. It turns out that there are a couple of inexpensive training devices, the Quincunx (Figure 2) and the Stat-a-pult® (Figures 3& 4), that can be used in classroom demonstrations of probability and statistics. The Quincunx enables the drop of small balls, one-by-one, into a maze of pins that deflect the path of each ball to the right or left, as they fall under the effect of gravity. The balls end up in one of several channels at the bottom of the drop, forming a symmetric distribution centered at the drop point, with the number of channels as the range. The pattern of pins can be modified by choosing "pin blocks" that either align with, or do not align with, the channels below; this permits the demonstration of distributions with same mean, but different spreads (variances). One can also shift the Quincunx drop location from location to location to show how the sample mean follows the (current) population mean; also to illustrate the effect of this additional source of variation on the overall distribution of dropped balls. And yes, there is Google access to a digital quincunx, but the physical aspect is lost.

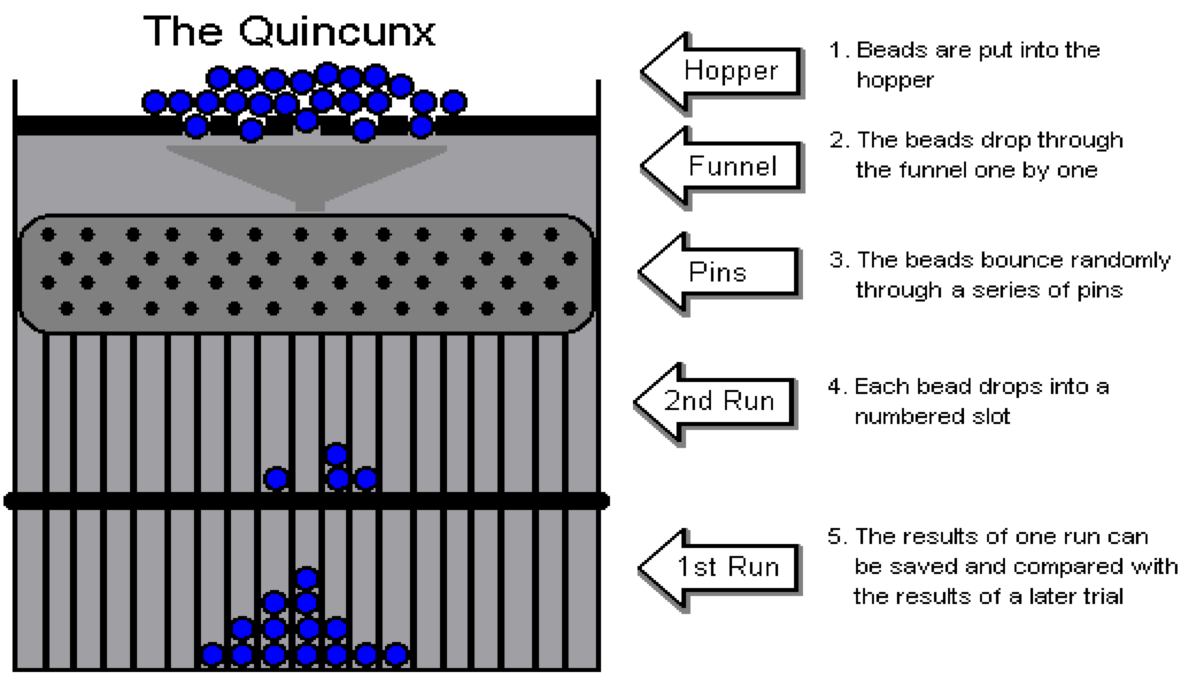

Figure 2. Image of a Quincunx and How it is Used in Demonstrations

The Stat-a-pult® is a miniature catapult with several adjustable components (Figure 3a); the performance of the device, under fixed conditions, is the distance a rubber ball travels from a fixed launch point to touch down, as measured by a spotter. So, it takes at least two people to complete a single launch and touch down, but others can be involved in setting up and marking off the distances, fetching the ball after landing, recording the results accurately, etc. as shown in Figure 3b. As the demonstration progresses, the instructor can show the variation in distance traveled under fixed conditions; then, the setting of the various components can be changed to show the distance effects, singularly or with multiple changes. This leads naturally to a discussion of the "optimal setting" and how it might be discovered through statistical design of experiments, instead of having to test all possible combinations of component settings. If the class is small enough, then teams of 2-6 students can be turned loose to repeat the simple experiments as illustrated by the instructor. This introduces some hands-on "fun" to the math-oriented engineering statistics course.

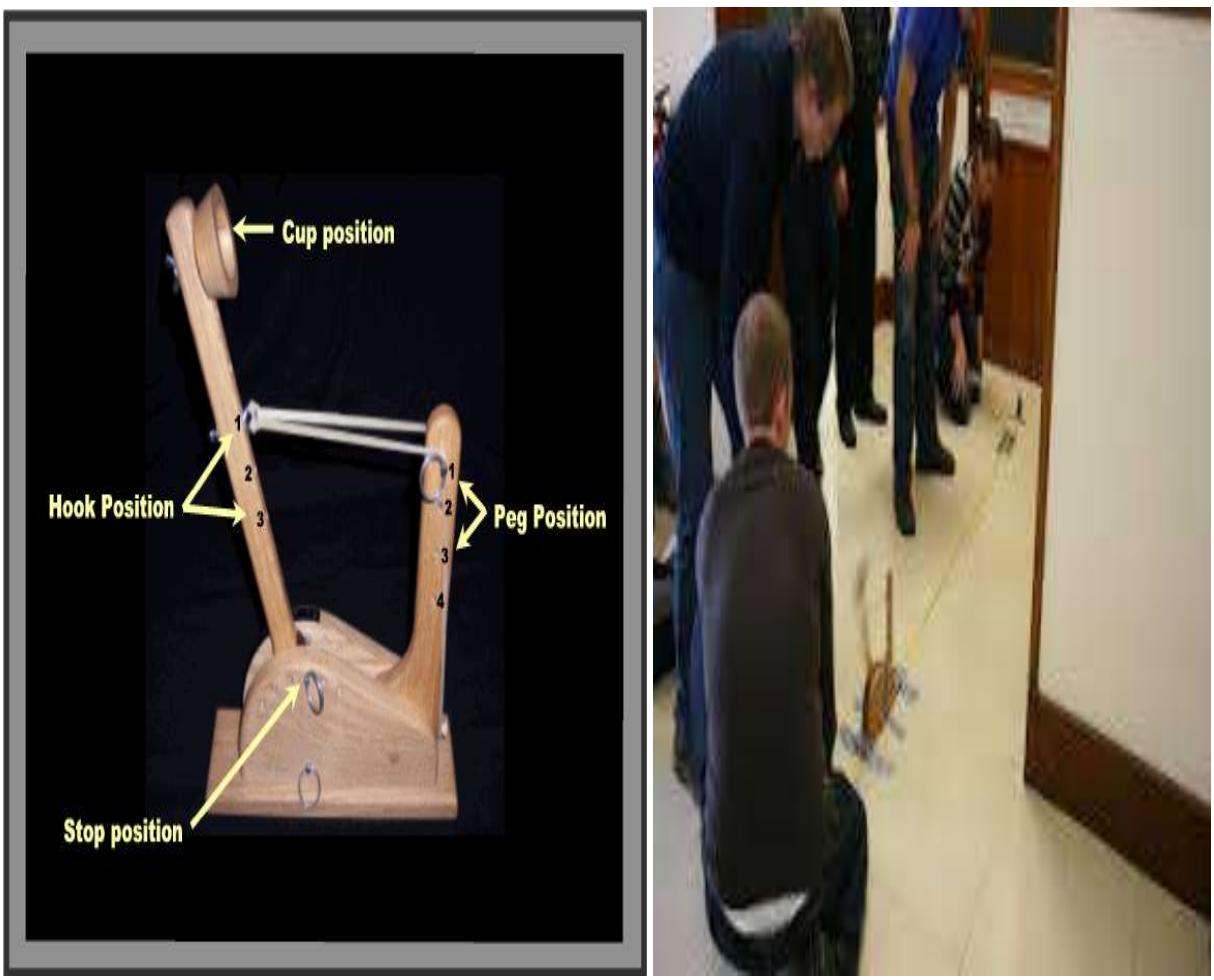

Figure 3. (a)Image of a Statapult and its Components; (b) How it is Used to Launch a Ball

Rotate among Delivery Methods To the disdain of many college instructors, Millennials have a shorter attention span than students from earlier decades. They want variety—in fact, surveys have shown they lose interest unless the delivery method changes every 10 minutes! So, in a typical 50-minute lecture, one should consider an appropriate rotation sequence among lecture (knowledge transfer), software tutorials, physical demonstrations, and applying the theory and methods of the lecture to data from real engineering problems. Starting with a problem or data set to be analyzed was recommended by Bisgaard [1], in contrast to starting with theory, but note that sometimes theory can lead back to application. For instance, using computer simulation to show the sum of random variables of any type is approximately normal, lends credence to the Central Limit Theorem; but then one can easily show that the *product* of random variables must be approximately lognormal. At this point, one can remind the class of the many rate x time relationships in physics and more generally, engineering.

Conclusions

There is a long history of articles similar to this one attempting to identify best practices in teaching probability and statistics to engineering students, who are often mixed together in sections with more than one major. Through review of the well-documented learning characteristics of today's Millennial students, the observations of two well-known engineering educators, and our own experiences teaching engineering statistics courses at UA the past 30 years, we have recommended a multi-faceted approach to modernize the introductory engineering statistics course. Hopefully other instructors, whether new or seasoned, can benefit from these recommendations.

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