Statistical Education for Engineers: An Initial Task Force Report
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Statistical Education for Engineers: An Initial Task Force Report

ROBERT V. HOGG et al.*

A three-day working conference to develop recommendations for the statistical education of engineers took place at the University of Iowa in July 1984. Although other areas, such as business, chemistry, and biology, are also important to improving the products of industry, we restricted our consideration to engineering. This report of the findings addresses the following questions: Who are the customers? What are their statistical needs? What types of courses, given by the industry for practicing engineers (called *in-house courses* in this report), are desirable? How do we approach statistical education for engineering management? What types of resources are desirable for instructional purposes? What is the best first course in statistics for engineering students? How can we convince the engineering profession that statistical ideas and methods can help improve quality and productivity in American industry and thus its competitive position in the international market?

1. INTRODUCTION

There has been much publicity in recent years concerning American industry's inability to compete successfully in the international marketplace. Many of these concerns focus on improving quality and productivity and thus the competitive position of American industry. To address these concerns effectively requires contributions from many disciplines. Applied Statistics is one such discipline. It provides engineers with such useful tools as statistical quality control, design of experiments, graphical data analysis, and powerful but easy-to-use statistical computer packages. Yet many of these tools are not being used in appropriate places. How can this be in an age when tough worldwide competition leaves us little choice but to take advantage of all technical tools available? The answer is, in part, that American engineers have not been taught about these tools—and this situation needs to be changed.

With this conviction, 42 statisticians and engineers participated in a three-day conference on statistical education for engineers at the University of Iowa, Iowa City, July 23–25, 1984.

Our goals in this conference were to

1. Identify the customers and their specific statistical needs;
2. Outline industrial training programs for practicing engineers and a reasonable first course for undergraduate engineering students to satisfy these needs, based on the clear identification of the need for applied statistics;
3. Identify resource materials and define pedagogical approaches, as possible, to make these programs effective.

Of course, given that the audience for these programs consists of engineers and applied scientists, statistical applications should complement and reinforce engineering concepts and methods, particularly in laboratory practice, development and assessment of engineering models, collection and interpretation of data, product and process design, and production and process control.

To utilize the training that occurs effectively, engineering management must understand and support the use of statistical tools. Without this understanding, there is a real possibility that the statistical techniques will not be used. Although the conference was not able to focus extensive efforts on how to build such management awareness, there was a clear consensus that statistical education for engineers must also include some education for their managers.

One surprising aspect of the work of the conference was the degree to which all participants agreed—despite diverse experience and occupations—on the basic statistical concepts that all engineers need to appreciate. These include

1. The omnipresence of variability
2. The use of simple graphical tools, such as histograms, scatterplots, probability plots, residual plots, and control charts
3. The basic concepts of statistical inference
4. The importance and essentials of carefully planned experimental designs
5. The philosophies of Shewhart, Deming, and other practitioners concerning the manufacturing of quality products

For many statisticians and engineering educators, this report reinforces the realization that an interdisciplinary, cooperative approach is necessary to respond to the challenges that industry faces. It is imperative that a dialogue between the engineering and statistical professions take place if major gains are to be made in quality and productivity.

Some of us at universities believe that there is little chance of persuading academic engineers to include more statistics in their curricula unless industry unmistakably demands it. It is therefore essential that influential industrial leaders promote the importance of statistical ideas and methods. Certainly successful applications provide our most convincing argument. This report provides some suggestions on what should be included in these programs. It is an important *first* step, and every opportunity should be taken

*Robert V. Hogg is Professor, Department of Statistics and Actuarial Science, University of Iowa, Iowa City, Iowa 52242. The author wants it made very clear, however, that the other 41 participants are also coauthors of this report; they and their affiliations are listed in the Appendix. In particular, the team leaders H. T. David, William Golomski, Bert Gunter, and William Parr were extremely helpful, as was Richard Gunst, who helped prepare a preliminary draft of this report. In addition, two other statisticians, who did not attend, should be mentioned: Ron Snee, for his suggestions in the planning stages of the conference, and Gerry Hahn, for his recommendations throughout the entire process, particularly in the preparation of the manuscript.

to spread the word among practicing professional engineers and engineering educators. We invite readers to share their comments and experiences with us by contacting Hogg. It is clear that the same type of conference concerning business statistics would also be worthwhile for the improvement of quality and productivity. In any case, progress in statistical education should be an ongoing effort.

2. STATISTICAL AREAS IMPORTANT TO INDUSTRY

The first question that the conference addressed was, Who are the customers and what are their statistical needs? The answers resulted in two lists that then formed the rows and the columns of a matrix, the general element of which reflects the amount of knowledge needed by that type of engineer in that particular statistical area. Of course, the specifics of these classifications vary from company to company; but the participants agreed that these—as generic distinctions—are broadly applicable even though some specific classifications have been omitted.

2.1 Customers

Customers were categorized along the following lines:

1. *Engineering management* is responsible for the work performed by the statistically trained engineers.
2. *Quality engineers* are responsible for product, material, and process quality and for ongoing monitoring of reliability of the manufactured product.
3. *Manufacturing/process engineers* (Mfg/Proc) are responsible for the manufacturing *process* design, improvement in process productivity and performance, process control, troubleshooting, and so on.
4. *Design engineers* are responsible for product designs and setting tolerances of *new* products.
5. *Product engineers* are responsible for design changes in response to costs, quality, and manufacturing needs associated with *existing* product lines.
6. *Reliability engineers* are responsible for the reliability engineering of *new* products and processes.
7. *Research and Development engineers* (R&D) are involved in research for *new* concepts that will lead to new products and processes.
8. *Test engineers* are responsible for development of test methods and test equipment for both new and existing products.

2.2 Statistical Areas

In listing the statistical needs, we recognized that there are some overlapping areas. In order to clarify these issues, we will make some fairly detailed remarks about some of these topics.

1. *Problem Solving* (P. Sol.) involves an orderly step-by-step "engineering" approach to improving process understanding. Structured, cooperative efforts unlock many resources and allow persons with diverse viewpoints to work constructively together using the scientific method. Possible tools that can be used are Fishbone or Ishikawa cause–effect diagrams that organize information, structure understanding, and aid in communication; Process flow diagrams; and Pareto diagrams that quantify the priorities and list the "vital few" keys of effective efforts.
2. *Fundamentals* (Fund.) of data variability and basic statistical methods for process understanding, control, and improvement are absolutely necessary. The engineer must understand what is observed: the actual value plus some random variable (noise). To improve productivity and quality, reduction in the variability of the process is required. Accordingly, there is a great need to have the process generate data that can be used to monitor, control, and improve the process.
3. *Design of Experiments* (DOX) indicates how to probe a process to get the most information at minimal cost. We should stress the interactive nature of experimentation and how this approach fits into the strategy of ongoing improvement and process learning. That is, it should be emphasized that statistical methods are consistent with and essential in the application of the scientific method. Topics to be included in DOX include measurement error, independence, replication versus duplication, randomization, blocking, main effects, full and fractional factorials (as compared to the poorer one-at-a-time approach), interaction, confounding, response surface design, product robustness, nested designs and variance components, evolutionary operation/plant experimentation, mixture designs, and accelerated testing.
4. *Statistical Inference* (S. Inf.) concerns the error structure of an estimate. That is, engineers should know the basic concepts associated with sampling distributions that explain why interval estimation and tests of hypotheses are successful.
5. *Graphical Techniques* (Graph) are extremely important, not only for the engineer's use, but in presenting materials to others.

a. Single-sample methods consist of stem-and-leaf arrays, box plots, histograms, dot plots, and model fitting. How well some of these probability models fit can be checked by using normal probability paper (more generally, q–q plotting). All of these measures of sample distributions can be used to check process capabilities against specifications. Other effective tools to describe the process signature are classical control charts ($\bar{x}$, R, p, c), as well as moving averages, CUSUMS, and statistics from newer multivariate techniques. In regard to the latter, more research could probably be done to develop new robust and multivariate methods for helping find assignable causes and unnatural patterns.

b. Relationships among multiple samples can be found by using some of the methods listed in single-sample methods, particularly histogram types of comparisons and q–q plotting.

c. Multivariate methods, such as scatterplots and multiple box plots, are extremely helpful and easy to do if appropriate computer software is available.

The last four areas are a little more specialized. Although not as important for all engineers, they are extremely important in certain industries.

6. *Modeling* (Model) includes linear and nonlinear regression.

7. *Life Testing and Reliability* (Life) includes accelerated life testing.

8. *Survey Sampling* (Surv.) involves efficient collection of data that can be used to describe the characteristics of a population.

9. *Acceptance Sampling* (Acc.) includes narrow limit gauging.

The matrix that gives our evaluation of the knowledge needed in each of these areas by different types of engineers in industry is given in Table 1. This matrix, with its column totals, provides a reasonable ordering, in our opinion, of the importance of these statistical areas for engineers working in industry. There is a distinct break in the score totals between the first five statistical areas and the last four. Again we emphasize, however, that even those last four could be extremely important to some engineers and certain industries.

3. POSSIBLE IN-HOUSE COURSES

There is no single course or set of courses that will be suitable for all engineers and all industries. Hence it was impossible for us to construct a generic program. But there were some points that the participants could easily agree upon:

1. The instruction should be driven by data and case studies, not topics. There is a great motivation for engineers in taking real data, particularly from their industry, and weaving in the statistical ideas. Computers, with appropriate software, should be available.
2. The statistical concepts should be motivated by real problems rather than taught in a logical mathematical order.
3. Because the amount of useful information is large, it is clear that the in-house statistical education for engineers should be *ongoing* and *modular*. These modules will be determined by the needs of the various industries.

With these points in mind and knowing that we cannot construct one set of courses for all engineers, we outlined three short courses, possibly of greatest interest.

3.1 Introduction To Applied Statistics

The first course, designed to be a prerequisite for the others, has as its goal the introduction of the concepts of variation and quantitative assessment of quality to the engineer. The topics to be covered are

1. Motivation. Why should we care? Provide motivating examples that are constructed in the work context of those being educated, indicating the large number of problems amenable to attack by statistical methods. This part is crucial.
2. The measurement process, including questions about how to decide what to measure, levels of measurement, and so on. Proper planning to obtain valid data is extremely important.
3. Cause–effect diagrams, including one such diagram produced by each person in the class
4. Pareto diagrams indicating the ordering of priorities
5. Histograms, stem-and-leaf arrays, and box-and-whisker plots
6. Variation and its implications for making inferences with finite information. The difference between a parameter and its estimate is stressed.
7. Basic $\bar{x}$, R, and p charts and their interpretation
8. Introduction to concepts of statistical inference and blocking through independent and dependent t tests, including further discussion of independence

To deemphasize calculations, we strongly urge the use of a computer in the course, particularly to get convenient graphical displays.

We suggest roughly six half-day sessions for this course, which includes roughly one-third of the time being spent on student activity. These sessions are to be spaced about one week apart, and involvement in the sessions by the immediate supervisor is highly desirable. The required outside work would be the creation of a cause–effect diagram. Another short project, if possible, would be desirable. Homework of a traditional sort could be provided for those who want it and then used for examples in succeeding sessions as review.

3.2 Statistical Process Control

The course on some elementary topics in statistical process control (SPC) has the following outline:

1. Basic control charts: $\bar{x}$ and R, $\bar{x}$ and s, p, u, c, and so on. There is a tendency to concentrate only on the mechanics; these should be minimized because few will actually find the mechanics difficult. Emphasize interpretation, set-up issues (especially subgroup determination), and consideration of assignable versus random causes.
2. Process capability assessment
3. Statistical tolerancing
4. Operating characteristic curves for control charts
5. CUSUM charts
6. A brief introduction to the concepts of acceptance sampling
7. Analysis of means is suggested to bridge the gap from SPC to classical inference.

Roughly eight half-day sessions are needed. There is a requirement of a job-related project that is to be completed by each student. Other optional homework can be assigned and used as review from one session to the next.

Table 1. Desirable Statistical Knowledge

	Statistical Area								
Engineer	*P. Sol.*	*Fund*	*DOX*	*S. Inf.*	*Graph*	*Model*	*Life*	*Surv.*	*Assoc.*
Management	3	2	1	1	3	0	0	1	1
Quality	3	3	3	3	3	2	2	3	3
Mfg/Proc	3	3	3	3	2	2	1	0	1
Design	3	3	3	3	2	1	3	1	1
Product	3	3	3	3	3	1	2	2	1
Reliability	3	3	3	3	2	3	3	2	2
R&D	3	3	3	3	3	3	1	1	0
Test	3	3	3	3	2	0	0	0	1
Total	24	23	22	22	20	12	12	10	10

NOTE: 0 = no knowledge necessary; 1 = understanding concepts, not mechanics; 2 = concepts and some mechanics; 3 = concepts and technical competence.

3.3 Planning Effective Experiments

This course should include issues of hypotheses testing and confidence intervals as related to the analysis of designed experiments. Some basic designs, along with concepts such as interactions, are considered. Consumers of the course will not necessarily be able to plan effective experiments *beforehand* and then carry out the analysis of their own without statistical assistance. Suggested topics are the following:

1. A quick survey of the basic ideas of confidence intervals and tests of hypotheses
2. Variability of experimental results and sampling distributions
3. One-way analysis of variance and multiple comparisons, including graphical displays
4. Fixed and random effects, including components of variance models (nested designs)
5. Two-way designs, including randomized complete block designs and the concept of interaction
6. Full and fractional designs, emphasizing that all variables are not created equal
7. Response surfaces

At least eight half-day sessions are needed. In a longer course or in a subsequent course, we could consider incomplete block designs, regression models, Taguchi-type designs, and so on. Others will find extensions to the Statistical Process Control course to be of great interest. Courses or programs in special topics such as evolutionary operation, multiple regression, reliability, and acceptance sampling should be provided if appropriate to the demands of the particular industry.

4. GUIDELINES FOR MANAGEMENT EDUCATION

We thought it appropriate to say something special about engineering management because we want to stress the impact of statistics on everything from corporate strategy to evaluation of experimental data. We recognize at least three levels of management that have different levels of control, spheres of influence, and decision-time horizons. They require different treatments. Top-level management, like the division president and the general managers, need to understand the impact of the use of statistics. At the next level of management, the managers need selected exposure to what both top management and first-line supervision have received. First-line supervision has the actual functional responsibility for the work performed by the statistically trained engineers reporting to them. In all cases, we recommend dealing with *concepts* and *issues* first.

We display in Table 2 the relationship among management level, concepts, viewpoint, and level of awareness. Awareness expresses the depth of understanding of a concept from a particular viewpoint. To help read this table, we define in the broadest of terms each of the statistical concepts that we feel management must grasp.

Table 2. Levels of Awareness

	Management Level			
Concepts	*Top*	*Upper/ Middle*	*First-Line Supervision*	*Engineers (Consultants)*
Decision strategy	3	3	3	3
Planning and implementation	3	3	3	3
Natural variation of data	1	2	2	3
Design strategy	1	2	2	2
Modeling	1	1	2	3
Response surfaces	1	2	2	3
Graphics	2	2	3	3
Viewpoint	Why to	Why to	What, When, Where	How to
Total exposure time (hrs.)	2	8	48	120+
Typical contact time (hrs.)	½–1	4–8	1–8	1–2

NOTE: 3 = Highest/Critical; 2 = Medium/Some Depth; 1 = Lowest/Surface.

1. *Decision Strategy*. Trade-offs between costs of data and risks
2. *Planning and Implementation*. The definition of the objective or targets to be met, nature of the measurements, the selection of appropriate diagnostic methods, the action plan, and follow-up
3. *Natural Variation of Data*. Real life data are shrouded by a "sea of fog." Numerous uncontrolled and unknown factors influence the observation process.
4. *Design Strategy*. The use of randomization, blocking, and other techniques to isolate sources of variation
5. *Modeling*. Approximating the real world by using simple mathematical descriptions
6. *Response Surfaces*. Contour map representation of a model
7. *Graphics*. Visual display of information

We feel that both management and engineers should be exposed simultaneously to this training. There may be some benefit in having management start before the engineers to given this entire process a top–down flavor. By and large, training should be done in one- or two-hour doses. We also see a crucial need for industrial case studies, across companies, industries, and so forth, to support each concept. A book such as *Statistics: A Guide to the Unknown* (Tanur et al. 1972) would be most appropriate.

5. RESOURCES FOR IN-HOUSE PROGRAMS

The widespread implementation of quality in-house training programs in statistics for professional engineers requires the availability of a variety of resources. As used in this report, the term "resources" encompasses the means whereby statistical training is provided to practicing engineers through any of several modes of instruction. The most critical need is for a well-trained statistician, ideally one who is experienced in the specific engineering focus of the company and able to communicate effectively in a classroom setting. No attempt is made to discuss instructors or their qualifications; rather, the primary focus is on written and visual materials that can be used to enhance instruction.

5.1 Formal Instructional Media

Based on the principle that there is no single mode of instruction that will suffice in all industrial environments, three major modes of instruction have been identified for special consideration: traditional (but possibly modified) classroom instruction, videotape instruction, and special-purpose reference materials. In order to be effective in an industrial setting, each of these modes of instruction must be specially tailored to its intended audience. In general we recommend that all formal instructional media contain a clear statement that designates (a) the course objectives, (b) the intended audience, (c) the specific subject matter to be covered, including the engineering specialization at which the material is directed, and (d) the competence level that will be achieved at the end of the instruction. In addition to these general recommendations that apply to all three modes of instruction, specific recommendations are proposed for each mode.

1. *Textbooks and Course Syllabi*. Textbooks and course syllabi for training programs should emphasize practical approaches to the solution of engineering problems. For example, topics on experimental design and the natural variation of experimental results should be introduced early in the instruction. Formal discussion of probability distributions, usually presented in early lectures of mathematically oriented statistics courses for engineers, should be introduced only as needed, with theoretical derivations kept to a minimum. Actual engineering applications should be stressed throughout the course. Case studies should be an integral component of this type of formal instruction and should tie together, where possible, different topics covered in the course.

2. *Videotape Modules*. Videotape modules can be effective substitutes for formal classroom instruction when qualified instructions are not available. Videotape modules are not to be regarded as preferable to instruction by an experienced professional statistician, but when properly used they can provide basic instruction on many statistical topics.

We recommend that several guidelines be followed in the creation and use of videotape modules. First, each component of instruction should not exceed 30 minutes. Second, printed materials should accompany the videotape. These printed materials should include copies of all displays used in the videotape, a synopsis of the topics discussed in the module, and study guide containing problems that reinforce the key ideas of the module. Finally, and most important, videotapes should be viewed in groups, preferably with a resource person who can clarify discussion points and answer questions about the presentation. A good example of video material is that produced by Westinghouse.

3. *Short, Directed Reference Materials*. Documents that have limited, focused objectives should be available as reference materials. These reference materials should motivate by discussing realistic engineering problems and provide guidance of a practical nature, rather than that of the traditional mathematical statistics texts.

Descriptive references similar to *Statistics: A Guide to the Unknown* (Tanur et al. 1972) might be proposed for managers. Of importance in this type of reference is a variety of articles that distinguish statistical principles of experimentation and process control from the deterministic training given engineers in colleges and universities. Product development and process engineers should have references that include a detailed statement of the problem under investigation, discussion of the experimental design, data listings and displays, and careful discussion of the conclusions down from the data analysis.

5.2 Hands-On Materials

The use of hands-on materials is intended to allow engineers to gain experience with statistical techniques in those instances when a working knowledge of these techniques is needed. Three possible methods of achieving that experience are listed here.

1. *In-House Experimentation*. Instructor involvement in actual in-house experiments is often the most desirable means of ensuring relevance and achieving a satisfying experience with statistical methods. The reporting of past successful uses of statistical methodology is an important motivational factor in the acceptance of statistical procedures by practicing engineers.

2. *Case Studies*. Case studies should be realistic but should not always contain all of the problems of actual experimentation. The realism is needed for relevance, but the inclusion of all of the problems that one might be required to face can obscure the intent of the instruction. A case study should focus on only a few concepts and attempt to stress only a small number of statistical issues.

3. *Computer-Aided Instruction*. The increasing prominence of microcomputers in industrial research opens a new avenue for instructional materials. Data for case studies can be supplied on diskettes, perhaps along with appropriate software and graphical displays. This is especially important when case studies contain so much data that an engineer would be reluctant to spend the time needed to enter the data into the computer. Workbook exercises can sometimes be more expeditiously solved via microcomputers than by using calculators, thereby allowing more time to concentrate on the statistical concepts contained in the instruction. Likewise, individual practice exercise can be computer-generated along with numerical solutions.

5.3 Statistical Software

Statistical software should be an integral component in the statistical training of professional engineers. Three recommendations are made concerning the use of statistical software in training programs for engineers:

1. Instructors should have suitable software available or have their own prepared.

2. Evaluations of statistical software should be published periodically so that instructors and engineering users can be guided to efficient, numerically accurate programs.

3. A suitable mechanism should be found whereby an American Statistical Association (ASA) section or standing committee would be charged with setting criteria for statistical software. Among the criteria for acceptable software must be a higher level of documentation than is available

today. Minimum criteria should require appendixes that describe the computing formulas and algorithms used to make the computations and a detailed explanation of all terms that appear as part of the output.

These recommendations are intended to stress the fact that practicing engineers, like practicing statisticians, are dependent on statistical software for much of the design and analysis of engineering experiments. The responsibility for identifying quality statistical software should not be shirked by the statistical profession.

5.4 Interchange of Information

Information on instructional materials is an important resource that warrants greater attention by the statistical profession. Two approaches are recommended.

1. *Between Statistical and Engineering Societies*. We encourage a greater exchange of information between ASA and the many engineering societies on meetings and symposia of mutual interest. The obvious mechanism within ASA is an announcement in *AMSTAT News*. Press releases to engineering newsletters on important special-purpose conferences would also heighten the awareness of professional engineers of developments in statistics that might be of importance to various groups within their profession. An emphasis within ASA should be initiated to approach engineering colleagues who are members of engineering accreditation boards about making statistical training a recommended, if not required, component in the university training of all engineers. To help with this interchange, statisticians should attend meetings of engineering societies and present papers to make their presence more widely known.
2. *Within ASA*. A clearinghouse should be established for instructional materials. Some effort of a similar nature for graphical aids and general-purpose teaching materials is already in place in the review sections of *The American Statistician*, but there is no concerted focus on engineering education. The ASA national office should investigate funding or the securing of funding for ASA sponsorship of continuing education programs in statistics for practicing engineers. Two benefits would accrue to the Association from such an effort. First, as an ASA continuing education program, the quality and competency of the instruction could be monitored by the statistical profession. Second, income from the program could be used to fund the development of other instructional materials, such as case studies and videotapes.

6. ACADEMIC PROGRAM

With the background and the knowledge of industry's needs, it is our conviction that there is a body of ideas concerning experimentation and measurement that are essential components of a modern engineering curriculum. Some of these concepts arise incidentally in the present engineering curricula. But many are not represented at all or are not headlined in their own right. Many of these clearly belong to the field of statistics.

These statistical concepts, plus details of their implementation, are best presented in, say, a one-semester Engineering Statistics course. Again, where such a semester course cannot, despite its value, fit into an existing curriculum, our synopsis may well serve to suggest or reinforce selected work units in existing courses or laboratory sections. That is, laboratory exercises can be used to introduce statistical practices to the engineering students.

Because students do not have the same motivation that the practicing engineers have, we suggest that whatever the format or amount of statistical material presented, students ought to be given the opportunity to experience, early and firsthand, the need for and value of statistical ideas. Two tested ways of securing such involvement are "black box" experiments and calibration exercises.

1. In the first, the instructor programs a hypothetical process, say a concave response to four factors plus a noise component. The student is then asked to find the optimum operating condition in a fixed number of runs. Students will value the preferred statistical experimental plan in direct proportion to how badly they will have floundered on their own.
2. The calibration exercises illustrate the creation of empirical relationships in the face of measurement error, and the ways in which such measurement error is taken into account.

A third proven way of involving the student, especially in the current climate of urgency surrounding statistics-related countermeasures to America's eroding trade position, is to bring current periodicals, both popular and technical, into the classroom, as well as other press and media materials. In any case, the student must be provided with proper motivation early in the course.

We list some *ideal* objectives and methods associated with such a course. Clearly we are considering classes of relatively small size, say approximately 25–30 students, with the necessary computer backup available. From experience, we know that the ideal does not always exist, but at least we can strive for these optimal conditions.

6.1 Objectives

Objectives of the course would include giving students the ability to

1. Plan data collection, turn data into information, and achieve action
2. Apply the methods taught in real-life situations
3. Communicate statistical information in oral and written form
4. Use computer and graphical techniques
5. Plan, analyze, and interpret the results of experiments
6. Understand the scientific method

6.2 Methods of Instruction

The methods of instruction should

1. Emphasize case studies and workshop and laboratory experience.
2. Make use of suitable, advanced computer hardware and software.

3. Require completion of an individual project, possibly a design of an experiment along with a suitable report.

We now describe a possible course, having three semester-hours of credit, with about 40 periods for lecture and discussion plus four or five periods for examinations and review. Although some theory is given to explain why certain statistical methods are successful, this is not a theoretical course, and most teaching is done *by examples*. Here we hope to be bold and fashion something radically different from existing courses, recognizing that the computer will play a major role in statistical education in the future.

6.3 A Possible Course for Engineering Students

A. Data collection, communication, and presentation (8 periods)
  1. Problem identification and flow diagrams
  2. Data collection and variability
     a. Variables versus attributes
     b. Sources of variation (time, product variability vs. measurement, assignable cause vs. random error)
  3. Measurement and error
  4. Descriptive statistics (mean, standard deviation, percentiles, etc.), noting difference between the true parameter and its estimate
  5. Useful techniques
     a. Pareto diagrams
     b. Ishikawa diagrams
     c. Graphics and appropriate software
     d. Histograms, stem-and-leaf arrays, scatterplots, residual plots
     e. Run charts, rational subgroups, control charts

B. Basic probability (7 periods)
  1. Models: Deterministic and probabilistic
  2. Laws of probability and their applications
  3. Reliability of products and systems
  4. Joint, marginal, and conditional probabilities
  5. Distributions: Normal, binomial, Poisson, others

C. Basic statistical inference (7 periods)
  1. Sample versus population
  2. Sampling distributions
  3. Central limit theorem
  4. Reference distributions
  5. Point and interval estimation
  6. Basic comparisons: One mean, two means, one proportion, one variance (optional), q–q plots and normal probability plots, signal to noise ratios (optional)

D. Regression models (4 periods)
  1. Simple linear regression
  2. Multiple regression
  3. Residual plots
  4. Correlation

E. Carefully designed experiments (10 periods)
  1. Objectives (screening, exploration, optimization)
  2. Comparisons
     a. Qualitative
     b. Classical (one variable at a time)
     c. Factorial experiments (interactions and graphical methods)
     d. Fractional factorials
  3. Concepts of replications, randomization, blocking reinforced
  4. Components of variance (nested designs with data obtained during and after production)
  5. Pitfalls of experimentation (lurking variables, collinearity, inadequate experimental ranges)

F. Reliability (4 periods)
  1. Failure rates
  2. Failure distributions
  3. Reliability calculations (series, parallel, k out of n)
  4. Graphical methods: Weibull plots, probability plots, failure rates
  5. Reliability predictions
  6. Field failure analysis

This is a very ambitious course, but some of us have tried courses similar to this one with some success. The use of the computer throughout the course permits more time for the interpretation of the resulting statistics. We hope that the student will appreciate the importance of good descriptions, modeling, basic statistical inference, and good experimental designs upon the completion of the course. In addition, we would also expect a book of case studies of some of these methods to be extremely useful to the instructors and students.

7. CONCLUSIONS

Today's statisticians know that our profession can contribute to the improved quality and productivity of American industry. Many engineers have not been taught, or have been taught poorly, the value of statistical ideas and applications. The purpose of this conference was to help correct this situation by considering better in-house statistical programs for practicing engineers and an exciting and more relevant first course for engineering students. We hope that statisticians involved in these programs will start making these suggested changes now.

Moreover, to help speed this process along, we need to have top-level management support our recommendation strongly. Only if employers insist upon these statistical programs will there be some chance of persuading academic engineers to include more statistics in their curricula. We need their support to get our programs moving—but more important, they need our statistical knowledge to gain a more competitive position for American industry.

APPENDIX

Robert V. Hogg served as the director of the conference, and the other participants were organized into four teams.

Team One. H. T. David, Captain (Iowa State), David W. Bacon (Queens), Daniel Peña (Madrid, Spain), Ron Askin (Iowa), Duane Dietrick (Arizona), Mel Peterson (Proctor & Gamble), William C. Guenther (Wyoming), David S. Moore (Purdue), James M. Landwehr (AT&T Bell Labs), Charles G. Pfeifer (DuPont).

Team Two. William A. Golomski, Captain (Golomski Assoc.), Fred Leone (ASA), Stephen Vardeman (Iowa State), John S. Ramberg (Arizona), John D. Hromi (Rochester Inst. Tech.), Ed Mykytka (Auburn), James M. McBride (IBM), Neil M. Werner (Corning Glass), A. Blanton Godfrey (AT&T Bell Labs), Lloyd Knowler (Iowa).

Team Three. Bert Gunter, Captain (RCA), Lynne B. Hare (T. J. Lipton), Marilyn M. Hixson (Harris Semiconductor), G. Rex Bryce (Brigham Young), Peter J. Jacobs (3M), Tom Boardman (Colorado State), E. B. Fowlkes (Bell Comm. Research), Robert L. Perry (McDonnell Douglas Elec.), W. J. Hill (Allied), Betty Stewart (U.S. Steel), Janet Fiero (Motorola).

Team Four. William C. Parr, Captain (Florida), Norm Heitkamp (Shell Dev.), Neil R. Ullman (College of Morris), Eileen Boardman (Colorado State), Bob E. Robertson (Intel), Charles Hendrix (Union Carbide), Richard F. Gunst (Southern Methodist), Ken Kotnour (3M), Mary Natrella (Nat. Bur. of Standards), Steve Zayac (Ford).

The first two teams were concerned primarily with the academic program, and the other two concentrated on inhouse industrial training programs. In addition, two prominent consultants from the engineering societies participated: Lionel Baldwin, President of National Technological University and former Dean of Engineering, Colorado State University, and Ed Jones of Iowa State University, representing the Accreditation Board for Engineering and Technology.

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