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Human Factors and Behavioral Science:

Introduction

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Human factors and its parent discipline, behavioral science, help us understand human capacities, interests, and needs. This understanding is especially important now, because modern technology makes unusual demands on its users. Knowledge and techniques derived from the behavioral sciences can help identify and design new products. This paper discusses the background and roles of the behavioral sciences, and it summarizes the contents of this issue.

This special issue of *The Bell System Technical Journal* presents a sample of recent activities of the behavioral science and human factors community at Bell Laboratories. Articles were drawn from several areas to give the reader an idea of the ways behavioral science and human factors contribute to the work at Bell Laboratories and, now, American Bell, a new subsidiary of AT&T.

This issue is intended for three groups of readers. First, behavioral scientists should gain a perspective of how their discipline is used in our Company. Second, members of the engineering and technical community who read this journal will see how behavioral science and human factors can contribute to the best use of technical innovation. The third audience this volume serves is the growing population of students who might find work in the field to be as interesting and challenging as we have.

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I. HUMAN USES FOR NEW TECHNOLOGY

We are now in a qualitatively new era of invention. Throughout history, imaginative people have known what they would like to do, but they have not had the means to do it. They wanted to fly, to communicate with each other from afar, to be entertained easily, and to have knowledge at their fingertips. Until now, reality has lagged behind imagination. Today, inventions such as the transistor, the laser, and large-scale circuit integration have reduced the gap between what we can imagine and what we can do. The future seems unlimited; but we face a new problem—how to make wise choices among unlimited opportunities.

Choices between alternative designs of a product have always reflected trade-offs among technical feasibility, cost, and utility to the user. But new technology has increased engineering flexibility and lowered the cost of components until the balance among these trade-offs has shifted dramatically toward the needs and desires of the user. Ways of designing a product to best fit users' interests can now be addressed as never before.

Word processing is a vivid example of this shift. When Christopher Sholes and his associates designed the typewriter a little over 100 years ago, even a slow operator would tie up the keys. Since faster machine action wasn't possible, Sholes' answer was to spread the high-use keys far apart in the key basket, which in turn forced a keyboard arrangement that is less than optimal for the user.[1] In contrast, it is not surprising to anyone now that a computer-based word processing system can keep up with a dextrous typist entering text from a keyboard. The machine can even operate on the text between key strokes. Such processing systems can instruct new users, provide page- or line-oriented editors, and format output according to users' needs. Computer-based text handling can thus be "user friendly"; it can allow the novice typist to substitute rudimentary knowledge of a set of computer programs for the psychomotor skills of an advanced typist. The balance is seen to have shifted even further toward the user when we consider the computer language analysis techniques described later in this issue (see the articles by Frase,[2] Macdonald,[3] and Gingrich[4]).

As human issues become more central to design, pressure increases to provide a technology of invention, design, and evaluation for human use. This technology is the focus of human factors or human performance engineering. It is an application of behavioral science concerned with the design of machines and procedures for human use. Bell Laboratories established the first industrial human factors laboratory in the late 1940s under the direction of John E. Karlin. Examples of early work include all-number-dialing studies, design of better dial layout, and development of objective preference methods. (Hanson[5] provides a history of human factors work at Bell Laboratories in this issue.) The need for this work has increased, and participation of human factors specialists has grown explosively in recent years. For example, the number of people with primary work assignments in human factors or behavioral science has tripled in the last decade, from a starting point of about 100 workers. Many of these people recently joined American Bell, a new subsidiary of AT&T, which designs and markets enhanced services and equipment such as telephones and PBXs. Human factors specialists are now involved in virtually every Bell Laboratories and American Bell development having an important human performance component.

Even so, the potential for the applied behavioral sciences has only begun to be realized, partially because technology has just begun to challenge our ability to imagine new applications, and partially because the contribution of behavioral and related sciences has been difficult to foresee. This volume shows, by example, the contribution of behavioral science to an understanding of human perceptual, cognitive, and motor behavior, and how human factors applies this understanding to the design of new products.

Today, we are not only faced with choices between alternative designs, we must also decide what *should* be designed. This is the hardest question. Currently, we have technologies searching for applications, and new computer applications increasingly resemble intelligent, almost human, actions. Hence, an active role for behavioral science in planning these applications is crucial.

II. BEHAVIORAL SCIENCE RESOURCES

Most of the people doing applied and basic behavioral science research at Bell Laboratories and American Bell have been trained as experimental psychologists. Not many have degrees in human factors, because until recently there have been few programs in the field. In the past fifteen years, psychological research on learning and perception has broadened to include cognitive psychology, which studies thinking, language, and other aspects of information processing. Psychologists are well acquainted with sensory and central nervous system limits on human information handling, through studies of thought processes, linguistic and problem-solving skills, learning and forgetting, social communication, perceptual motor skills, and strength and endurance. Psychologists are also trained in experimental design, statistics, and the measurement of human performance, attitudes, preferences, and motivation.

Behavioral science work in Bell Laboratories has been differentiated mainly by its intent and the clientele that uses it. Basic research has been directed more at understanding the processes underlying behavior, while applied research, emanating from human factors groups, has been associated with designing specific products to meet the needs, interests, and performance capabilities of its users. If research and applications specialists were to collaborate on a study, the measures taken of a person's performance—for instance, reaction time to red or green lights—would be of equal interest to both, but would have been collected for different reasons. For research, we would interpret these measures as a reflection of some underlying process, while for applications we would see the behavior as a fact to be reckoned with in product design. For example, Pierce and Karlin[6] found that reading rate is independent of the number of alternative words on a list of fixed length. The researcher might interpret this result as a reflection of channel capacity of humans as information processors. The applications designer might find the invariance of reading rates important for determining transmission requirements for a speech communication system.

In basic research, we attempt to structure work to provide generality beyond the experimental conditions under which data were collected. Researchers routinely publish work, which is read by other researchers, academics, students, and their colleagues. Applied research, on the other hand, often requires team cooperation, and people are responsible to others for providing information needed to complete a design. Although information gathered is often private and is generally collected to answer questions about the product being designed, data collected in one application often find good use in other applications (see McCormick[7] and Woodson[8]). Applied work has sometimes been seen by some as just the use, refinement, and dissemination of existing methods, rather than the invention and development of tools that generalize across tasks. This is wrong. Many behavioral concepts and techniques, important to theory as well as application, have arisen from practical problems. Aptitude testing and the measurement of human channel capacity are only two examples.

The role of basic research in Bell Laboratories in the study of psychological processes is well known to the outside world through research published over the last 20 years. Hanson[5] briefly summarizes highlights of that work in this volume. An example of applied work completes this section.

The human factors specialist contributes to product design at each stage in product development. One trade-off of particular concern is the extent to which the operation of a product can be made self-evident and require only minimal user training. Training can represent a substantial investment for a new electronic telephone system being installed in a large business having hundreds or thousands of users. The number and range of features available to each user mean that even a well-designed system will have to be carefully explained.

Dooling and Klemmer[9] have described work conducted on training procedures for business telephone users. The problem was that, although customers were happy with their systems, they wanted more training. But telephone companies found that two-hour training sessions, run with small groups of users, were too expensive. The results of several studies led to a more efficient training package that required only one hour of training time. The highlights of these studies are as follows.

Originally, participants in a session were trained in the detailed operation of as many as a dozen features in the two-hour session. More information was being presented than many participants could absorb. Testing showed that a card summarizing the operation of the features was a powerful performance aid. Consequently, training people to use the card replaced much of the detailed explanation and contributed to a reduction in training time. Learning to use telephone features is a cognitive task with only a minor motor component. If it is not a difficult manual task is it necessary to give hands-on experience? A set of laboratory and field studies showed that working the features on the telephone in the session did not significantly aid user performance. Here was a way to further shorten the training session, by eliminating unnecessary activities. Finally, self-instruction was found to be as effective as the group sessions both in laboratory experiments and in field studies. Thus, it was not crucial for all users to attend the training sessions.

Human factors specialists contributed here by proposing alternative training schemes based on what they knew about training and the ways people learn efficiently. They then devised studies and gathered data on the efficiency of those alternatives. Providing recommendations from theory alone would not have been enough to convince either the human factors people or telephone company management to use new procedures.

The skills of behavioral science personnel are critical now. Throughout the computer industry, much is said about "user-friendly" systems, yet in few places are the tools of behavioral science well understood, much less effectively applied. Computers are no longer just science and engineering tools; they are used every day at work, at school, and at home. Computers are for everyone, and for the Bell System this means finding new ways to relate technology to human needs and abilities.

III. STRUCTURE AND THEMES OF THIS SPECIAL ISSUE

This issue is divided into five sections. The "History and Methods" section describes the growth of human factors work at Bell Laboratories and techniques that have been used to study human response to communications products. Hanson's paper reviews human factors history, while Eigen's paper describes field test methods. Many techniques are used by behavioral scientists, of which field testing is only one. However, Eigen's paper gives an overview of one traditional use for human factors work—i.e., to evaluate products created by communications engineers.

The second section, "Characteristics of Human Performance," describes fundamental properties of human perception and performance. Julesz' and Bergen's paper describes mechanisms of visual perception, concentrating on the perception of texture. The paper by Rosenbaum explains how people control the timing of finger movements, and this may, in the future, help us understand how better to design keyboards and other control devices and tools. The final two papers in this section address higher-level cognitive processes. The paper by Cleveland, Harris, and McGill describes studies of how people derive information from graphic displays, while the paper by Egan explores how people reason when solving verbal problems. In particular, Egan shows that people can be trained to think in new ways, using strategies they normally do not use. These papers provide context for understanding possible limits and potentials for human adaptation to new technology.

The third section, "New Technological Demands," includes papers that deal with the unusual requirements that modern technology places on us. The paper by Donegan and Koppes introduces the three papers that follow it; their introduction emphasizes the wide variety of skills and characteristics that are needed by the craft personnel who install, maintain, and repair telecommunications equipment. The paper by Kohl describes work on the design of shapes to improve handling physical objects, the paper by Paul describes improved designs for splicing connectors, and the final paper in this trilogy, by Flamm, describes connecting-block design changes that reduce errors often made with complex apparatus. Following these papers, the article by Cohen moves on to the design of keyboards and people's ability to use new technology, such as membrane keyboards. Thus, papers in this section progress from simple to more complex performance.

The fourth section, "Interface Design," expands the theme of verbal interactions demanded by new technology. The paper by Furnas, Landauer, Gomez, and Dumais explores alternate ways to design key words to ease people's interactions with computers. The paper by Streeter, Ackroff, and Taylor extends this concern to the design of abbreviations for command names. The theme of human interactions involving verbal information is carried forward in the paper by Karhan, Riley, and Schoeffler, as they describe the design of telephone cards to provide easy access to dialing information people need when phoning. This theme is extended in the paper by Coke and Koether, which explores the match between people's ability to read and the reading demands placed on them by the language of telecommunications documents. The final paper, by Holmgren, shows that technology, too, has limits, and that proper adaptation of humans to the limited speech of machines can make it possible for machines to understand what humans say.

The fifth and final section of this issue, "New Functions for Technology," is an example of bringing behavioral science to bear on the design of new products. The papers in this section, by Frase, Macdonald, and Gingrich, describe the *UNIX* Writer's Workbench software, a set of programs that do many things editors do when they proofread and comment on various features of written material. This section exemplifies the issue raised at the start of this introduction; we have the technology, we understand the physical principles needed to design new electronic tools; we have the engineering skills to build those tools, and we have the computing techniques to program them. But we need a behavioral perspective to know where human minds falter and need help, and where they excel and are best left alone. Human factors—behavioral science, generally—is an essential resource in this new era of communication design.

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REFERENCES

1. C. Leckberg, "The Tyranny of Qwerty," Saturday Review, *55*, No. 40 (September 1972), pp. 37–40.
2. L. T. Frase, "*UNIX*™ Writer's Workbench Software: Philosophy," B.S.T.J., this issue.
3. N. H. Macdonald, "The *UNIX*™ Writer's Workbench Software: Rationale and Design," B.S.T.J., this issue.

4. P. S. Gingrich, "The *UNIX*™ Writer's Workbench Software: Results of a Field Study," B.S.T.J., this issue.
5. B. L. Hanson, "A Brief History of Applied Behavioral Science at Bell Laboratories," B.S.T.J., this issue.
6. J. R. Pierce and J. E. Karlin, "Reading Rates and the Information Rate of a Human Channel," B.S.T.J., *36* (March 1957), pp. 497–516.
7. E. J. McCormick, *Human Factors in Engineering and Design*, 4th ed., New York: McGraw-Hill, 1976.
8. W. E. Woodson, *Human Factors Design Handbook*, New York: McGraw-Hill, 1981.
9. D. J. Dooling and E. T. Klemmer, "New Technology for Business Telephone Users: Some Findings from Human Factors Studies," in *Information Technology and Psychology: Prospects for the Future* (edited by R. A. Kasschau, et al.), New York: Praeger Publishers, 1982, pp. 148–65.

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