PROVIDING "REAL" CONTEXT IN STATISTICAL QUALITY CONTROL COURSES FOR ENGINEERS

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Even the best engineering undergraduates often have little enthusiasm for our statistics courses. Some of their disinterest is really traceable not just to a skepticism about whether using our apparently boring methods will help them be better engineers, but to an even more fundamental ignorance of what engineers do and what kinds of environments they work in. Where a statistician has the luxury of giving a second course in engineering statistics (like a statistical quality control (SQC) course), some part of that course can be aimed at providing not just statistical methodology, but also a proper context for that methodology. This paper discusses ideas in this direction, some of which I have used in an SQC course for industrial engineering students and are documented on a course Web page at:
http://www.public.iastate.edu/~vardeman/IE361/ie361vard.html, and others of which I am still thinking about how to utilize.

INTRODUCTION

Over the past 10-15 years, a number of individuals have made serious and sustained efforts to produce new statistics textbooks and other course materials that are genuinely (and “obviously”) relevant to engineering practice. My experience, however, is that in spite of the facts that there is important new textbook material available and that many of us have worked hard to move away from the “baby math stat” stereotype, the reception (and probably the long term effectiveness) of our university engineering statistics courses has improved very little. On the basis of substantial experience teaching and supervising a variety of versions of introductory engineering statistics (several of which are described in Vardeman, 1991) and the somewhat unique opportunity to regularly teach a “second” course in applied engineering statistics (a statistical quality control course), I am convinced that this says more about the audience's frame of reference than it does about the current relevance of our introductory courses.

Most undergraduate engineering students (at least the ones I see at Iowa State University (ISU)) typically have very little idea what engineers do, let alone any concept of the environments in which they work. Examples and exercises that “should” motivate them don't, and in many cases even cause them extra consternation as they get frustrated with the subject-matter specifics of an unfamiliar application and fail to grasp the statistical principles being applied. Many students in our first courses are far happier with exercises like “An engineer collects measurements 3,4,2,6,4. Make a 90% confidence interval for μ.” than they are with ones that begin like “Here are some data on numbers of bonds (out of 96) showing some evidence of ceramic pull-out on a device called a dual in-line package. (Low numbers are good.) Experimental factors and their levels are…”. I view this reality as largely insoluble in the context of a first course, as there is a certain amount of basic material that must be covered in a relatively small number of credit hours, and I think we have an obligation to present it in terms of engineering applications, not “in the abstract”. However, where a statistician has the luxury of presenting a *second* course in engineering statistics, some part of that course can be devoted to supplying some of the context that the typical student lacks.

The ISU SQC course is easily the best-received undergraduate engineering “statistics” course at the university, and I believe that much of its good reception derives from the “real” context supplied for the technical material. In this paper I will discuss some of the ways that context is conveyed in the course, and some additional ideas that I am still thinking about how to incorporate. These include 1) significant external process improvement projects, 2) required papers and guest lectures on “current quality culture”, 3) in-class demonstrations and hands-on laboratories, and 4) the use of irony/humor/Dilbert in motivating clear-headed critique of the environment in which methods taught in the course are applied.

EXTERNAL PROJECTS

My experience has been that the engineering students most receptive to instruction in basic statistical methods and thinking are those who have completed an internship or co-op experience in industry, particularly in manufacturing. They come to a statistics course with an understanding that variability matters and that data *really are* one's "guide to the unknown". An effective (if somewhat demanding) means of giving all students in a second course access to this perspective is to include a "mini-internship" in the course, in the form of a required external group project.

Our SQC students at ISU are required to find a real client business (or other organization) and attempt to improve some real process, organizing their efforts around a logical/statistical paradigm laid out in Chapter 1 of their textbook (Vardeman & Jobe, 1999). (See the URL in this paper's abstract for a current version of the project statement.) Process improvement is an inherently statistical proposition, and the project has often been spectacularly successful in convincing students that statistical thinking and methods are important to their futures as engineers. Many initially quite disinterested students have gotten very excited about the course's technical content and what they can do with it. In the past 10 years, three different student groups have won regional professional society paper competitions using their projects as bases, and two of these groups have been national runners-up. A paper based on another group's project is to appear in the journal *Quality Engineering* in 2002.

It is one thing to hear lectures about quantifying gauge precision and accuracy, but quite another to need to do it in order to decide whether measurements can be trusted to guide real improvements in a paint mixing process. It is one thing to hear lectures about Shewhart control charting, but quite another to really need to do it in order to ascertain whether a particular machine tool counted on to make money for a real client is behaving in a consistent manner. And it is one thing to hear lectures about multiple regression analysis, but quite another to see that it can be used in a response surface analysis that measurably improves the output of an injection molding machine. I have found that if *any* part of what they've seen in our statistics courses proves useful in these projects, engineering students become more receptive to the proposition that the rest of what we've shown them might also be helpful. It is not uncommon to hear end-of-course comments like "I sure wish I had paid more attention in beginning stat."

It should be said that what I'm suggesting here is really much different from the kind of outside-of-class data collection and analysis project that is now (happily) quite common in first statistics courses taught to a variety of audiences (e.g., Moore, 1996; Vardeman, 1996). These "plan, execute and analyze the results of your own data-based study" exercises are certainly of value. We use them in engineering statistics at ISU, as is evident in the student-generated data sets that populate Vardeman (1994) and Vardeman and Jobe (2001). But in my experience, they have been nowhere near as effective as the external process improvement projects in the SQC course in terms of really capturing the hearts of engineering undergraduates. It is relatively easy to "go through the motions" of completing one of the standard class projects without any real engagement. It is not so easy to interact with a client who owns a real process and stands to benefit from its improvement without developing any appreciation for the genuine usefulness of good data collection and analysis.

MINI-PAPERS AND GUEST LECTURERS

It is a perverse, but nevertheless persistent fact of human nature that we are often inclined to take the word of a personally unknown "outsider" over that of a familiar "local." In the context of a university SQC course, this and the engineering student's characteristic impatience with anything that might prove to be "impractical," have the implication that the emphases of both the instructor (no matter how knowledgeable) and the textbook (no matter how erudite) are sometimes viewed as less credible than those of outside "experts." I have found it useful to then call to witness such authorities when teaching SQC … not by quoting or referencing them, but by having the *students* find out what they have to say. I have done this in two ways.

First, I regularly assign "quality culture mini-papers" early in the SQC course. Again, the current version of the assignment statement can be found at the URL listed in this paper's abstract.. I'm sure that it's unusual to assign even a small such "research paper" in what is basically a statistical methods course, but I have found this device effective in establishing the relevance of the course content and emphases. Students look through a variety of Web sites and books for basic information on topics like “Six Sigma Programs”, “ISO 9000 Certification”, “the Malcolm Baldridge Award”, “Robust Engineering”, “Deming”, “Taguchi”, “ASQ Quality Engineer Certification”, “Quality Function Deployment”, etc. I cannot say that students are always discerning about what part of that which they locate is more than hyperbole intended primarily to help sell a particular consultant’s services. But they do get an early sense that the issues addressed in the course are alive outside the classroom, raising their general interest level. And as the course goes on, they also begin to see (at least after I force them to read the whole set of papers and quiz them about possible logical and conflict-of-interest issues) that it is important to know enough about the statistical issues involved in the current quality scene to tell real expertise from nonsense.

Second, we have sometimes been able to use external guest lectures to provide context in the SQC course. We are fortunate to have an ISU alum who as a division head for a Fortune 150 company led an effort that culminated in the winning of a Malcolm Baldridge Award, who is a solid technical engineer we are glad to have in class, and who lives close enough to the university to provide occasional guest lectures. When a real national leader of industry talks to undergraduate engineers about the importance of measuring and improving process capability, they listen, whether or not the same topic seemed important in the text or when discussed by their instructor. I can’t recommend using a class period this way unless a guest lecturer is available who is both highly positioned *and* technically credible. But when such a person can speak to a class, his or her input can be very important to convincing students of the strategic importance of statistical thinking and methods in engineering.

IN-CLASS DEMONSTRATIONS AND HANDS-ON LABORATORIES

It is by now fairly well-accepted that all varieties of basic statistics courses can and should have elements that amount to the kinds of physical demonstrations and laboratory experiences that engineers and scientists associate with their major courses (e.g., Bisgaard 1991; Spurrier, Edwards & Thombs, 1995, 1996; Aliaga & Gunderson, 1998; Barton & Nowack, 1998). I have used such on a limited basis (but nevertheless to good effect) in the ISU SQC course. And when my time, the laboratory space and the financial resources needed to purchase enough equipment permit, I hope to modestly increase the part these elements play in the course.

I do not subscribe to the currently fashionable “different-modes-of-learning/learner-centered-classroom/active-learning” doctrine. Where there is no realistic, genuinely compelling physical demonstration or laboratory exercise obvious and available, I believe that simply doing an artificial “laboratory” for the sake of doing one is a waste of precious class time. But there *are* some matters that it is far easier for engineering statistics students to grasp when they can physically see them, than when they are only discussed in the abstract.

The reality of, the practical importance and implications of, and the quantification of *measurement error* is one such set of issues. (I currently spend around 20% of the SQC class time on these matters, as I am increasingly convinced that they are fundamental to engineering practice in general and SQC in particular.) We consider simple concepts of gauge precision and accuracy, the partitioning of observed variability into part-to-part/process variation and measurement variation, and the use of (inverse) regression methods to improve measurement accuracy. I have found that when students can physically see at least semi-real demonstrations of the necessity of these, they are much more ready to endure my expositions of the implications of a model like $y_{ij} = x_i + \varepsilon_{ij}$ than when I simply launch into the exposition with no physical motivation. The last time I taught the SQC course, we did some in-class measuring of the widths of the mass-produced binder clips in Figure 1 with the vernier micrometer in the same figure. When $m = 7$ measurements on the same clip yield standard deviation .0035 mm and single measurements on $n = 10$ different clips yield standard deviation .0254 mm “before their very eyes,” students are on their way to believing that there is both measurement and unit-to-unit variation, and that it might be a good idea to be able to separate them.

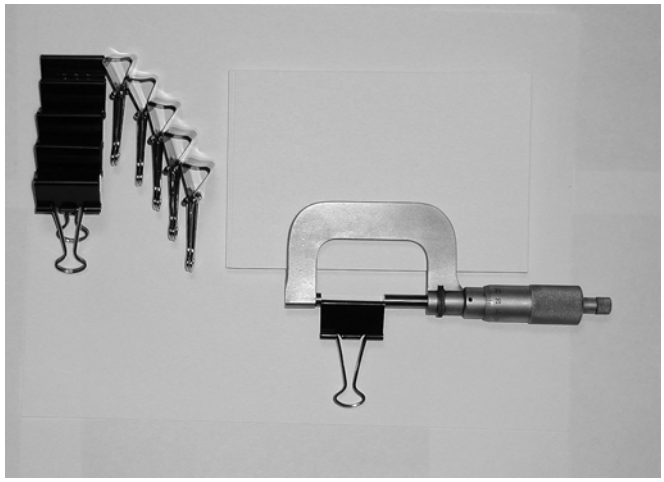

Figure 1. Vernier Micrometer and Binder Clips

Similarly, to make concrete the notions of calibration to physical standards and the role of regression analysis in that endeavor, we have done some additional in-class measurement studies in the SQC course. Figure 2 shows a digital caliper (that I set to its metric mode in which it reads to .1 mm) and some (old and beautifully machined) gauge blocks (marked in units of .001 inch). After measuring 10 different blocks (marked from .100 in to .200 in) twice each, it is perfectly natural and concrete to say to the students “So, this eleventh block isn’t marked. I measure it at 3.9 mm with the digital caliper. How thick do you think it “really” is? And, by the way, how good is your number?”

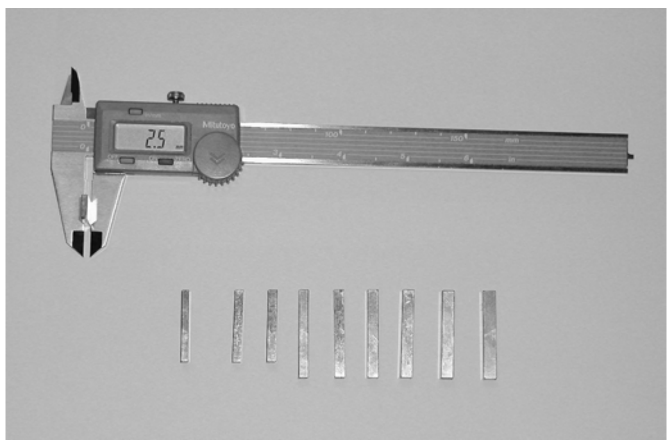

Figure 2. Digital Caliper and Gauge Blocks

I’d like to have enough laboratory space and equipment to ask groups of 2 or 3 students to collect data like those described above for themselves, working from a page or two of written instructions and some fill-in-the-blank worksheets. And I’d like to find more realistic replacements for what amount to my versions of the old Deming Seminar “red beads process monitoring drama” and the “students measure hat sizes of volunteers” repeatability and reproducibility exercise of Lackey (1998). And I’d really like to discover realistic alternatives to the well-traveled “paper helicopter” and “toy catapult” experiments to use with my SQC students. (These last two devices may well be effective in some settings. People do claim to have success using them to teach the basics of factorial and response surface experimentation to working engineers. But I've never had an expectation of success with skeptical undergraduates strong to enough to cause me to invest the class period or two required to employ these.)

There is much to be done here. The challenge is to find and organize demonstrations and laboratories that are realistic and at the same time inexpensive, compact, memorable and on-the-point.

IRONY/HUMOR/DILBERT

Working engineers don't apply statistical thinking and methods in a vacuum. They work in environments/corporate-cultures that are often (not only internally contradictory and self-defeating, but more to the present point) not supportive of thoughtful and effective application of statistical tools. This is in spite of the fact that much corporate lip service is paid these days to notions (like “quality” and “continual improvement” and “six sigma”) loosely associated with statistics. Part of what I have always tried to do in the SQC course is to put the technical content into its proper perspective as genuinely useful *but no panacea*, and to warn of some of the ways that its effectiveness can be lost. I do this as an intended inoculation against the failure of the methods for human reasons unrelated to the merits of the technology. I judge that my efforts in this direction have been largely futile. On occasion, students with work experience in industry nod knowingly during one of my sermons about the dangers that await them on the other side of graduation. But most students stare blankly and probably don't remember a thing I say. They simply have no frame of reference to see that matters of corporate culture (and personal mental laziness) can render technical efforts quite impotent.

One way it might be possible to better convey a sense of the environments in which SQC methods are really applied (and the kinds of human obstacles to be overcome if they are to be effective) is to make more use of irony and humor in the classroom. Scott Adams is one of my favorite cartoonists and his work seems like a tool that might be helpful here. With his alter-ego nerd-engineer "Dilbert" (and Dilbert's too-true-to-life cast of coworkers), Adams daily skewers corporate and societal stupidity in general. (See, for example, his Web site www.dilbert.com.)

What is relevant here is that because statistical and “quality” issues really are pervasive, Adams fairly regularly comments on them specifically. I have collected whole series of Dilbert cartoons on ISO 9000, Six Sigma, Malcolm Baldridge, general quality initiatives, statistical literacy, etc. that describe the way things often are in practice. The texts from a few of my favorites:

- Dogbert the consultant: “You've got to implement a six sigma program or else you're doomed.” Pointy-Haired Boss: “Aren't you the same consultant who sold us the worthless TQM program a few years ago?” Dogbert: “I assure you that this program has a totally, totally different name.” PH Boss: “When can we start?” (Dilbert, 10/3/01)
- Pointy-Haired Boss: “I'm putting you in charge of getting our ‘ISO 9000 certification’. We don't know what it is, but it looks great on brochures.” Dilbert: “I think it certifies that we follow a consistent process.” PH Boss: “That's us; we always lie on our brochures.” (Dilbert, 12/6/94)
- Pointy-Haired Boss (to Dilbert and coworkers): “I'm assigning each of you to a separate ‘quality initiative’.” Wally: “Is there any risk this will devour our productive hours, lower our morale and have no impact on our profitability?” PH Boss: “And we'll have a contest to come up with a name for the overall initiative.” Wally: "How about ‘qualicide’?” (Dilbert, 7/11/96)
- Pointy-Haired Boss (to Dilbert and coworkers): “It has come to my attention that 40% of your sick days are on Fridays and Mondays. This is unacceptable.” Naïve Intern: “HA HA HA!!! THAT'S A GOOD ONE!!!” Naïve Intern (next panel): “Please tell me he was kidding.” Wally: “Welcome to hell, kid.” (Dilbert, 4/18/96)

These cartoons describe more eloquently and memorably than I ever could the unexamined “bandwagon” mentality sometimes associated with quality initiatives (and preyed on by the unscrupulous), the constant temptation in the direction of form over substance, the possibility that programs and methods take on existences independent of any good purpose they might have served, and the price of quantitative illiteracy. And these are matters that can completely swamp the effects of good technical work if they are not taken into account.

If one sees potential in Dilbert (or other such tools) for informing students about what awaits them in applying their technical knowledge in industry, the natural question that arises is “Exactly how can I use this kind of device?” Leaving aside issues of copyright and permissions (that I'm presently not exactly sure how to handle) there is the matter of how to expose students to the commentary the strips provide. I'd like to have an inexpensive focused collection for the students to buy and write a short paper analyzing (in the style of the mini-paper assignment referred to above). Lacking that, I am thinking that the next time I teach the course, I may make it a fairly regular practice to place a well-chosen strip on an overhead before class and then dedicate a minute or two at the beginning of class in dialogue on “So what's the message here?” This seems to me to have potential as an efficient and engaging means of making some of these points.

SUMMARY

The main contention here has been that student ignorance of what engineers really do and the environments they work is partially responsible for disinterest in undergraduate engineering statistics courses. In the context of a 2nd course in the subject, there are things we can do to address this ignorance. I've described some possibilities I see, and am hopeful there will be increasing and ongoing discussion on this topic.

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