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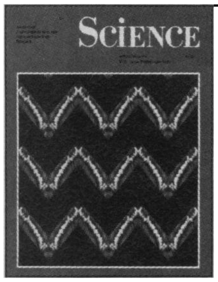

COVER Scanning tunneling microscope images of an uncoated DNA fragment adsorbed on a single-crystal gold surface under water. The image, which has been repeated in a chevron pattern, is 700 Å by 700 Å and is viewed at an angle of about 45° with respect to the surface. The individual 36 Å twists of the helix backbone can be seen. See page 1063. [Photograph courtesy of S. M. Lindsay, Department of Physics, Arizona State University, Tempe, AZ 85287]

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Teaching Statistics to Engineers

The competitive position of industry in the United States demands that we greatly increase the knowledge of statistics among our engineering graduates. Too many of today's manufacturers still rely on antiquated "quality control" methods, but economic survival in today's world of complex technology cannot be ensured without access to modern productivity tools, notably application of statistical methods. The Accreditation Board for Engineering and Technology (ABET) is now considering a proposal to make statistics an integral part of accredited undergraduate engineering programs. This proposal needs to be adopted.

Consider the molding process in which an integrated circuit chip is encapsulated in its familiar block of black plastic. The resin must cover the chip quickly, completely, and permanently, without disturbing the delicate wires that connect the circuit to the exterior metal "legs" which provide electrical contact. Success depends on a host of factors—temperature, pressure, mold design, material composition, viscosity, wire size, bonding method, and type of machine.

Each of these factors must be optimized to ensure quality results. But how does one find these optimum values? By experimenting with each one in isolation, critical interactions might be missed—raising the temperature might yield better results on one mold model but poor results on another, for example. On the other hand, attempting to vary each factor in all possible combinations could easily drive the number of experimental trials into the millions. No wonder that many traditional manufacturers still address only the obvious possibilities and hope for the best. Clearly, that kind of "best" is no longer good enough. Modern technology demands a far higher level of quality than a seat-of-the-pants approach can produce.

What is needed in this example, and thousands of others like it, is an application of methods from the area that statisticians call experimental design. A carefully selected number of experimental trials is carried out. In this selection, the factor combinations are chosen to allow estimation of the main effects of factors and those interactions judged to be critical by the engineer. Then sophisticated statistical methods are used to analyze the data. Such experiments require knowledge of statistics and engineering knowledge of the process at hand. It is no accident that today's leaders in quality manufacture encourage the use of statistically designed experiments at all stages of their processes—and see to it that their engineers have the training needed to succeed in these endeavors.

What training in statistics do today's U.S. engineering graduates receive? At present, most electrical engineers limit their studies of statistical variability to the stochastic processes involved in signal processing. Most others, such as civil, chemical, and mechanical engineers, can usually get one course in probability and statistics. Industrial engineers are typically given more, something between one and three semesters of course work. Despite some recent trends toward improvement, courses tend to emphasize the theory of statistics, in isolation, without relating it sufficiently to engineering processes.

Since Japan's universities have similar shortcomings, that country's employers routinely provide their engineers with substantial training in statistics. For example, one experimental design course taught by a Japanese professional organization lasts 30 days. In contrast, U.S. industry generally provides less than one-tenth as much training in experimental design and to only a small fraction of its engineers.

In most respects, the superior training of U.S. university graduates remains a key pillar of our economic strength. Unlike the Japanese, whose industries have adapted to shortcomings in their system of higher education by providing extensive on-the-job training, U.S. companies have normally been able to rely on university-based training for needed expertise. While the private sector must enhance its own training programs, it is clearly incumbent upon our engineering schools to adapt to evolving needs as quickly and effectively as possible. Change is never easy. Each addition necessarily displaces some other portion of the curriculum. Nevertheless, the adoption of the accreditation proposal by ABET would be an important step in ensuring the industrial future of the United States.

—ARNO PENZIAS, *Vice President for Research, AT&T Bell Laboratories, Murray Hill, NJ 07974*