PSYCHOLOGY AND THE DESIGN OF MACHINES

FRANKLIN V. TAYLOR

U. S. Naval Research Laboratory, Washington, D. C.

Psychologists have been helping engineers design machines for more than fifteen years. It all began during World War II with the rapid development of radars, sonars, aircraft control systems, and other similar devices. Previous to this time, the only role played by psychologists relative to military mechanisms was that of doing research and giving advice on the selection and training of the operators. However, very early in the war, it became apparent that these Procrustean attempts to fit the man to the machine were not enough. Regardless of how much he could be stretched by training or pared down through selection, there were still many military equipments which the man just could not be moulded to fit. They required of him too many hands, too many feet, or in the case of some of the more complex devices, too many heads.

Sometimes they called for the operator to see targets which were close to invisible, or to understand speech in the presence of deafening noise, to track simultaneously in three coordinates with the two hands, to solve in analogue form complex differential equations, or to consider large amounts of information and to reach life-and-death decisions in split seconds and with no hope of another try. Of course the man often failed in one or another of these tasks. As a result, bombs and bullets often missed their mark, planes crashed, friendly ships were fired upon and sunk. Whales were depth-charged.

Because of these "human errors," as they were called, psychologists were asked to help the engineers produce machines which required less of the man and which, at the same time, exploited his special abilities. The story of what happened is sufficiently well known not to require any lengthy retelling here. In brief, the psychologists went to work, and with the help of anatomists, physiologists, and, of course, engineers they started a new inter-discipline aimed at better machine design and called variously human engineering, biomechanics, psychotechnology, or engineering psychology. The new field has developed rapidly in the seventeen or eighteen years of its existence, and it has now attained sufficient respectability to be accorded divisional status by the American Psychological Association. At the last meeting of the Council of Representatives, authorization was given for the founding of The Society of Engineering Psychologists as Division 21 of the APA.

It seems fitting, now that engineering psychology has been recognized as a viable entity, that we examine this new field to find out just what it is that psychology is doing for the design of machines. It is probably even more necessary that we also inquire into what the participation in the design of machines is doing for, or to, psychology. Many young people are being lured into human engineering by the abundant opportunities provided for advancement and the tantalizing salaries offered by commercial organizations. It has been suggested by an unassailable authority that a major breakthrough in the field of psychology in recent years has been the psychologists' discovery of money. It may be remarked that it was undoubtedly an engineering psychologist who first got wind of the find.

In all seriousness, however, psychologists who might otherwise conduct basic research may be attracted into this new applied area, and it is therefore important to know what it represents professionally and scientifically in order to evaluate its threat or its promise. To decide what actions to take relative to encouraging the further development of the field, answers are needed to questions such as the following: To what extent is engineering psychology engineering, to what extent is it psychology, and to what extent is it neither? Is it a fruitful scientific area? Is it, indeed, a scientific area at all?

In the attempt to provide answers to these questions, let us look at psychologists caught in the act, so to speak, of doing human engineering. However, before we can meaningfully analyze the behavior of engineering psychologists, the concept of

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1 This paper is substantially the same as that delivered as an address on April 12, 1957 at the 28th Annual Meeting of the Eastern Psychological Association.
the man-machine system must be described. Human engineers have for some time now looked upon the man and the machine which he operated as interacting parts of one overall system. In Fig. 1 is shown a paradigm of the concept. This may be viewed as a radar device, a pilot-aircraft control system, a submarine diving control station, the captain’s station on the bridge of his ship, or, in fact, any man-machine system at all.

In essence, it represents the human operator as an organic data transmission and processing link inserted between the mechanical or electronic displays and controls of a machine. An input of some type is transformed by the mechanisms into a signal which appears on a display. Perhaps it is shown as a pointer reading, a pattern of lights, or a pip on a cathode ray tube. However it appears, the presented information is read by the operator, processed mentally, and transformed into control responses. Switches are thrown, buttons are pushed, or force is applied to a joy stick. The control signal, after transformation by the mechanisms, becomes the system output, and in some devices it acts upon the displays as well. These latter are called “closed-loop” systems in contrast to “open-loop” systems wherein the displays do not reflect the human’s response.

When the man and the machine are considered in this fashion, it immediately becomes obvious that, in order to design properly the mechanical components, the characteristics of the man and his role in the system must be taken into full account. Human engineering seeks to do this and to provide as much assistance to the system designer as possible. Specifically, the psychologist tries to help his engineering colleague in three different ways. First of all, he studies the psychology of the human as a system component. Second, he assists the engineer in experimentally evaluating prototype man-machine systems. Finally, he teams up with engineers to participate actively in the design of machines. Each of these human engineering functions will be described in turn, beginning with the last and the least scientific activity.
HUMAN ENGINEERING TECHNOLOGY

The academic psychologist often forgets, or perhaps never knew, that human engineering is not only a science, it is also a technology; it not only tries to find out things about the interaction of men and machines, it builds the latter. And, surprisingly enough, it is not just the engineers who do the building. There are psychologists also, renegades to be sure but psychologists nevertheless, who are taking an active hand in the design of systems. It is true that with some their apostacy is venial, having progressed only to the stage of writing human engineering handbooks; but with others the defection is more serious, it having developed to the stage where they can spend anything up to full time in systems planning and design with only a twinge or two of longing for the serenity of the research laboratory and the comfort of statistics.

The aim of the human engineering technologist is to apply the knowledge of human behavior, which he and others have gained, to the structuring of machines. He seeks to translate scientific findings into electronic circuits and “black boxes” which in specific situations will compensate for the human’s limitations or complement his abilities. Specifically, the practicing engineering psychologist works on an engineering team and participates in the design of man-machine systems. Using procedural analysis techniques, drawing upon his psychological knowledge and attitudes, and employing his common sense and creative ability, the human engineer proceeds to contribute to system development at three levels of complexity.

At the simplest, he designs individual displays, controls, or display-control relationships. At a somewhat more complex level, the human engineering technologist contributes to the design of consoles and instrument panels. At the highest level of complexity, he assists in structuring large systems composed of many mechanical elements and frequently several human beings. In this capacity he helps to determine what information must flow through the system, how it must be processed, how many men are required, what tasks they will perform, and what type of information each one will need. In short, the engineering psychologist helps at this level to determine the configuration of the system.

Human engineering technology is much more extensively practiced by psychologists than is generally recognized by those who are not closely identified with the field. The specific nature of each accomplishment and the difficulty of assigning individual credit for team effort conspire with security and proprietary considerations to keep the lay and psychological public in almost complete ignorance of the technological products of human engineering. However, literally hundreds of devices and systems have been affected to a greater or less extent during the last ten years by the efforts of engineering psychologists. Every major type of military equipment has received some attention, as have also certain nonmilitary products such as aircraft instruments and cabins, flight control towers, artificial limbs, semiautomatic post office sorting equipment, telephone sets, theodolites, experimental equipment for the earth satellite program, control panels for an atomic reactor, and numerous industrial machines.

Although there are no statistics available as to precisely how much time psychologists devote to technology, an informal estimate based on my own experience would suggest that approximately one-third of the engineering psychology effort in government and industry is devoted to the practice of equipment design.

Now, how does this practical activity tie in with psychology? Certainly it cannot be denied that in one sense of the term it is an area of applied psychology. Facts about human behavior are being utilized in the design of machines. Yet in another sense it cannot be regarded as psychology at all, for certainly the design of machines is engineering, regardless of who does it or of the extent of interest on the part of the designer in human behavior. To deny this in favor of the view that system design is applied psychology because of its human reference, converts all engineers to psychologists the moment they take into account the behavior of the human for whom they are designing the machine. Certainly we do not customarily consider all occupations oriented toward human behavior to be psychology. If we did, the APA would undoubtedly be the largest professional society in the world, speaking for actors, school teachers, policemen, politicians, and members of the clergy, in addition to its present membership. So far as I know, such an expansion is not yet contemplated.

A second difficulty which stands in the way of incorporating the design aspects of human engineering under psychology arises from the nature of the
goal of systems design. Whereas the primary aim of the practitioners of the more conventional applied psychologies is to control and influence people, the human engineering designer seeks to produce more effective machines. While psychology has, in the past, been applied to improving human performance by selecting, training, and motivating normal men, by curing mentally ill men, and by persuading both to buy toothpaste and television sets, human engineering aims first at building better systems and only secondarily at improving the lot of the operator. Thus, whereas conventional psychology, both basic and applied, is anthropocentric, human engineering is mechanocentric.

Because of these peculiarities of the new field, one is forced to the conclusion that it is of questionable profit to attempt to maintain that human engineering technology is a branch of psychology. Or if one still wishes to do so, it must be admitted that it is psychology most diluted and highly contaminated with physical science and engineering considerations. Although this, of course, does not reflect in any way upon the importance to society of human engineering, it does raise questions concerning the training and professional affiliation of those psychologists who decide to enter this exciting new trans-disciplinary technology.

MAN-MACHINE SYSTEMS EVALUATION

The second way in which the engineering psychologist assists in the design of machines is by taking part in systems evaluations. Like human engineering technology, evaluation studies require a sizeable effort yet receive scarcely any publicity. Evaluations have been performed on headphones, range finders, gunsights, fire control and missile control systems, radar sets, information plotting systems, combat information centers, aircraft control towers, and numerous assorted display and control components. In some instances, the experiments have been carried out in the laboratory with the system inputs being simulated. In other cases, the tests are conducted in the field. But in both situations, the attendant complexities and difficulties of statistical control make this necessary variety of research as trying as any in which psychologists are likely to participate.

The reason that psychologists were called upon in the first place to assist in these evaluations was that they possessed methods for dealing with human variability. In contrast, the engineers generally had worked only with time-stationary components and, therefore, found themselves at somewhat of a loss when they were called upon to assess the performance of devices which were being operated by men.

It is easy to see that psychologists have something definite to offer in regard to this aspect of systems design, and it is not surprising, therefore, that their services are often sought out and accepted. However, the question which we wish to pose, albeit a bit bluntly, is what are the psychologists getting out of it in turn, besides a living? Certainly they are making a contribution to the engineering of better systems, and the consciousness of this may be all that is required for the satisfaction of the individual. Yet, one might wish to know if there were any other returns—to science in general or to psychology in particular.

Admittedly, this is a difficult question which will be more easily answered fifty years from now than at present after only a few years of this activity. But one thing can be said right now about experiments performed on man-machine systems: if one's main object is to learn about human behavior, the use of a complex systems experiment is an uncommonly unwieldy way to go about it.

This may be illustrated with a preposterous, hypothetical systems evaluation. Suppose we wished to compare the performance of a boy on a bicycle with that of a boy hopping on a pogo stick. The main independent variable would be the nature of the boy-machine system; the dependent variable could be, for example, the length of time to travel a quarter mile.

Here we would have a perfectly proper systems test. At least it could be made proper through adequate attention to the training of the boys and to statistical precautions to overcome human variability. Also, the experiment would undoubtedly yield clear and unambiguous results. Assuming that the maintenance of the two conveyances was adequate to the point where neither broke down during the race, the boy-bicycle system would very likely prove to be superior to the boy-pogo stick complex. It is granted that, before positive recommendations could be made concerning the adoption of one vehicle system over the other as a general means of boyish travel, other system criteria such as initial cost, cost of replacing parts, safety, maneuverability, ease of stowage, and consumer acceptance would have to be considered. But this is
always true and constitutes no valid criticism of the evaluation. The test itself could have been highly successful; and, if so, we would have learned from it something about systems.

But what have we learned about boys? After all, we are psychologists and are interested in the laws of human behavior. What anthropomorphic relationships are revealed by the study? It would seem clear that in our contrived example we have learned next to nothing of interest to psychology. Apart from finding out that boys can learn to operate both bicycles and pogo sticks, the test has disclosed nothing about the characteristics of the human operator. There are several reasons for this.

First of all, the dependent variable in the experiment is a measure of system performance, not human performance. It is perfectly apparent that the fact that one system is better than the other does not mean that the boy in the superior system is doing better in any real sense than the boy who loses the race. Quite the contrary might be true. The boy on the losing pogo stick may actually be doing a better job of pogo stick jumping than the bicycle rider is doing of his bicycle riding. As long as one is dealing with a system performance variable, the behavior of the human in the system can only be inferred, and often the inference is hazardous indeed.

This would not be a serious matter if it were always possible to find some other dependent variable which did directly reflect human behavior. But in many studies no meaningful, uncontaminated, human performance variable exists. Whenever the human responds through some variety of control, his response is inextricably tied up with the physical properties of the control itself. Thus, in our example, it is not possible to measure hopping independently of the physical characteristics of the pogo stick hopped on, nor pedaling in the absence of pedals. Try as one will, one cannot pedal a pogo stick nor effectively hop through the air on a bike. Since it is impossible to separate the manner in which the human applies force from the characteristics of the thing to which the force is applied, there is no way of getting a pure measure of man’s behavior in many systems studies and, as a matter of fact, in many laboratory experiments not construed as dealing with systems.

The basic indeterminability of human response has, of course, been recognized for a long time. Philosophers and psychologists have pointed out repeatedly that behavior is an interaction among different kinds of things and that it is arbitrary and misleading to say that one of the things (usually the animate one) is doing the behaving while the others make up the environment. Thus, we say that we are studying the behavior of a man walking (1) and not the behavior of the ground under his feet. Yet, of course, the walking behavior would be impossible without the ground, just as it would without the man. Both, and much else besides, are necessary for the walking to occur, and any measurement of the behavior reflects the characteristics of all of the interacting objects and forces.

Now all this is of very little consequence to psychology so long as the parts of the human’s environment which interact with his motor output remain unchanged during an experiment. If, in the walking study, the ground underfoot was always of the same general firmness, levelness, and texture, its contribution to the behavior could be neglected. Similarly, if in a tracking investigation the S always uses the same joy stick working through the same system dynamics, it matters not a whit that the performance measured is that of the man-joy stick system and not of the man alone.

But let the properties of the objects to which the man applies force be varied, un-knowingly or deliberately, and it becomes vital to recognize the contaminated nature of the performance measure. Change the ground from hard to muddy, or the tracking control from joy stick to handwheel, and the altered performance resulting is a composite of direct effects and man-environment interactions impossible to untangle without further research. When this is not recognized and the behavioral shift is attributed exclusively to the man, one blunders scientifically.

Conventional psychology has generally avoided this problem of confounded dependent variables by working much more frequently with sensory and state-of-the-organism parameters than with human output variables. Engineering psychology, however, has deliberately undertaken to work with system variables, with the result that the performance measures are almost never pure human response scores. Although this repeated experience has alerted some of the experimenting human engineers to the inferential pitfalls of blindly equating system performance with human performance, there are still those who fall into the trap. One still
occasionally hears said, for example, that human tracking performance is improved or degraded by changes in the nature of the control or by alterations in the control dynamics. Such statements may be true but they are certainly not justified, for tracking performance, as measured, is system behavior which can change radically as a result of altered dynamics without reflecting any comparable change on the part of the man.

But it is not only the dependent variable which gives the human engineer trouble in making psychological hay out of systems studies. The independent variables are often even more troublesome because they frequently embody many parameters. Consider the independent variable in our example. When the pogo stick is substituted for the bicycle, actually four sets of dimensions are involved. First of all, the controls are shifted: pedals and handlebars are traded for a spring-mounted step and a pole. Secondly, the system dynamics are changed as they relate to the transformation of human energy into motion along the ground. Third, the sensory inputs to the boys are modified (the displays are altered, so to speak): with the pogo stick the visual world bobs up and down, with the bicycle it glides by; with the pogo stick the boy’s weight is all upon his feet, with the bicycle he feels pressure from his seat. Finally, the operator’s task is completely transformed: the psychomotor performance of hopping up and down along a Z axis while simultaneously maneuvering along X and Y coordinates, through shifting balance around these axes, is an entirely different stunt from controlling in X through balancing around X, steering around Z, and pedalling around Y—the latter is the task of the bicycle rider.

Now even if one had a measure of human performance as a dependent variable, which one does not, it is clear that next to nothing of psychological interest could be learned by manipulating this multiparameter, independent, system variable. Since the displays, the controls, the dynamics, and the psychomotor task are all varied simultaneously, the logic of experiment is so completely violated that it is impossible to partial out the individual effects of any of the components upon the performance of the system or of the man. All that one can know in such a systems test is the combined effects of the dimensionally massive, independent variable—in other words, that one system is better than another. This is of value in deciding between systems, but it may be suggested that it is impoverished psychological research.

Of course, our example is a reductio ad absurdum intentionally. In many systems experiments, the independent variables are less complex than in the illustration. Yet it is almost always true that system variables comprise more diverse dimensions than do the variables customarily chosen for psychological analysis.

But it is not just the complexity and dimensional confounding typical of system variables which make it hard to derive psychologically relevant facts from man-machine systems tests. A further difficulty stems from the shift in the operator’s task (already alluded to) which so often results from the manipulation of the physical parameters of the system. We have pointed out that the psychomotor processes involved in riding a bicycle are entirely different from those underlying hopping about on a pogo stick. Similar radical differences in the operator’s task are often to be observed when real systems are compared. One system may require the operator to act analogously to a complex differential equation-solver, while another may require of him nothing more than proportional responding. One radar warning system may require the operator to calculate the threat of each target and to indicate the most threatening; another may compute the threat automatically and place a marker around the target to be signalled.

Clearly, the operator’s tasks differ so much from one of these systems to the next that it would never have occurred to a psychologist to compare them. The differences are so gross, so obvious, that they obscure the need for relating the tasks, for placing them on some kind of a useful continuum and for scaling the distances in between. Yet these behaviors must be compared in some way and the knowledge made available to engineers if the human is to be employed effectively in man-machine systems. Changing the operator’s task from one of these complex psychomotor processes to another may produce startling improvements in system performance, and the principles determining the substitution of the task must be discovered if systems design is to progress.

But can we consider this to be good psychology? Do those who regard themselves as scientific psychologists wish to spend their time comparing and analyzing vastly dissimilar psychomotor tasks? Is it sophisticated psychology to compare the speed of
running with that of walking, or the ability to add in one's head with that of adding on a machine calculator, or the skill of playing a piano with that of operating a phonograph? I think that most psychologists would agree that, although these kinds of comparisons might be relevant to systems design, they are not quite the stuff out of which conventional psychology is made. Likewise, many would no doubt agree that the contaminated variables of systems research are to be avoided whenever possible in psychological investigations. Some might even go so far as to put the two together and suggest that the time spent by psychologists in evaluating systems is a dead loss to the science of psychology. Of such a view we will have more to say shortly.

ENGINEERING PROPERTIES OF THE MAN

The third and final way in which psychologists help in the design of machines is through studying, by conventional means, the behavior of the man as a machine operator. Although, as has just been remarked, psychologists have not yet quite brought themselves to making systematically the gross comparisons required by the system designers, they have undertaken to study selected aspects of the behavior of the man as a system component. The intent here is to provide the engineers or the technologically oriented psychologists with information concerning certain of the characteristics of the man in order that the properties of the machine may be made to harmonize with them.

In contrast to the other two types of assistance furnished, this is precisely what psychologists would be expected to do. Furthermore, with the exception of some experiments on displays and controls which are actually masked systems tests employing confounded variables, the psychology is both satisfying and sanitary. The preponderance of the work is unambiguously directed toward discovering laws of human behavior, and it is as scientific as ever one could wish.

However, although the work in this domain of engineering psychology is every bit as respectable as that of the parent subject, it is far more limited. Whereas psychology in the generic sense embraces all manner of human action, engineering psychology deals with a much more restricted variety of behavior. This class of responses may be characterized in a number of different ways:

1. First off, as was pointed out at the very beginning, the human in a man-machine system can be considered as an information transmission and processing link between the displays and the controls of the machine. When so viewed, his behavior consists of reading off information, transforming it mentally, and emitting it as action on the controls. Thus, the performance may be described as of the type in which the operator's responses image in some way the pattern or sequence of certain of the input events. For example, the judgments of a tone comes on and withholds his response when he hears nothing, or he presses one key when he sees a red light and a different key when he sees a green one, he perceives the range and bearing of a radar target and identifies its location verbally, he moves a cursor to follow the motion of a target image. In all these cases, the essential interest in the behavior focuses upon the correlation in space and time between events in a restricted and predefined stimulus “space” and corresponding events in a preselected response “space.”

2. Another way to characterize the behaviors studied in engineering psychology is to indicate that they are voluntary and task-directed or purposeful. The operator of a man-machine system is always consciously trying to perform some task. Perhaps it is to follow on a keyboard the successive spatial positions of a signal light, perhaps to see a visual target imbedded in “noise” and to signal its position, possibly it is to watch a bank of displays in order to determine malfunction and to take action where necessary. In all cases, the operator is voluntarily trying to accomplish something specific; he is not just free associating, or living.

3. A third characteristic of the human operator's behavior emerges as a corollary of voluntary control. The class of human responses of interest to the engineering psychologist involves chiefly the striate muscles. Because it is through the action of this type of effector that men speak and apply force to levers and handwheels, it is these muscles which play the dominant role in the human's control of machines.

4. Finally, practical considerations dictate that vision and audition be the sense modalities most often supplying the input to the human transmission channel. Because of the nature and location of the eyes and ears and because of their high informational capacity, they are ideal noncontact
transducers for signal energies emitted by the mechanical or electronic displays of machines.

These four characteristics define the human reactions investigated in engineering psychology as falling within the narrow confines of the classical category of “sensorimotor” or “psychomotor” behavior. But actually, the subject matter is even more limited than this. As was mentioned earlier, the main task of the psychologist-human engineer is to provide system-relevant facts concerning human behavior, and it must be emphasized that not all facts, even though they concern psychomotor performance, can meet this criterion. The hundreds of studies conducted with the pursuit-rotor, for example, have generated very few facts having the remotest relation to the design of systems.

Because it is recognized that not all good sensorimotor psychology is necessarily good engineering psychology, steps are being taken to get at the kinds of behavioral information which the engineers really need. In order to do this, the concepts and models of orthodox psychology are beginning to be replaced by physical and mathematical constructs and engineering models. We have already encountered the notion of the man as an information channel. Systems psychologists also view him as a multipurpose computer and as a feedback control system. The virtue of these engineering models is that they furnish ready-made a mathematics which has already proved itself of value when applied to the inanimate portions of the man-machine system and which may turn out to be useful for the human element as well. In addition, they provide the behavioral scientist with a new set of system-inspired hypothetical constructs and concepts which may redirect his research and stimulate entirely novel lines of inquiry.

Whereas orthodox psychomotor psychology still speaks in a construct language consisting of terms like stimulus, response, sensation, perception, attention, anticipation, and expectancy, the new “hardware” school is rapidly developing a concept argot which, although quite unintelligible to outsiders, is providing considerable inspiration to the initiates. Human behavior for this psychological avant-garde is a matter of inputs, outputs, storage, coding, transfer functions, and bandpass.

And this is far more than a matter of language. The research itself is changing. Questions about human behavior are now being asked experimen-

tally which were literally inconceivable a few years ago. Yet they are the very questions to which engineers desire answers. How stationary and linear is the man? What frequencies can he pass and how many bits per second can he transmit under a variety of different conditions? How does the human’s gain change with different system dynamics? How well can he perform as a single integrator, or double integrator, or triple integrator? How effectively can he act as the surrogate for different computer functions? These are some of the experimental questions which engineering psychologists are beginning to ask and which, no doubt, will be asked with increasing frequency as the new field develops.

It is probably not too much to expect that one day soon we will have a completely revised textbook of human engineering, perhaps entitled *The Engineering Properties of the Man*, which will present to engineers in a form which is useful to them the system-relevant facts of psychology as then known. Instead of conventional chapter headings like “Seeing,” “Hearing,” “Speaking,” “Moving,” and “Working,” it might contain such rubrics as “Mechanical Properties of the Man,” “Transduction,” “Informational Capacity and Bandwidth,” “Linear Properties of the Man” (including analogue addition, integration, differentiation, and multiplication by constants), and “Nonlinear Properties of the Man” (including, it must be confessed, most everything else). Such a treatise, when it is written, will certainly be welcomed by the system designer, and he will waste no time in putting the information to use. Its reception by the orthodox psychologist, however, is somewhat more unpredictable, and it is conceivable that he will consider it, and the research programs which fed into it, more in the nature of an esoteric horror than a blessing. Certainly it must be expected that this “brave new world” of mechanomorphic psychology will, at least at first, be as limited in its appeal as it is in its coverage.

**ENGINEERING PSYCHOLOGY AND SCIENCE**

We have now had a look at the three ways in which psychologists contribute to the design of machines. We have seen that they act not only as scientists, seeking knowledge for others to use, but also as technologists, actively participating in the planning and design of man-operated mechanisms. In playing the latter role, they have clearly stepped
out of their field and entered that of engineering. Even as scientists they seem to have moved away from psychology as classically conceived, for on the one hand they have expanded their subject matter to include the behavior of systems, while on the other they have restricted their interest in human performance to a narrow class of system-relevant psychomotor behaviors.

Must we conclude, therefore, that human engineering, in serving the system designer, will only draw from psychology and not contribute to it? Such might seem to follow from what has gone before, but such a conclusion is almost diametrically opposed to the one which will now be offered. I should like to suggest that the involvement of psychologists in the design of man-machine systems is one of the most important events that has occurred in psychology. I believe that, when psychologists started tinkering with machines and seriously trying to learn how they could better be designed, an opportunity was provided for something to happen of utmost significance to science. And I think it has already begun to happen. This is the destruction of the barrier which has hitherto existed between the psychological sciences and the physical sciences.

Psychologists have conventionally thought and talked in a construct language which is different from that of physics. Traditionally the concepts of psychology tend to be relatively imprecise. At first, this indefiniteness was regarded as almost a necessity; for while physics dealt with physical things, psychology dealt with the mind, and of course the mind was nonobjective. Then later, the mind was abolished, and psychology became anthropomony, the science of human behavior, and there was less excuse for metaphor. Yet metaphor is with us still, although officially outlawed and in disgrace.

But even when similes are avoided and the concepts are given precise operational definitions, the construct language of psychology is very different from that employed in the physical sciences. First of all, the vocabularies are as dissimilar as are those of English and German. Secondly and more important, the constructs themselves often differ in the nature of their generality, elegance, and fruitfulness, with those of physics far in the lead. Although psychologists have become more scientific in their instrumental procedures, using better and better research tools and employing statistics of ever-increasing power, they are still working with pretty much the same old types of syntactically impoverished concepts. Today we conceptualize the man as doing the kinds of things which he and other creatures with minds have always done: like perceiving, thinking, learning, forgetting, living, and dying. This has tended to result in a perseverative replowing of the same ground, a redoing of the same experiments.

Since psychologists have not conceived of the living organism as an analogue device capable of imitating a wide variety of mathematically describable physical operations, no construct terms have been added to the vocabulary of psychology which overlap directly with those of physics or engineering. Because of this, there has never been any real possibility of describing the behavior of both the man and of the physical objects and events in his environment in the same terms. The language of psychology had to be used to describe the behavior of the man; the language of physics, the environment. Of course, never before was there a need to develop a scientific notation in which one could express with equal facility the operation of minds and the working of mechanisms.

But that need has now arisen. The advent of human engineering—when psychologists for the first time began to look carefully at mechanical and electronic processes and engineers started to consider seriously the characteristics of human behavior—brought the problem into sudden, clear focus. One just could not effectively design complexes embodying both men and machines so long as the two components were conceptualized as being entirely different and behaviorally unrelated. Universal concepts applicable equally to humans or mechanisms were needed. A meta-language of action became a necessity!

The emergence of the systems viewpoint was essential to this important, although simple, intellectual discovery. It made two things obvious for the first time. It drew attention to the fact that in many circumstances the behavior of the man was inseparably confounded with that of the mechanical portions of his environment. This meant that psychologists often could not study human behavior apart from that of the physical and inanimate world—that all along they had been studying the behavior of man-environment systems and not that of the men alone. The inseparability of the behavior of living organisms from that of the physical
environment with which they are in dynamic interaction certainly argues against maintaining separate sciences and construct languages: one for the environment, the other for that which is environed.

But the concept of the man-machine system does more than this. Not only does it emphasize the dynamic inextricability of the man and the machine with which he works, it suggests that human and mechanical processes are to some extent inter-changeable, although not necessarily equally precise. Thus, the system designer has the choice of having required computations performed by a mechanical computer or by the man—the process is the same in either case, although the accuracy may be vastly different. Again, this recognition that human behavior and mechanical or electronic processes can be surrogates for each other provides an excellent reason for seeking to conceptualize men and machines in terms of the same models.

Engineering psychology has begun to do this as we have already seen. It is beginning to adopt engineering techniques, to ask experimentally how well men can differentiate or integrate or amplify, how their gains change or their frequency response characteristics shift. It is starting to apply to human behavior the trans-science concepts and methods of information theory and feedback servo analysis. It has begun to use cybernetics, not just talk about it.

In short, in starting to contribute to the design of machines, psychologists have begun theoretically and pragmatically to pull together the psychological and physical sciences. Just how far they can be moved toward one another at the concept level has yet to be seen. Certainly today there are no physical or engineering models which are sufficiently complex to be used profitably with any but the most primitive of human behaviors. But, then, there are no models of any type, hardware or software, which are satisfactory.

One can only look at what has already been accomplished, apply his own hunches and prejudices, take a deep breath, and guess. My guess is that psychology, biology, and physics will some day all employ the same physics-mathematical meta-language when describing the behavior of those particular system components which fall within their purview. Furthermore, should this ever come about, it will have resulted, at least in part, from the efforts of psychologists to design machines.

REFERENCE
