

Enhancing the Statistics Education of Practicing Engineers

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Abstract

Engineering statistics education impacts the use and implementation levels of statistical methods in the workplace as well as US market competition. For engineers in Europe and Japan, two of our main industrial competitors, study more statistics. There is no room to add statistical material in the engineering curriculum (or in most any other areas). Our proposed solution, under the existing constraints, is to move them up and down the stream. Teach intro material in grade school, Teach basic inference, modeling and statistical thinking in college. Make studying advanced statistics a "lifelong" endeavor, through better use of individual learning methods, taught via Professional-Industry-Academe "institutes" that bridge the gap between these two levels. This solution simultaneously addresses the problem three stages, by providing statistics education to practicing engineers, training to college students and by enticing the interest in science and engineering.

Keywords: statistics education; lifelong learning.

1. Problem Statement

With this paper, we pursue three objectives. First, we describe a problem; then we scope its importance and its consequences. Finally, we propose a solution.

Two key issues in engineering statistical education are: (1) engineers need to use it in their work (Hogg, 1985; Ketterning, 1995), because of the natural variation in performance measures (e.g. device life, reliability) and, (2) given the amount of undergraduate engineering curriculum topics, there is little room for adding more of it. Stats courses are usually too theoretical and overloaded (Romeu, 1998). Hence, many engineering students leave college lacking stats thinking and strongly disliking the subject. However when they start practicing, students discover that they really need it, and that they now have to learn it on their own

On the other hand, raising the statistical knowledge of the average engineer expands the use of industrial statistics methods, such as those presented at the FTC, among the engineering community. For, many advanced techniques may be difficult to understand by most engineers, due to the huge gap between college

level stats, and the level required for applying it in the field, as attested by the body of knowledge (BOK) in most professional certification programs.

Then assume there are only 300,000 engineers in the US, and that only 10% of them use statistics at work. Conferences such as FTC should be filled with many of these 30,000. But they are not. Why? Would it be because they lack the background to understand the statistical methods they implement? If so, there is a pressing need to bridge this educational gap.

This paper addresses this crucial issue. We investigate ways to provide practicing engineers new methods to learn stats on their own, at their pace, after college. We summarize the problem in the following points:

1. Engineering curriculum is currently extremely busy,
2. There is very little if any space to add additional subjects, let alone to add more statistics.
3. There is uncertainty about the field of specialization each engineer will work on, after their graduation
4. But in these fields (e.g. statistics) engineers will need additional and advanced instruction.
5. Only a small percentage of all engineers pursue a graduate education. Hence, they must acquire such additional education on their own, at the workplace.
6. They will receive such additional instruction by attending meetings or conferences, technical readings, preparing certification exams, receiving mentoring etc.
8. Most of this material is unstructured, unsequenced, of heterogeneous quality, and difficult to access.

Our proposed solution, under the existing constraints, consists of three parts. First, teach basics starting in grade school. Leave basic inference, modeling and statistical thinking to college. Finally, make statistics a "lifelong learning" endeavor via *Professional-Industry-Academe institutes*. The solution attacks the mentioned problem in its three stages: *past, present and future*.

By the *past*, we mean providing advanced statistical knowledge to *already practicing* engineers. By the *present*, we mean providing more hands-on stats knowledge to current *engineering students*. By *future*, we mean providing basic statistics to (and enticing an interest in science and engineering of) *grade school* students.

9. We propose that Industry-Government-Academe *institutes* integrate and support the educational efforts
10. A specific example, presented as *proof of concept*, is our Quality and Reliability (Q&R) Institute.
11. In these regional institutes, undergraduate and graduate student interns will help provide its services.
12. Small/Medium size regional industry and service organizations will receive “free” tech assessments.
13. Practicing engineers will receive instruction.
14. High School pre-engineering teachers, will also receive tutoring, and support in their activities.
15. High School students will attend special functions, and participate in engineering fairs and competitions.

In the rest of this paper we address all these issues, of vital importance to engineering statistical education.

2. Survey description and results

Statistics educators have spent big efforts researching the education of school children, undergraduate, and graduate students. But we found almost no information about the problem of post-college stats education.

Practicing engineers require a higher level of stats than that taught at college, namely that of ASQ CRE/CQE certification exam BOKs, or similar. Thence, they have to acquire it, on their own, after leaving college.

Filling the information void, as well as finding out how engineers learn, on their own, triggered the need for a *pilot survey*. We recognize that ours is not a randomly drawn sample, taken from the entire population, but a self-selected one. However, as a first cut, as well as to gain insight into the problem, it fulfills its mission.

We summarised the methods used by engineers to acquire statistical knowledge into: (1) reading books, journals, manuals and other hard copy materials, (2) reading Web materials, (3) taking on-line courses and learning software, (4) attending conferences, chapter meeting, etc. (5) preparing professional certification exams, (6) taking short training courses, (7) receiving mentoring from experienced colleagues, and (8) other sources, such as hands-on, trial and error, practical experiences, and (Six Sigma type) at-work training.

To characterise the survey taker, we asked their (9) education level, (10) application area (academe, industry, government), (11) speciality (mechanical, electrical, industrial, etc.), (12) total number of stats courses taken in college, (13) years practicing engineering, (14) country, and (15) their gender.

Of the current 62 responses, 59 are from the US. There were 8% females, 56% with graduate degrees, 60% had 16+ years of experience and 90% were from industry. We continue collecting data (Romeu, 2006a).

Survey results show how 16% have not taken any statistics courses in college (33% among BS), 38% took only one (38%) and 26% have taken 2 courses (24%). Hence, 1/3 of engineers with a BS degree have never taken statistics in college, and another 1/3 has taken a single course. Hence, 2/3 of all surveyed engineers had none or very little statistical training. Then, engineers that pursue graduate school have a better opportunity of learning statistics. Only 7% had never taken a statistics course. (Romeu, 2006b)

The survey showed how independent *Readings* (38%) constitute the preferred method that engineers use to enhance their statistical knowledge. Engineers prefer hard copy (28%) and web-based tutorials (10%) with detailed, step-by-step numerical examples, developing practical applications. *Hard-copy* (books, journals, etc.) *readings* are still prevalent, but the Internet is taking over, especially among the younger generation.

Easily downloaded *web tutorials* discuss distributions, confidence intervals, hypothesis testing, SPC/QC, reliability and availability modeling and data analysis, etc. They can be obtained through professional organizations such as ASQ, IASE, ASA, or RSS. Also via peer-reviewed publications in the Web (e.g. SERJ, Chance or JSE), statistics projects like CAUSEWEB or information centers (RIAC). There are even books and handbooks in the Web such as that of the National Institute of Standards and Technology, NIST.

However, their technical quality varies. In addition, they lack a single point of departure, as well as listing, classifying and sequencing. Often, there are excellent materials available that engineers don't even know exist –let alone where to find them, or in what order to read them. The usual procedure is to explore a topic, via *Goggle* or other search engine, and sort through the many results obtained, some relevant and other that are not. A very slow and inefficient procedure, indeed!

Web Tutorials can be very effective for the engineer who, from office or home, and on their own time, can learn the statistical methods that were not provided during their university studies, but that are crucial for their professional practice. Hence, web tutorials are poised to become the learning tool of the future. Some examples of industrial web tutorials can be found at: <http://web.cortland.edu/romeu/urls.html>

Professional short courses are also a very popular alternative to taking longer, well-structured sequence of courses in graduate school. Our sample reflected that 20% of the statistics that practicing engineers learn on their own is obtained via short courses, and Black Belt training.

But courses often focus on a single topic, developing it briefly and seldom in-depth, and vary in quality. With the proper content and background, short courses provide a useful first experience, readily applicable by the practising engineer who is usually in need of a tool that solves an immediate problem. However, such immediacy constitutes their main drawback.

For example, taking a regression short course without adequate background may well result a training course on regression software. Regression assumptions, or the procedures to check them, may not be included, or not fully explained in the short course, for lack of time.

On the other hand, if topics are taught at full length, short courses would no longer be short, defeating their purpose of providing an alternative to college. New middle-of-the-road approaches (e.g. sequencing them) will allow teaching advanced statistics methods while still circumventing the long detours of Academe.

Some problems of teaching short statistics courses include disparity in student levels, and differences in their expectations. For example, the same class may include senior engineers, who have not taken a formal statistics course in years, but frequently work with this topic, and novices with little statistical background. Managers and data collectors may only be interested in recognising a statistical problem, or in interpreting the information gathered. Analysts, who implement the statistical methods on real data, may need the details. An example of a reliability statistics short course is: <http://quanterion.com/RIAC/Training/Presentations/ReliabilityStatistics.asp>

Survey found that chapter *meetings* and professional *conferences* provide about 7% of statistical knowledge, plus 20% from professional *certification training* and exams. Finally, the survey shows how *mentoring*, received from more experienced colleagues, hands-on *trial and error* practical experiences, etc. contribute the remaining 15%.

Survey results present a fairly complete and reasonable picture of how practicing engineers study statistics on their own, during their professional life. For detailed results of the mentioned survey, or further discussion about ways that engineers acquire statistical knowledge on their own, see Romeu 2006 a, b, c and d.

3. Proposed Solution

So far, we have discussed the nature and origins of the problem at hand, which can be synthesized as one of lack of space in the college curriculum to teach all the statistics an engineer needs. We now propose to *move statistics material up and down* the education stream.

Introductory descriptive and probability stats (EDA, discrete probability) can be taught from grade school. Teaching engineering students boxplots, histograms and pie charts is grossly inefficient. Societies such as ASA/ASQ/ISI/RSS/IASE have done a lot of work to integrate stats into the *grade school* curriculum.

This leaves *inference, testing and modeling* (regression and ANOVA) *to college*. Engineering students should take applied courses, with real-life applications, that help them *develop statistical thinking* (Romeu, 1998, 2004) and not courses based on rote (Romeu, 2007).

Finally, *advanced topics* (multivariate analysis, DOE, regression, etc.) would be acquired as part of a *lifelong learning* process. *Local institutes*, supporting activities such as chapter meetings and conferences, certification training, workshops and short courses, mentoring, etc. should be created. These activities are currently poorly coordinated and lack a unifying thread that fosters the structured acquisition of knowledge.

The *Academe-Industry-Professional Societies Institutes* would help engineers *bridge their education level gap*, by acquiring advanced knowledge. Already practicing engineers (*past*) would receive well-structured courses. College students (*present*) would work as interns, gaining practical knowledge. High School students (*future*) would attend meetings and training sessions, encouraging them to pursue careers in engineering.

College student interns would keep operating costs low. Under a professor's guidance, they provide free assessments and technical assistance to small and midsize organizations, gaining practical experience, Faculty would gain better insight about industry needs, and industries that cannot currently afford it, would receive this service. Finally, professional organizations could use such professors and students as mentors and instructors in (presential and distance learning) short courses that support certification efforts.

Workshops could use freely available material, already in the Web, or new ones, developed by professional organizations and the *institutes* themselves. Engineers would have a place where they could periodically go, for consultation and for networking, establishing new

contacts that would help them grow professionally and to find work, in an everyday more challenging economy. The proposed *institutes* could also help organize mentoring systems (Romeu, 2006e), whereby older and retired engineers would share their rich working experiences with the younger ones.

4. Institute Characteristics and Operation

The *main objective* of the proposed institutes is to help practicing engineers *bridge the gap* between their limited college level statistics (estimation, testing and basic regression and ANOVA) and industrial statistics certification levels (advanced regression and design of experiments, SPC, reliability, etc.). The *second activity* of such institutes, and one that helps them obtain financial support, is *providing free* (or very low cost) professional *services and technical assessments* to local, small and medium size organizations that cannot otherwise afford them.

Such *institutes* would be located in engineering schools. There, they would assess and sequence the existing web tutorials and study material supporting professional certifications, as well as develop new ones. They would develop periodical forums, short conferences and mentoring activities. In short, they would help create a *community of users* in their midst. These activities would attract support from federal, state and local government, as well as from industry.

One *key element* of these institutes is their *Board of Advisors*. This group would be formed by delegates from state and local government, big industry donors and small industry customers, interns and students and university faculty and administrators. Each of these have important input to provide, that would improve the institute functions, help define direction, focus on problem-solving activities rather than in more abstract research, and find new customers and donors.

Such institutes would not become competitors of the private consultants or professional organizations that currently provide such services. On the contrary, they would become catalysts for future customers who, at present, either do not understand the need for these services, or cannot afford to pay for them.

Finally, local institutes would network, not only across regions but also across areas of scientific interests and specialization. This implies the existence of a network of institutes, of different subjects, around the Nation.

This spring, the Academy of Science held a *corrosion education* workshop (the Materials Forum, 2007) to address a similar problem in that area (Rose, 2007). It

was organized by the Division of Engineering and Physical Sciences, NRC/NAS. This *demonstrates* how *the problem of bridging the gap* between college and professional practice educational levels is a *general problem in engineering*. Institutes addressing different science areas would conduct joint activities, exchange ideas, students, faculty etc. for mutual benefit.

5. A Quality and Reliability Institute

As an example of the proposed institutes we offer our <http://lcs.syr.edu/faculty/jlromeu/SUQRPrpExcSm.pdf> *Quality and Reliability (Q&R) Institute* proposal, which we submitted to CNYTDO, Central New York Technology Development Organization. CNYTDO then forwarded it to NYSTAR. Both found that such *institute* “would be a real asset to the region, as well as to New York State”. But neither agency had funds to support the project and we continue our search.

The Q&R *institute* would help practicing engineers in CNY bridge the gap between their limited college stats studies and the ASQ CRE/CQE certification levels, by developing tutorials, workshops and short courses in reliability modeling, DOE, SPC, acceptance sampling, sequential testing, Gage R&R, Bayesian methods, etc.

We actually developed similar activities during many years, as statistical advisor for the Reliability Analysis Center (RAC, recently renamed RIAC), an information and analysis center for the DOD and its contractors. We offered short courses, produced web tutorials, had Web forum and provided free consultation to the DOD contractors. Our Q&R Institute extends this service to the CNY industrial and service community, at large. More information on the RIAC, is at <http://theriac.org>

The free assessments provided by the Q&R *institute* to small and medium CNY organizations would help train student interns and obtain funds. Such free assessments could become, for these small organizations, what the GI Bill was, for the returning WWII service men and women: a revolution in broadening opportunities!

HS teachers and students would periodically attend functions, and the institute would provide *judges* for HS engineering fairs and competitions. In this way, the Q&R institute addresses the *past, present and future* stages of the education problem discussed above.

We have encountered some obstacles in our quest for funding the Q&R institute. First, those who liked the idea had no funds to support them. We then turned to NSF, but this agency prefers to fund basic research and novel engineering education programs.

Finally, we have also considered local industry and government. But these sources can be directly tapped by the university and are reserved for other, prioritized and more ambitious projects. Hence, they are out of our access possibilities. We are still pursuing our project, and hope to find other sponsors in the future.

6. Discussion

There are two key issues regarding how practicing engineers learn statistics, which need to be confronted and resolved. First, that many engineers need to apply statistics in their work, at a level far beyond college. Secondly, that for lack of space in the curriculum, they do not receive enough (or are not adequately taught) statistics in college.

This situation is not likely to change in the near future. Moreover, this situation goes beyond statistics (we saw it in corrosion studies). As a result, once engineers reach the workplace, they are forced to seek alternative ways of acquiring additional (statistical) knowledge, in order to effectively bridge this educational gap and adequately function in their careers.

The proposed *Professional Organizations-Academe-Industry* institutes have an important role to play. And its three main players (industry, academe and professional societies) will gain the most from it.

First, engineers (*past, present and future*) will learn what they need at their own pace, in their own time, throughout their professional lives. Universities will better educate students and faculty, and generate more individual and corporate support from their local communities. Professional societies would become, with Academe, natural local organizers, supporters and mentors of these *institutes*. They would provide direction, oversight, structure, books and learning materials, as well as specialized instructors that would teach better structured, short courses and workshops.

Big industry also has an important role to play, with an important pay-off. Every day more, big industries subcontract work to smaller *suppliers*, spending huge amounts of time, money and resources supervising and assessing their output. Better trained engineers in these supplier shops (that cannot afford in-house training) would contribute to lower assessment costs, improving product and process quality and reliability, sales and profits, and US competitiveness in world markets.

The US government would also gain by raising the educational levels of practicing engineers. This would help to keep American industry at home, as well as engineers and workers on the rolls, instead of on the

dole, increasing the tax base and government revenues. The GI Bill “created” the modern American middle class and handsomely recuperated, in taxes, the money invested. In a similar way, the proposed *institutes* would recuperate the funds invested in them.

Finally, this paper was presented at a special FTC session, sponsored by the Quality and Productivity Section of ASA and dedicated to engineering education. It was followed by a Panel discussion and an open participation. Session Chair and Panelists Drs. J. D. Williams (GE Global Research), G. Vining (Virginia Tech), W. R. Myers (Procter & Gamble) and C. M. Anderson-Cook (Los Alamos), represented all three sectors (academe, industry, government).

Anderson-Cook expressed how LANL integrates new and experienced engineers into working groups, thus fostering mentorship. Also, how matching appropriate method to problem, and fitting experimentation and data into theory, they foster stats thinking. Myers told of the large efforts his organization spends in training their engineers in statistical methods, so they are able to implement the advanced research methods they use/ This is a course of action that smaller organizations are not able to implement.

Finally, Vining, compared table of contents of several well-respected, engineering statistics textbooks, and found they were essentially the same. He also noticed how, every ten years, we have similar discussion about statistics education, and nothing really changes. We know well of this problem, having participated in these discussions since the start (Romeu, 1986, 1997). Then, a member of the audience signaled out that upper management should also be involved in this problem.

These three last issues are tightly knit. Educators alone are not able to change things at the university, unless other, more important, forces concur. This is why periodic crises have not brought substantial change. However, university does listen to industry executives, whose corporations hire their graduates and who handsomely donate to college endowments.

If Educators can find ways to mobilize industry executives, then things may finally start to move.

7. Conclusions

Better statistical education of practicing engineers will benefit engineers, universities, corporations, local, state and federal government, and the public at large. However, these stake-holders must be prepared to underwrite the work required to bridge the education level of practicing engineers, if it is to occur at all.

The problem discussed here has a *larger dimension* than just statistical training. Many other engineering areas and careers face a similar situation, and perhaps would benefit from a similar solution. In general, terms, *lifelong learning is the way of the future*. For, as modern technology advances, careers require more extensive and interconnected knowledge. And the university by itself cannot provide all the knowledge that modern professionals will need, during their lives, in the short span of four years of an undergraduate.

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