Measurement and Evaluation

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> "I often say that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it in numbers your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge but you have scarcely in your thoughts advanced to the stage of science, whatever the matter may be."
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> —*Lord Kelvin*

M OST of us devote appreciable time in the course of daily activity to making evaluations and forming value judgments. Every time we make a purchase, watch television, eat a meal—the list is endless—we make evaluations. Factors considered may involve monetary costs, saving of labor and time, ethical principles, aesthetic enjoyment, and many other matters.

In order to reach a final decision, it is usually necessary to combine, or even to counterbalance, evaluations made in many subsidiary categories. Those subgroups to which numbers can be applied, such as initial monetary cost and maximum attainable speed, are the easiest to consider, while those to which numbers cannot be easily assigned are more difficult to evaluate.

The establishment of standards is a recognized aid in the making of evaluations. Standards may consist simply of a set of lower limits; any product which fails to meet them is automatically eliminated from consideration. Examples of this hurdle or barrier type are some of the standards of the Underwriters' Laboratories for electrical appliances. A variant of this kind of standard may involve an upper as well as a lower limit, such as the "go—no-go" type. Conversely, a standard may involve the expression of a ratio of the specific item to the ultimate attainable, so each evaluation is a rating indicating how closely the limit is approached. A standard of this type is involved in the grading of examinations. (Even then the relationship between the score and the practical application is not always clear; the "A" student is not always successful in later life.) An intermediate form of standard is a rank ordering of individual

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items, along some defined scale, thus allowing comparison of each item with the average and its fellows.

All these types of standards are clearly of value, so the establishment of standards, at least tentatively, should generally precede the process of evaluation. In the production of materials and the fabrication of products of all kinds, industry and Government depend on established standards in making purchases, compliance testing, and the design of more complex products. For many years the American Society for Testing and Materials, the American Standards Association, numerous trade associations, and various Government agencies have sponsored development of standards and specifications.

Now what has all this to do with artificial limbs and braces? Evaluation serves one primary purpose in this case—the improvement of the product, a special type of man-machine combination. If the artificial limb could duplicate exactly all the functions of the natural limb in spite of the limited resources of power, sensibility, and control remaining available to the amputee, presumably we would have an ideal prosthesis. Minimal standards can rule out gross malfunctions, frequent and hazardous physical breakdowns, and obvious discomfort. Reasonably accurate lower and upper boundaries of physical dimensions to match specific categories of amputees can be established from anthropometric data illuminated by the best experience of the industry. In another sense, the physical strengths and practical minimal wall thicknesses set lower limits to weights, while maximal tolerable weights and inertias can also be estimated. By specifying the functional capabilities of the human limb we can establish the maximum standards we would like to achieve with our replacement. (The frequent recent suggestions of servo systems or "man amplifiers," though, imply that merely human performance may not be an upper bound.)

These standards of several types should be specified in many categories. Any problem, no matter how complex, can be approached by breaking it down into small segments which can be analyzed. It is only as we define the significant categories, establish and progressively refine standards, and make objective evaluations that further appreciable advances in artificial limbs and braces will be made.