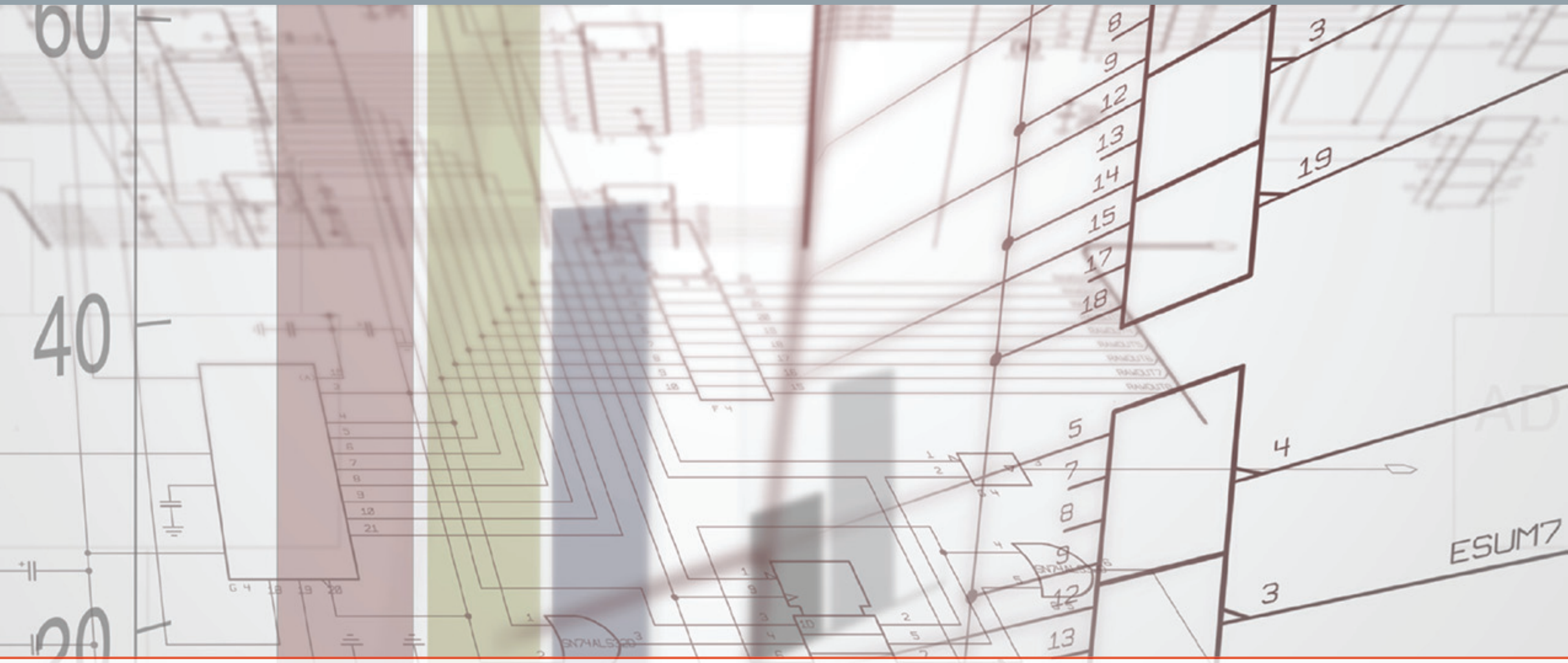

ON THE STATISTICS EDUCATION OF AMERICAN ENGINEERS

Jorge Luis Romeu, Ph.D., RIAC and Syracuse University

Two facts in engineering statistical education are: (1) engineers need to use statistics in their work, because of the natural variation in performance measures (e.g. device life, reliability), but they don't study enough of it and, (2) given the amount of undergraduate engineering curriculum topics, there is little room for adding more. As a consequence stats courses are usually too theoretical and overloaded, resulting in many engineering students leaving college lacking stats thinking, the most important thing they should learn, and strongly disliking the subject itself. However, when they start practicing, many students discover that they need stats badly, and that they now have to learn it on their own. The proof of these statements lie in the huge gap between college level stats, and the level required for applying it in the field, as reflected by the body of knowledge (BOK) in most professional certification programs (e.g. ASQ CRE/CQE).

This paper addresses this crucial issue. We investigate ways to provide already practicing engineers efficient methods to learn stats on their own, at their pace, after leaving college. Our proposed solution, under the existing constrains, is to move statistical material up and down the education stream. Teach intro stats in grade school. Then, teach basic inference, modeling and statistical thinking in college. Finally, make the study of advanced statistics a "lifelong" endeavor, through better use of individualized learning methods. This can be accomplished by the creation of Professional-Industry-Academe "institutes" that bridge the gap between the current limited levels that engineering students receive in college, and the levels required to efficiently work in the field.

Our proposed solution simultaneously addresses this problem's key three stages, which we call "past, present and future". We do so by providing specific proposals in statistics education for currently practicing engineers. Then, by providing better training to college students (who will become the future engineers). Finally, by enticing interest in science and engineering of current high school children and their teachers. This will ensure continuity for future generations.

1. Problem Statement

With this paper, we pursue three objectives. First, we want to describe a problem. Then we want to scope its importance and consequences. Finally, we want to 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) but they don't study enough of it 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. 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

This paper addresses this crucial issue. We investigate new methods so that practicing engineers can learn statistics 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.
7. Most of this material is unstructured, unsequenced, of heterogeneous quality, and difficult to access.
8. Our proposed solution, under the existing constrains, consists of three parts. First, teaching basics stats in grade school, leaving basic inference, modeling and statistical thinking to college. Then, to make statistics a "lifelong learning" endeavor via *Professional-Industry-Academeme institutes*. The solution attacks the mentioned problem in its three stages: *past, present and future*.
9. 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. We propose the following:
10. That Industry-Government-Academeme *institutes* integrate and support the educational efforts. A *proof of concept* example is provided by our Quality and Reliability (Q&R) Institute.
11. Undergraduate and graduate student interns will help provide these regional institute services.
12. Small/Medium size local industry/service organizations will receive *free* technical assessments.
13. Practicing engineers will receive instruction in statistical subjects
14. High School (HS) pre-engineering teachers, will receive tutoring, and support in their activities.
15. HS 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 as well as to professional education in general.

2. Literature Review

For many years now, statisticians have spent big efforts on issues related to statistical education. Starting by the education of school children, statisticians have assessed the issues for undergraduate and graduate students. But this author has found very little about the problem of after-college engineering education. Due to the brevity of this paper we can only overview a few educational efforts: first, among statistics organizations, then, among individual educators.

Centers for Statistical Education, designed to study how school students learn statistics have been organized at ASA (http://www.amstat.org/education/index.cfm?fuseaction=main) and the RSS (http://www.rsscse.org.uk/). IASE (http://www.stat.auckland.ac.nz/~iase/) the education section of ISI, has studied how statistics is taught and learned at every level, from early childhood to the graduate school, publishing their research findings in their electronic journal SERJ. The CAUSEWEB Consortium (http://www.causeweb.org/) was instrumental in organizing USCOTS, the American version of ICOTS, and includes much material on undergraduate education. Other good education projects are Merlot (http://taste.merlot.org/), on multimedia teaching and learning, ARTIST on course assessment (https://app.gen.umn.edu/artist/) and Technomath, about IT and math training in the industrial workplace (http://www.ioe.ac.uk/tlrp/technomaths/). For additional information about web sited on statistical topics, see the Appendix at the end of this paper.

At the general statistics education level, we refer to the work of Batanero, Bickel, Bailar, Blumberg, Chance, Garfield, Joliffe, Locke, McGillivary, Moore, Ottaviani, Pearle, Rumsey, E. Sanchez and Wilde, among many excellent researchers. Specific references can be found through the above-mentioned web pages of journals, organizations and institutions, or through Google.

Specific improvements in the way statistics is taught in engineering schools have been proposed by Hogg et al. (1985), Hoadley and Kettenring (1990), Kettering (1995), Bisgaard (1991) and Snee (1993) among others. Spedding (1998 among other papers) has proposed media improvements, and Romeu (as far back as 1986, and as recently as 2007) has advocated the use of practical applications, student projects, group learning, and technology and statistical software. Examples of the use such practical approaches in graduate engineering statistics classes can be found in page: http://lcs.syr.edu/faculty/romeu/ecschedul.html

Notwithstanding the excellence in the mentioned work, these papers and researchers do not address the problem of after college statistical education (e.g., Technomath pursues workforce training, including stats, but at the basic level). We find, after 30 years teaching in engineering departments, and consulting in quality and reliability, that many engineers have difficulty understanding concepts like confidence intervals, hypothesis tests or modeling. For example, some engineers assess regression via its Index of Fit (R^2), instead of using the t or F statistics or the p-values, and then fail to check all model assumptions before using them.

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In the rest of this paper we show some ways practicing engineers use to cope with their lack of statistics background, learning the subject on their own, on the job, we discuss some problems involved in some of these learning endeavors, and we propose some solutions.

3. 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 its 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.

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, 2006)

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 recognizing 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/Reliability-Statistics.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.

4. 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) and not courses based on rote (Romeu, 2008).

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-ProfessionalSocieties 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 in asynchronous 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 these *institutes*. 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, whereby older and retired engineers would share their rich working experiences with the younger ones.

5. 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.

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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*. Moreover, we would state that this is a general problem in *professional education*.

The described Institutes, addressing different professional areas, could conduct joint activities, exchanging ideas, students, faculty etc., for mutual benefit.

6. An Example: the Quality and Reliability Institute

Our proposal (http://lcs.syr.edu/faculty/romeu/SUQRPrpExcSm.pdf) for a *Quality and Reliability (Q&R) Institute* was submitted in 2005 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 the National Science Foundation, but this agency prefers to fund *basic research and innovative* engineering education programs.

Finally, we have also considered applying for support to 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 beyond our support possibilities. We are still pursuing our project, and hope to find other sponsors in the future.

7. 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 what they learn in college. Secondly, that for lack of space in the curriculum, engineers do not receive enough (or are not adequately taught in) statistics in college.

Such situation is not likely to change in the near future. Moreover, such situation goes far beyond statistics (we discussed how it has risen 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 pillars (industry, academe and professional societies) will gain the most.

First, engineers (*past, present and future*) will learn what they lack, about statistics, 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, the 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*. As a result, industry spends huge amounts of time, money and resources supervising and assessing their output. Better trained engineers in supplier shops (that cannot afford in-house training) would substantially contribute to lower assessment costs, also improving product and process quality and reliability, sales and profits, as well as raising 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. And it would also increase the tax base and government revenues. The GI Bill "created" the modern American middle class. And it handsomely recuperated in middle class taxes, the money it invested. In a similar way, the proposed *institutes* would recuperate, from the taxes of richer, stronger industries and of their employees, the funds invested in them.

Finally, an earlier version of this paper was presented at a special session of the 2007 Fall Technical Conference (FTC), sponsored by the ASA and ASQ (Romeu, 2007). The session was dedicated to engineering education, and was followed by a Panel discussion and public participation. The Session Chair and Panelists were: Drs. J. D. Williams (GE Global Research), G. Vining (Virginia Tech), W. R. Myers (Procter & Gamble) and C. M. Anderson-Cook (Los Alamos Nat. Lab). They are all well known statisticians and educators, and represent all three pillars (academe, industry, government) of our proposed *institutes*.

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. Such example shows a course of action that smaller organizations are unlikely to implement, and demonstrates how economically advantageous the proposed institutes would result, both to industry and government.

Vining, compared the table of contents of several well-respected engineering statistics textbooks, and found they all covered essentially the same material. He also noticed how, every ten years or so, statisticians have similar discussions about statistics education. And nothing really changes. We know well of this problem, having participated in such discussions since the start (Romeu, 1986, 1997, 2007). Issues are raised, but little follow-up is implemented.

Finally, a member of the audience signaled out that upper management should also be involved in this problem. He suggested that, lacking involvement in statistical education, management is not very interested in the problem. And they exert little pressure on the other participants.

But 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 our periodic crises have not brought substantial change. However, university does listen to industry executives, whose corporations hire their graduates, and who handsomely donate to their college endowments.

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

8. Conclusions

Better statistical education of American practicing engineers will surely benefit the engineering community, universities, corporations, local, state and federal government, and the public at large. However, all 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 even other 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.

Acknowledgements

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APPENDIX: URLs of Selected Statistical Education Resources:

American Statistical Association. http://www.amstat.org; its Statistical Journals on Line http://www.amstat.org/publications/index.cfm and its Sections on Engineering and Quality and Productivity (http://www.amstat.org/sections/sectionlist.cfm).

American Society for Quality, http://www.asq.org. Free material is available through its Statistics, http://www.asq.org/statistics/1 and Reliability (http://www.asq.org/reliability/ Divisions.

Chance Magazine. http://www.amstat.org/publications/chance/

Fulbright Speakers Specialist Program: http://www.iie.org/cies/Specialists

International Statistical Institute. Main page: http://www.cbs.nl/isi/ Also check its Business and Industry Section and the Intl. Assoc. for Statistical Education pages.

Instituto Inter Americano de Estadisticas. http://www.contraloria.gob.pa/inec/IASI/publi_journal.html

JSE Journal of Statistical Education: http://www.amstat.org/PUBLICATIONS/JSE

Journal of Case Studies in Business, Industry and Government Statistics: http://www.bentley.edu/csbigs

Journal of Teaching Statistics: http://www.rsscse.org.uk/ts

Juarez Lincoln Marti Int'l. Education Project. http://web.cortland.edu/matresearch

Math World: http://mathworld.colfram.com/topics/ProbabilityandStatistics.html

Minitab tutorials. http://www.minitab.com/en-US/training/tutorials/

National Institute of Standards and Technology. http://www.itl.nist.gov/div898/handbook/

SERJ: Statistical Education Research Journal of the International Association for Statistical Education. http://www.stat.auckland.ac.nz/~iase/publications.php

Royal Statistical Society. Journals for members. http://www.rss.org.uk

RSS resources for Statistical Education: http://www.rsscse.org.uk/resources/he-resources

WISE: web interface for Statistics Education: http://wise.cgu.edu