Modern technologies and curriculum development in introductory statistics courses in engineering

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1. Introduction

During the last twenty five years the most important companies have begun to incorporate deep changes in their management philosophies. These philosophies stress the systematic use of statistical methods for continual improvement. This has led to a great demand for statistical knowledge on the part of engineers and technicians of industry (Montgomery and Runger, 1999). Intensive statistical courses are included in all the engineering curricula of Spanish universities. The most common criticism of the teaching of engineering statistics in Spain in the 80s was that it was too academic in focus, excessively theoretical, and divorced from the real problems that can appear in the industrial and business world (Peña et al., 1990). These criticisms also described statistics education in other countries (Godfrey 1986, p. 36): "For too long we in the statistics profession have tolerated poor statistics teaching, which produces courses that are often rated as the worst course or the most useless course that graduates in other fields claim they have ever taken. We too often teach what appears to the students a collection of unrelated methods illustrated by examples taken from coin-tossing, card-playing and dice-rolling. And then we expect the students to be able to translate this wide variety of methods with simple gambling examples to complex industrial problems involving the application of a large number of methods".

An Educational Innovation Project was initiated in 1989 at the Universidad Politécnica de Valencia out of the conviction that the results of the teaching/learning process were unsatisfactory (Romero et al. 1995). Some of the problems were a consequence of overly theoretical teaching with too little experimental training. An important goal of the project was to integrate new technologies into the teaching of statistics. This could not be accomplished without a thorough reorganization of the curriculum.

Nicholls (2001) comments: “Advances in Information Technology (IT) and the resultant impact of these advances have led to a much more data based society, a trend that can be expected to continue into a foreseeable future. This phenomenon has had a real impact on the Statistics discipline in general and on the training of both professional statisticians and users of Statistics in particular”. IT advances have had an impact on both course content and delivery. This paper considers engineering statistics education and how new technologies have changed its curriculum. A case study at the Universidad Politécnica de Valencia is described emphasizing the important role of technology resources.

2. The context of change

The reform movement in mathematics education that has taken place over the last two decades has influenced statistics education and led to a review of content, pedagogy, and technology at all levels of education (Moore, 1997). Changes in the three areas have gradually been adopted as a means of offering continuing improvement in the teaching of statistics. The recommended changes may be summarized as follows:

- Highlighting connections between statistics and other sciences
- Understanding and using students' prior conceptions
- An emphasis on analyzing and interpreting data
- More active participation on the part of the students
- Solving real-world problems
- Small-group cooperative learning
- More technology and communicating skills regarding data and chance

The experts stress the importance of improving students' technology skills. During the last years statistics educators have taken the responsibility for the evaluation of new technologies from the perspective of education (e.g. Biehler, 1997; Utts et al. 2003).

Engineering statistics courses should be designed to prepare the students to use statistical thinking and reasoning, and provide them with the necessary skills to interpret and evaluate data analyses. Techniques should be presented embodied in case-studies of intrinsic interest to a wide variety of students. An important goal of integrating technology in the statistics curriculum is the creation of a learning environment within which students are able to choose when and how to use it. Calculations should be given secondary priority. Derivations and hand calculations are to be replaced by the widespread use of statistical computing methods, and an emphasis is placed on the analysis of real data. Students do not need to become facile with making graphs by hand when the computer can do automatically. This also allows students to focus on questions relevant to the exposition of a problem and on the interpretation and critical analysis of the results. The lecturer adopts the role of `facilitator' (Moore, 1997), and motivates statistical concepts, activities and problems.

3. Changing content in engineering statistics

New content in engineering statistics reflects the computing-intensive nature of statistical practice. Computers are the medium for how we handle large and complex data sets, which are very frequent in businesses. Methodologies for analyzing these new types of data require the use of modern technologies. Certain understandings in statistical thinking can not be realized in reasonable timeframe without technology: Examples include exploratory data analysis, sampling distributions and regression. Exploratory analysis is characterized by an (Velleman and Hoaglin, 1992) "iterative process of describing patterns, subtracting them, and searching anew for pattern in the residuals [that] continues until the data analyst decides to stop". This iterative process is tedious indeed if the analyses are not automated.

New technologies allow implementing simulations that can help students' understanding of probability and variation. Simulations provide an alternative to proofs and algebraic derivations as a way of improving students' understanding of important

facts. The central limit theorem, always a fact that can not be proved to beginners, is both more comprehensible and mode convincing when seen at work via simulation and graphics. These simulation experiences can be built on later to teach statistical practices such as bootstrapping and Monte Carlo techniques.

The bootstrap is a good example of synergy between technology and content. It is conceptually an extension of the core idea of a sampling distribution that is widely useful and impossible without fast computing. Bootstrap appears in research papers and advanced courses, but the idea is quite simple and can easily be added to an introductory engineering statistics course. Weldon (2002) indicates that "It is important that students have been exposed to the idea of simulation for a painless introduction to the bootstrap". This author illustrates with two examples how this technique might be used to introduce and explain the relative stability of averages, and to assess the variability of an estimated parameter in a real-data context.

Every engineer needs a good practical knowledge of design of experiments. Hoerl et al. (1997) comment that an intro course in engineering statistics should also include basic concepts of planning data-based investigations, including the major concepts of design of experiments. Technology has facilitated to teach design of experiments at earlier levels than was previously the case. Some of the statistics courses taught at the Universidad Politécnica de Valencia, include a module introducing experimental design. A student completing this module will be able to describe the difference between an observational study and an experiment, assess the likely main and interaction effects by looking at an interaction plot, perform a randomization for a complete randomized design, and access a package via the web to generate a randomized design.

4. Concerns for the future

The current interest in analyzing large and complex data sets has motivated the application of modern methodologies emerging from the fields of Data Base Management, Artificial Intelligence or Pattern Recognition, among others. For many in the information sciences the process of analyzing data with these techniques is known as Data Mining. An introduction to these methodologies (pattern recognition, neural networks, genetic programming) would be of interest in an advanced engineering statistics course.

Over the past few years there has been and increase in the use of the Internet as a resource for helping teach statistics. Web-based material can be interactive and more engaging than printed text. As technology advances and student enrollments increase many universities are exploring the use of web-based instruction. The options range from the use of web-based applications in traditional classrooms to full-blown online courses in which there is no face-to-face contact. Since 2003, the Universidad Politécnica de Valencia is offering Internet-based statistics courses that utilize both distance learning via the web and the traditional classroom format in some combination. However, the final outcome of the teaching with these new technologies may not be known for some years. Then we shall be able to verify whether our students have incorporated the statistical techniques into their knowledge and applied them as tools for data analysis and decision-making in real problems that will arise in their future professional work.

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RÉSUMÉ

Cet article traite le sujet de l'influence des nouvelles technologies dans les changements du programme d'études de cours d'introduction à la statistique destinés aux étudiants d'ingénierie. L'article aborde le cas pratique de l'enseignement de cette matière à l'Université Polytechnique de Valence (Espagne) où, depuis 25 ans, des projets d'innovation éducative ont été mis en œuvre afin d'améliorer la qualité du processus d'enseignement – apprentissage de la statistique.