ChE survey

APPLIED STATISTICS

Are ChE Educators Meeting the Challenge?

(A Survey of Statistics in the Chemical Engineering Curricula)

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W.A. Shewhart had a dream of a "statistically minded generation" (W. E. Deming, 1939[1]). This dream exists today, says R.G. Batson,[2] "but, as we are all keenly aware, not in the U.S."

For years, industry has recognized the need for chemical engineers to understand and use applied statistics. Increasingly stringent quality requirements and emphasis on TQM (Total Quality Management) have intensified this need in recent years. Probably more in-house courses on statistics-related topics are given to engineers in industry than on any other technical subject. Since at least the 1960s, surveys of engineers and managers in industry have repeatedly shown a shortfall in this area.[3] What are chemical engineering educators doing to correct this deficiency? Will we relinquish our job of educating chemical engineers in such an important area?

ABET has added the accreditation criterion, "Students must demonstrate knowledge of the application of probability and statistics to engineering problems" (Sec. IV.C.3.h). What evidence will educators present to a visiting team during ABET accreditation that graduates meet this criterion? Chemical engineering students take mathematics courses through differential equations, but do they have even an introduction to the random variable and stochastic processes? Even more important, are they sufficiently prepared to use statistics correctly and efficiently in their industrial careers? Or will the industrial emphasis on TQM be a surprise and a stumbling block for the new graduate?

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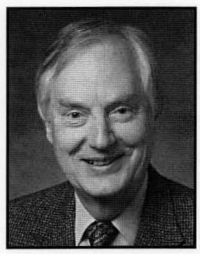

The survey that forms the basis of this article was sent to 172 chemical engineering departments in the United States and Canada and was devised to develop information on the status of applied statistics as background for educators and industry to view our progress toward the above goals. The purpose of the survey was not to establish the "ideal course" or sequence, but to stimulate thought and discussion in this direction. It is, to the best of our knowledge, the first survey on the extent to which statistics is included in the chemical engineering curriculum.

The questionnaire was sent as a single-page attachment to the annual course survey by the Chemical Engineering Education Projects Committee of AIChE in April of 1993 and was conducted by the late Edwin Eisen (McNeese State University). A follow-up request from John Griffith was sent to non-respondents in August, and forms continued to be returned in 1994. Inquiries were made about the status of inclusion of the usual topics of applied statistics. The important related subjects of experimental design and quality control were added.

THE SURVEY

The purpose of this survey was to present a summary of the status of statistics-related education in chemical engineering. The questions asked were

> *ABET has added the requirement "Students must demonstrate knowledge of the applications of probability and statistics to engineering problems." Are these topics included in your required curriculum? Are you planning curriculum changes on this topic? Are elective courses including these topics taken by some of the chemical engineering students?*

In addition to responses to the above questions, information about the courses (*e.g.,* is the course required, the department that offers the course, coverage of the field, and the textbooks used) was requested, and this information is summarized along with responses to the above questions.

RESPONSES

Of the 112 departments that replied to the survey (65% returned), all but five provided usable information for analysis. Eighty-six (80%) reported that topics pertaining to the ABET criterion are included in their required curriculum; 21 (20%) said no such topics are required. Therefore, most chemical engineering curricula require some statistics either as a separate course or as part of a course.

Note that the survey was sent to the entire population of chemical engineering departments and not simply to a sample selection. Therefore, there are no confidence intervals or "margins of error." The 60 non-responding departments (35%), however, are not expected to parallel the results presented here. Without direct substantiation, the author believes departments that do not have applied statistics in their curricula were less likely to respond to the survey. An absolute lower limit on the percentage of schools that include such topics is obtained from the positive replies out of the questionnaires sent, which is 50%, in comparison with 80% of the actual responses.

The question "Are you planning curriculum changes on this topic?" resulted in 31% "yes" responses from the participating schools. Percentages of the 107 useful responses are presented in tabular form for accuracy in Figure 1. These results, along with the 80% including statistics in the curriculum noted above are shown on the 3-D bar graph in Figure 1. The rectangle heights represent percentages of the useful 107 responses. Please refer to the "Total" columns first on each question; these are the tallest bars at the rear for each axis. The 100% grand total that would appear in the rear corner is purposely omitted to better display the important results. You will first see the 80-20% response to the "In Curriculum?" question. On the question of changes to the curriculum, 18% of the responses were blank, but all these respondents did answer the requirement question. Then, as lower limits, 31% plan to make changes and 51% do not. As expected, these two responses interact. For those with a requirement, only one-third are planning changes (21% yes; 42% no), while about half of those with no requirement plan changes (10% yes; 9% no).

		In Curriculum?		
		No	Yes	Total
	Total	20	80	
Planning Change?	No	9	41	49
	Yes	10	21	32
	Blank	11	18	19

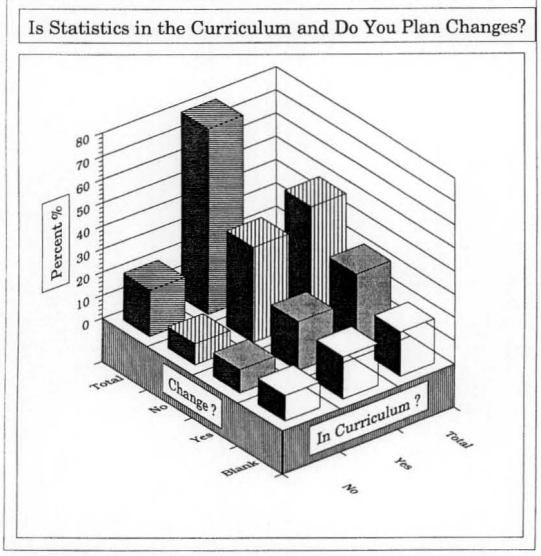

Figure 1. *Percentages of the total 107 survey responses to the two questions "Are statistical topics included in your required curriculum?" and "Are you planning curriculum changes on this topic?"*

Of the 80% that require statistics in the curriculum, 42% have a major course on this topic (see Figure 2). Major course coverage is defined as greater than one credit hour of statistics that includes four or more of the seven topics listed in Table 1. Slightly more, 45%, include statistics in a course and do not have the coverage defined for major coverage.

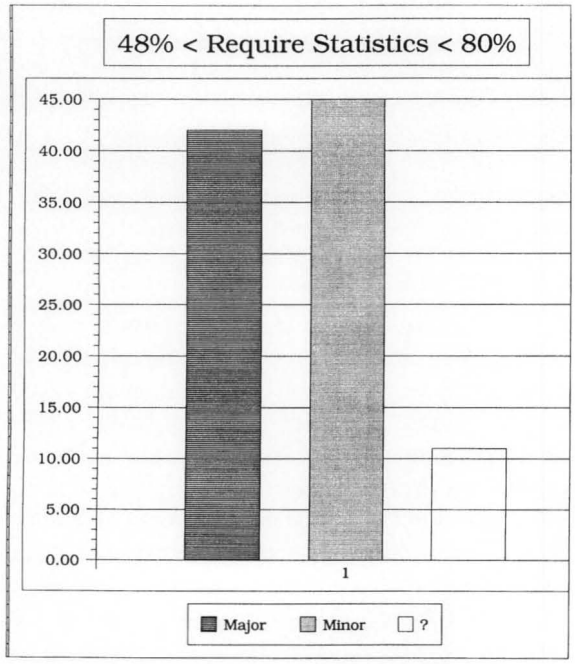

Figure 2. *For those schools that require statistical topics, the percentage that require a major amount of a course (greater than 1 credit hour and more than 3 topics from Table 1) or a minor amount are compared. If it was not possible to make this decision based on the information supplied, the school was counted in the (?) bar.*

TABLE 1
Statistics Related Topics Listed on the Questionnaire
(Submitter noted if topic is in each course.)

- ◑ Distributions
- ◑ Statistics, t, χ^2, F
- ◑ Regression Modeling
- ◑ Analysis of Variance
- ◑ Design of Experiments
- ◑ Quality Control
- ◑ Other (as needed)

Some (11%) report a course but did not provide sufficient detail to make this determination.

Figure 3 is a bar chart and table of detailed breakdown percentages for those departments that require a major course. Sixty percent place it in the junior year, and the rest are equally divided between the sophomore and senior years. No "major" course coverage, as defined above, was reported for the freshman year. The majority of these courses (57%) are offered by the chemical engineering departments. About a third of the courses are from mathematics or statistics departments, and the remaining 9% are offered by other engineering departments, mostly industrial engineering. The math/stat courses are concentrated even more heavily in the junior year; the number is close to that given by chemical engineering departments in the junior year.

When only a smaller part of a required course is statistics (see Figure 4), the courses reported are all taught within chemical engineering but are divided between class (58%) and laboratory (42%). More of the classes are in the sophomore and junior years. Few are during the freshman year, and an intermediate number are in the senior year. The laboratory courses are, of course, heavily concentrated in the senior year, with less than one-third of the labs in the junior year. Overall, there is a progression of increasing numbers of courses toward the end of the curriculum. Application of the content to other courses is thus limited.

STATISTICS ELECTIVES

Suitable applied statistics elective course(s) that some chemical engineering students take were reported by 86% of the departments responding to the questionnaire. Figure 5 includes the "blank" responses, so 78% is the corresponding figure. Surprisingly, whether or not statistics is required in the curriculum, about the same percentage of departments report some chemical engineering students take statistics electives. Perhaps the students' need for statistics when none is required is balanced by further interest in electives when the subject is required. Furthermore, whether or not some chemical engineering students take a statistics elective does not affect the school's decision to change the curriculum. The regularity of the response bars indicating no interaction to these two questions can be noted in Figure 5. The elective response is totally independent of the other two "yes and no" questions of Figure 1. For this reason, electives were analyzed separately.

The number of chemical engineering students who elect such a course was not asked on this survey since a detailed study of student records would have been required to determine the percentage of students who take such an elective course. Not even a single remark to the effect that many or most of the chemical engineers take these electives was offered on the survey sheets. We might infer that the number of chemical engineers introduced to statistics

		Year			
		Soph'more	Junior	Senior	Total
Dept.	Total	20	60	20	
	ChE	14	29	14	57
	Math/Stat	3	26	6	34
	Engr	3	6	0	9

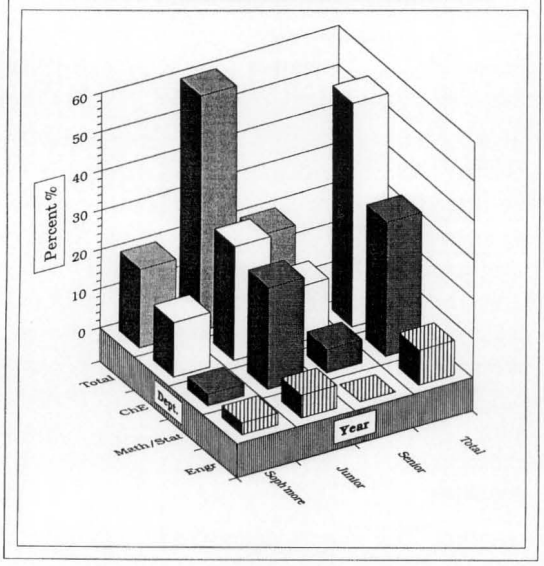

Figure 3. *The percentage of schools requiring a course with major amount of statistics is displayed by the combination of the department offering the course and the year in which students normally take the course.*

Type	Year				
	Freshman	Soph'more	Junior	Senior	Total
Total	5	20	32	43	
ChE Class	5	20	20	13	58
ChE Lab	0	0	12	30	42

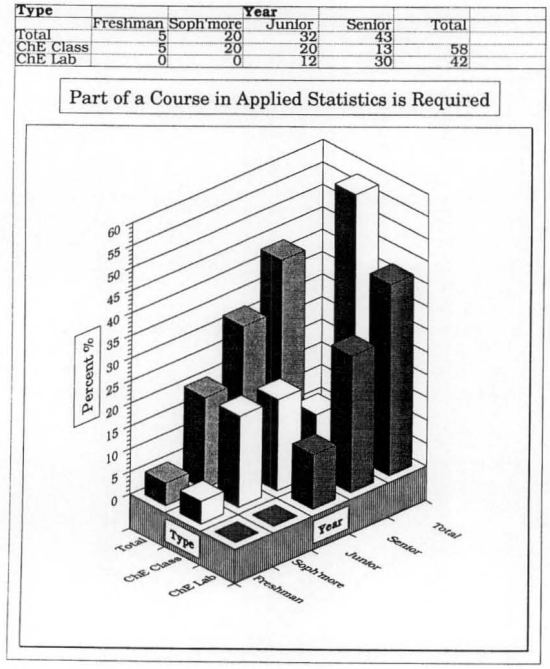

Figure 4. *When the schools require less statistics than that defined as major in Figure 2, statistics is often included with a chemical engineering laboratory course. Alternatively, statistics is included with a "class," which is a lecture and/or recitation. The percentage of each of these and the year in which students normally take the course is displayed.*

through an elective course is low.

Elective courses that have a major emphasis on statistics are offered in sixteen chemical engineering departments. Twelve of these courses include six or all seven of the topics listed in Table 1. The topics most often *not* included from this list are the applied topics of experimental design and quality control. Although these are useful topics, they usually follow more basic statistics in a course. Other topics of a statistical nature that were noted by the respondents are propagation of error, time series, nonparametric analysis, maximum likelihood, uncertainty analysis, and SPC. Also noted were several software packages such as SAS, Minitab, and Matlab.

TEXTBOOKS

The response to the request that the text be listed was both disappointing and revealing. It had been expected that texts for courses outside chemical engineering would often not be known by the supplier of this information, but even within chemical engineering only a few texts were listed, and there was no predominant one. The five mentioned more than one time are

- *Box, G.E.P., W.G. Hunter, and J.S. Hunter, Statistics for Experimenters, Wiley, New York, NY (1978)*
- *Devore, Jay L., Probability and Statistics for Engineering and the Sciences, 3rd ed., Brooks/Cole, Monterey, CA (1991)*
- *Hogg, R.V., and J. Ledolter, Engineering Statistics, 2nd ed., Macmillan (1992)*
- *Mason, R.L., R.F. Gunst, and J.L. Hess, Statistical Design and Analysis of Experiments: With Applications to Engineering and Science, Wiley, New York, NY (1989)*
- *Walpole, R.E., and R.H. Myers, Probability and Statistics for Engineers and Scientists, 3rd ed., Macmillan (1985)*

It should be noted that several new texts with titles that included "statistics for engineers" have been published since the start of this survey.

		Change Curriculum?			
		Blank	Yes	No	Total
Some Elective?	Total	19	32	49	
	Yes	16	25	37	78
	No	2	5	6	13
	Blank	1	2	6	9

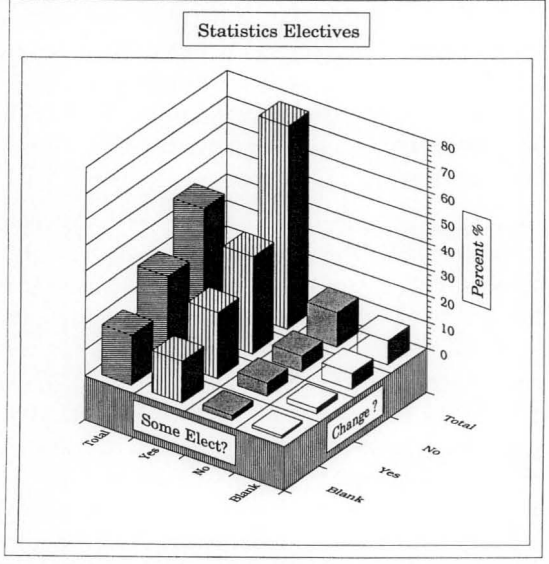

Figure 5. *Whether or not some chemical engineering engineering students elect statistics-related courses does not affect the department's decision to make curriculum changes regarding statistics.*

CONCLUSIONS

Over half of the chemical engineering curricula has at least some applied statistics in required courses. Many departments are adding statistics to required courses and are currently changing their curriculum in this regard. It will be necessary for others to include this general topic to meet the new ABET criteria. The required extent of coverage will undoubtedly depend much on the specific accreditor(s)' interpretation as this requirement is enforced through the coming years.

A preferred approach, whether the curriculum now includes applied statistics or not, is to look to the needs of the graduate chemical engineer. With computers in universal use, the extensive calculations to apply statistics can be readily performed. Good experimental design is essential for the efficiency and productivity demanded in today's markets. There is an elusive optimum range for the amount of applied statistics in the chemical engineering curriculum. In achieving these goals, decisions will be necessary on what portion of the current curricula will be supplemented or supplanted. A single course, with material carefully selected for maximum application both in the curriculum and in industry, will likely be the minimum need.

An early introduction to stochastic variables in mathematics courses would help to "pave the way" toward engineering applications courses. Elective courses will continue to increase the availability of these topics to the interested student, but they are not a substitute for a minimum requirement for understanding of statistics of the stochastic variable in parallel with mathematics of the deterministic variable.

ACKNOWLEDGMENT

Edwin Eisen kindly offered to include the questionnaire with his annual survey of courses. After his death, D. John Griffith continued the work and I am indebted to them for such help. I also thank the 107 professors who completed the questionnaires that provided the data for this paper.

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1. Deming, W.E., Shewhart, W.A., *Statistical Method from the Viewpoint of Quality Control,* Dept. of Agriculture, Washington, DC (1939)
2. Batson, R.G., "Statistical Training: A National Necessity," *Eng. Ed.,* Sept/Oct, 598 (1989)
3. "Two Surveys Show: What Engineers Would Study," *Engineer* (Engineers Joint Council), **6**(2), Summer/Fall, 4 (1965) ❐