Human Factors in Industrial Design

The Designer's Companion

John H. Burgess

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Preface

Human factors material tailored to a designer's orientation has seemed to me for some time to be a most needed contribution in the human factors literature. Human factors specialists usually have a background in experimental psychology or industrial engineering. Both of these fields rely heavily on statistics and mathematical analytical techniques. Psychologists are also quite extensively trained in human anatomy, physiology and neurology. Such background components in either—or both—mathematics and biological science are generally lacking in a designer's curriculum.

While a human factors specialist emphasizes scientific validity and reliability of data in human performance, the designer generally has a different emphasis. Industrial designers may concentrate more on the aesthetic characteristics and marketability of a product, whereas the engineer's emphasis is more on the functional performance of the equipment. When more specific emphasis is to be placed on human factors, as is frequently the case in military projects, human factors experts are called in. In other than military projects, it has been my experience that the human factors aspects of a project are simply glossed over. Human factors design decisions are then made on an intuitive, or, if you will, on a quasi-random basis. The latter, indeed, may be the case in perhaps 80 to 90 percent of all nonmilitary design projects.

In a typical engineering graphics textbook, as a case in point, there was virtually no indexing nor referencing for human engineering. The book stated simply that it is the industrial engineer who is *responsible* for a human factors component: ". . . Not only must the industrial engineer have a sound knowledge of the principles of engineering, but he must possess an understanding of the human factor . . ." (*Engineering Graphics* by R. Hammond, et al., p.6).

In teaching human factors to third-year design students, I found both faculty and students to be keenly interested in the human factors aspects of design. However, a generic human factors background was lacking in their training. Consequently, they tended to find the human factors material in typical human factors texts difficult to assimilate. The reason for this seems generally to be in the differences in emphasis; while human factors texts are written for specialists, a designer requires simplified and expedient techniques for immediate design applications.

The material I have devised is thus oriented primarily to a design emphasis. The human user of products is described in terms that a designer might easily understand—as a kind of black box with definitive perceptual sensitivities and processing characteristics and output modes of response.

The text is best suited as a companion volume required as an integral part of substantive design courses. While a separate human factors course for designers, emphasizing the validity of data and research applications, will enhance the depth of understanding, an ongoing curriculum requirement for human-factors applications may be the most pertinent. Indeed, simply teaching a human factors course to designers, without an essential design emphasis, may tend to isolate the subject matter. The student may get the unfortunate message that such considerations are not really all that relevant to design. The integration of human factors into design courses should no longer be a compartmentalized study nor made to seem to be simply an unnecessary embellishment in design. A human factors component in virtually any engineering or industrial design project is paramount to good design and consumer satisfaction. A real need emerges to translate the human factors imperative into operational design terms and such a premise has been made the central theme of this book.

The material has been sectionalized in the text to accommodate design curricula that proceed from simple to complex design projects. Thus, human factors analytical techniques are presented, in operational terms and by way of examples, that can be applied to a gradation of complexity—from simple hand tools to complicated systems. Basic human engineering data and cases of application are included, as well as references for acquiring more unique design data when needed.

In the process of developing an effective pedagogical procedure, I found that engineering and industrial design students were particularly receptive to carrying out design exercises. This particularly became the case once they were familiarized with human factors analytical methods and principles of application. Thus, each section calls for detailed practical human factors analyses of activities and tasks. Human engineering data applications are called for in product improvement and initial product design as well as for the more complex systems analyses.

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Introduction

Human factors is a general term that applies when any consideration is given in design for the users of a product or piece of equipment. It also applies when a Human Operator (HO)[1] is used to fulfill operating requirements in more complex systems. The term also refers to what is called "human engineering," "engineering psychology," or "ergonomics."[2]

The term was first used in the 1940s during World War II, though, of course, generic types of human factors concerns have operated for centuries. In recent times, Charles Babbage wrote a book entitled *Economy of Machinery and Manufacture* (1832) in which he laid out methods for making jobs easier and more economical. Adam Smith also did this a half-century earlier in his book, *Wealth of Nations* (1776). Later, the industrial engineer Frederick Taylor, at the Midvale Steel Company in Philadelphia, studied the human factors of hand tools, the object being to increase human productivity. The famous Gilbreths studied motion and economy factors in work during the 1920s and 30s, and their methods became extensively used for improving industrial effici-

1. The term "HO" will be used extensively throughout the text, generically referring to both male and female human users. Functional characteristics of the HO, with pertinent capabilities and limitations, are described in the chapters that follow.

2. deMontmollin and Bainbridge see a difference between the American definition of ergonomics and that of the British and Europeans. In America, they see it as referring to biomechanics and the work environment. In Europe, they claim, "ergonomics" is synonymous with what Americans mean by "human factors." (Refer to the *Human Factors Society Bulletin*, June, 1985, p. 1ff.)

ency. The psychologist Hugo Munsterberg first used psychological testing in industry for personnel selection.

Human factors studies became extensive during World War II when poor human engineering had cost both sides many lives and resulted in ineffective weapons. Such names as Helson, Craig, Ellson, Fitts, Flexman, Grether, Kaufman, Loucks and Mitchell were among the many British and American engineering psychologists who improved weapons efficiency during the war.

After the war, engineering psychologists participated in systematizing machine systems for more effective human operator use of weapons in the "cold war." Military operations proved to be most successful when human operator capabilities were considered throughout the entire system development program. Early work at the Navy, Army Signal Corps and Air Force human engineering laboratories provided voluminous data. Alphonse Chapanis at John Hopkins University wrote among the first in a series of textbooks summarizing and updating the human engineering state of the art.

Human engineering is commonly recognized to be an important part of the development process in most aerospace and military products. Human factors in the design of civilian products and industrial operations is only beginning to receive such attention, largely due to publicized incidents where human error has been found to be responsible for accidents. For example, the Three Mile Island nuclear plant incident in Pennsylvania proved to be a most costly and dangerous episode that was traceable to poor human engineering.

In modern industry, accidents have been found to be attributable to the poor human engineering of equipment. The neglected human factor has resulted in hazardous operations, inconveniences and inefficiencies in both product and industrial operations. With the advent of increasing numbers of female workers in the workplace, the female human factor has also been sorely neglected; women are subjected to ill-fitting face masks, coveralls and footwear, as well as tools and equipment only poorly designed for them. All this, of course, means discomfort and poor morale for the worker, and poor productivity for the industry.

Product life is also often severely compromised, partly due to the lack of good ergonomic or human factors design. The early digital watches, for example, were so difficult to set and reset that many consumers simply gave up in disgust.

Numerous aircraft accidents continue to be traceable to human error and, in turn, the lack of good human engineering. Automobile mishaps are attributable to any of a number of poor human engineering design features including the roadway subsystem, traffic regulatory and maintenance subsystems, and the vehicle subsystem itself.

Nuclear power plants, chemical factories, coal mining machines, and a myriad of product-safety deficiencies can be found to be associated with, or directly related to, the lack of human factors considerations, or just poorly human engineered user interfaces.

Human operator interactions occur in almost all steps in the life cycle of a machine or piece of equipment, and industrial design and engineering must assume direct responsibility for how these interactions occur. The machine may simply be an appliance or other domestic product, or it can be a complex operational system, but the responsibility is still there to provide the most efficient human engineering design features possible. These human interfaces should be considered in every design project. All aspects of interaction with the machine should be determined for a valid specification of display and control requirements. The condition of the ambient and machine-generated environments should also be determined. From such data and from special design studies, sound human engineering applications can be made.

Engineering and industrial design students must be sensitized to all aspects of human interfacing in their product designs. This will assure that a well-rounded and mature perspective on human factors will be incorporated. By assuming such responsibility at the beginning of design, costly human error and poor human performance or productivity can later be prevented.

Human Factors in Industrial Design (ID)

Industrial designers are taught the basics of human factors methods and data applications. However, in some ID curricula, human factors instruction is limited to a kind of general admonition, viz., to be sure to consider the "human" aspects of the product. A book by Henry Dreyfuss, *The Measure of Man: Human Factors in Design*, often becomes the sole human factors source material for an industrial designer.

Chief components of the ID curriculum may include such courses as drafting, strategies of material usage, development of sensitivity to product form, the use of light, shade and color in design, product aesthetics and subjective creativity, product forms for mass production, space analysis as a means of visual communication, industrial graphics, the use of two- and three-dimensional mockups, etc. Industrial design has been defined as the imaginative development of manufactured products and product systems that "serve the physical needs and satisfy the psychological desires of people."

It can be seen that ID curricula seem to present a broad, almost philosophical, premise in design. Use of such phrasing in curricula description as "humane performance justifying a product's existence" presents more of an abstraction than a technical basis for human factors. Indeed, a review of industrial design curricula in general tends to indicate the need for introducing a more fundamental human factors technology. The best means of presenting and assimilating this point of view for the ID student might be an integrative one. Thus, every phase of an industrial designer's training should ideally also incorporate valid human engineering principles. The abstract regard for "humanics" in industrial design must then be translated into meaningful perceptual-motor terms that can be realistically applied to design configurations.

Human Factors in Engineering

The diversity of puristic engineering fields also bespeaks a common need for incorporating the human factors technology into design. Aerospace engineering, agricultural engineering, ceramic engineering, chemical engineering, civil engineering, electrical and avionics engineering, mechanical, metallurgical and nuclear engineering may all require a well-integrated human factors component in the design curriculum.

Design is the common denominator of engineering. It is the iterative process through which an engineer is able to optimally convert available resources into devices or systems that satisfy the human needs to which the design is addressed. Engineering schools, of course, recognize that the engineer's discipline and skills are more fundamentally acquired through practice and application. Engineering students, they realize, lack the experience and knowledge necessary for evaluating optimal solutions or to perform the necessary detailed analysis to achieve these. They can, however, and they must begin at the outset to learn and to practice methods of the kind of orderly thinking into which their cumulative knowledge can eventually be integrated.

Engineering training programs emphatically assume the value and importance of designing for human needs; technical human factors data for design interfaces, however, are generally a neglected facet of engineering curricula. These should become an emphatic part of the information-gathering phase of design (Hammond, et al., 1979). In fact, in most engineering academic contexts, little appears to be known or taught about the human operator's makeup and perceptual-motor requirements. Though it would, perhaps, be neither necessary nor practical to require a special human factors curriculum component in an engineer's training, an integrated approach could be of considerable value for the engineer as well as the industrial designer. The information-gathering phase in any engineering project should also ideally incorporate valid human engineering principles to be applied in the design approach.

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Material in the text has been organized to accommodate the curriculum needs of both industrial designers and the different engineering disciplines. It is expected that a measure of sound human engineering can be meaningfully integrated into any industrial design or engineering course or project. The nature of the human operator as an essential component in the design process is thus presented without going into any great depth. Indeed, more extensive human factors analyses can be left to the human factors specialist when necessary for the accomplishment of more complicated design solutions.

When human factors expertise is not immediately available, members of a design team can at least apply human factors analytical methods and design principles by knowing the rudiments of this science. Human factors approaches to analysis are thus described in the text. This, it is expected, will enable designers to apply meaningful substantive human factors data in design even in the absence of the specialist.

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I
What You Should Know About the Human User

1
The Nature of the Human Operator

To determine what is needed in the human factors aspects of design, it becomes necessary to understand certain fundamentals about the human user (HU) or operator. For purposes of design, the HU—or human operator (HO)—might be considered to be a kind of black box with a number of extrusions of body members as well as internal components (see Figure 1.1). It has a head with a brain, eyes, ears, nose and a mouth. It has limbs with muscles and a nervous network that connects to muscles, bones and internal organs. The organs keep the body fueled, operate in a combustion and waste-disposal process, and maintain equilibrium of the entire organism in balancing all the other subsystems.

The HO black box, for categorizing purposes, may be considered to be a complex system composed of four subsystems of body components:

1) The receptor subsystem, or the senses
2) The information-processing subsystem or the brain and the voluntary and automatic nerve networks,
3) The effector subsystem, or the muscles that hold and move the skeletal frame members,
4) The support subsystem which is made up of all the internal organs

The Receptor Subsystem

The receptor subsystem is made up of the senses, or *channels*, through which information from the external world enters the black box.