Designing for People

Whether it is the car you drive or the app on your smartphone, technology has an increasingly powerful influence on you. When designed with people in mind, this influence can improve lives and productivity. This book provides a broad introduction on how to attend to the needs, capabilities, and preferences of people in the design process. We combine methods of design thinking and systems thinking to understand people's needs and evaluate whether those needs are met. This book also provides a detailed description of the capabilities and limits of people—both mental and physical—and how these can guide the design of everything from typography to teams and from data visualization to habits. The book includes:

- Over 70 design principles for displays, controls, human-computer interaction, automation, and workspace layout
- Integrative discussion of the research and theory underlying these guidelines, supported by over 1,000 references
- Examples of successful and unsuccessful designs and exercises that link principles and theory to applications in consumer products, the workplace, and high risk-systems

We hope this book gives a useful introduction to the diverse field of human factors engineering.

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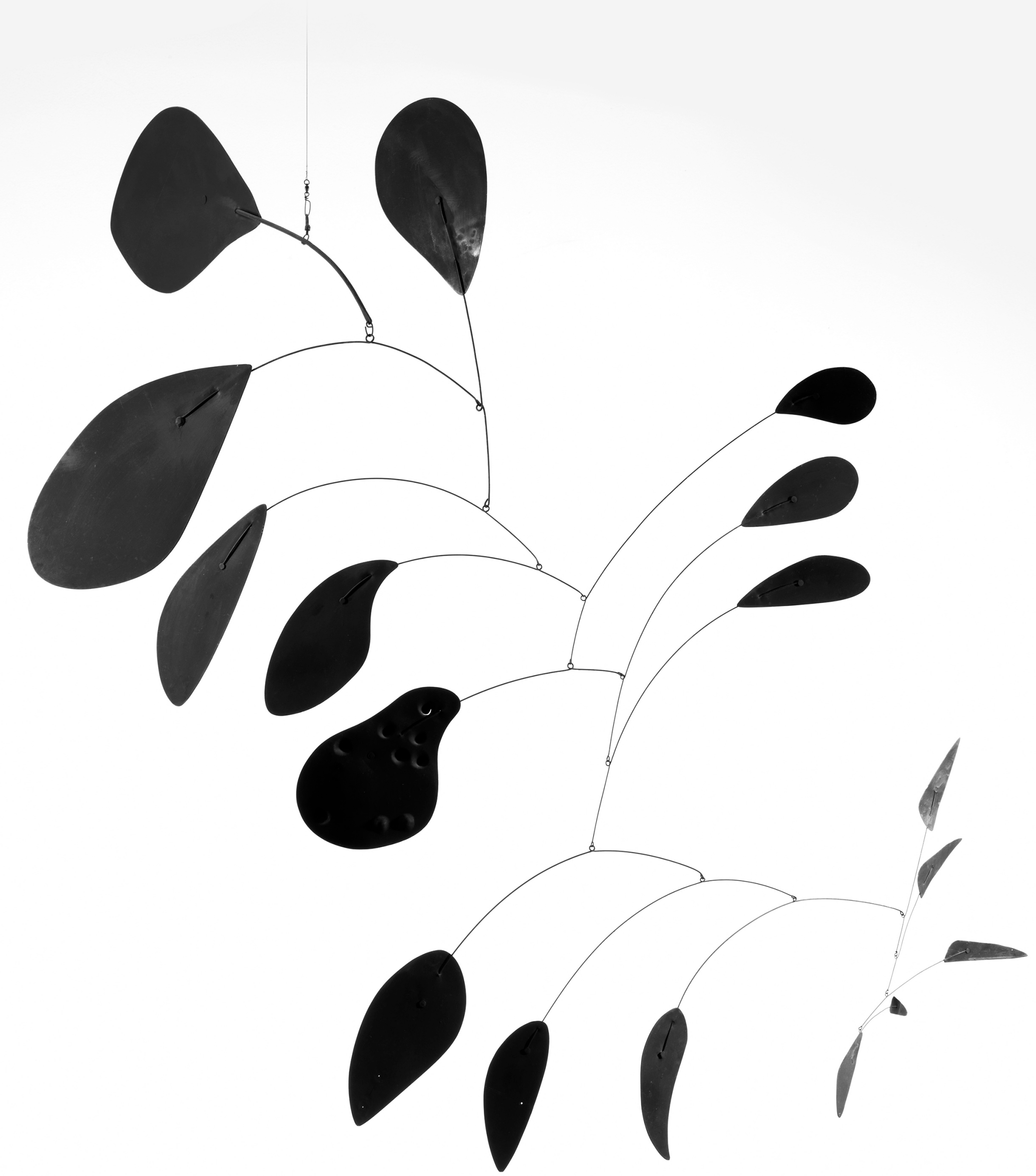
An INTRODUCTION to HUMAN FACTORS ENGINEERING



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Preface

One reason we wrote this book is to help engineers and system designers understand how human strengths and limitations, both mental and physical, affect the success of their designs. This book shows how attending to people can lead to safer, more productive, and more satisfying experiences. The book compiles human factors engineering knowledge and methods to accomplish these goals.

No system that engineers create exists without contact with people, and so our primary audience is the engineering or computer science undergraduate, who will design hardware, software, and processes. Hence, we do not assume that readers will have taken an introductory course in psychology, and so we try to present some of the necessary psychological fundamentals that are relevant to engineering design choices.

We also believe, however, that the book will be useful for applied psychology courses. For psychology students, the book shows how their knowledge of psychological science is relevant to system design. In this way, the book introduces psychology students to the world of engineering. Beyond students, we hope this book will help those assigned human factors engineering work, but who have no formal training in the discipline, and those who want a reference to current literature in the area. Thus we hope the book will not only reach students in both engineering colleges and psychology departments, but will also be a useful reference for those already designing for people.

Intending to meet the needs of these readers, we emphasize design principles and methodologies over theory and research. We illustrate these principles with real-world design examples and show how these principles are based on humans' psychological, biological, and physical characteristics to give the reader an understanding of the science base underlying the principles. Because of our focus on principles, we do not spend much time addressing psychological theory or research paradigms. For those needing a deeper understanding of the science behind the principles we provide citations for the underlying research—approximately 70 citations per chapter.

Structuring the book was a design challenge, and the result is far from perfect. In the spirit of iterative design, we used a beta version to solicit feedback from students. This feedback led to many small and large changes. Each chapter now has a mini table of contents to orient readers to the contents of each chapter. The book has a sidebar, which makes it possible to reduce the distance between the figures and the associated text (see Chapter 8 on display design). The sidebar also makes it possible to include additional examples and highlight important points. We did not address all comments. Students often complain about references to related chapters, saying that they are distracting, but research says that the effort in thinking about connections to other chapters leads to more robust learning (see Chapter 6 on cognition).

To an engineer, good enough means perfect. With an artist, there's no such thing as perfect. (A. Calder)

Capturing all the information relevant to human factors engineering greatly exceeds the scope of an introductory textbook. We do not expect that this will be a stand-alone reference manual for applying human factors in design. Many specific numbers variables, formulae, were not included in this text in the interest of space. However, we point to sources at that end of each chapter that include these details.

Overall, we believe that the strengths of the book lie in its relatively intuitive and readable style. We hope to have illustrated principles clearly, with examples and without excessive detail.

New technology is rapidly changing the design landscape. Automation is becoming more capable, voice controls are enabling conversations with computers, and augmented reality is changing how we view the world. In some ways the book will be outdated the day it is published, but the basic concepts remain relevant. With this in mind, we tried to strike a balance between presenting information associated with different aspects of human performance on one hand (e.g., physical limitation, visual performance, and memory failures) and particularly important domains of application, such as human-computer interaction and automation design.

Some may wonder about the image on the cover. It is a photograph of a mobile by Alexander Calder, the creator of that art form. His mobile was chosen for several reasons. Calder was a mechanical engineer and an artist and so embodies the intersection of technology and the arts that typifies the field of human factors engineering. His work highlights the importance of considering aesthetics in design. More importantly, his work shows the interconnections between elements of a system. Touch one element of the mobile and the others move in complex ways. The intricate tradeoffs and balances that must be considered in crafting a mobile must also be considered in crafting systems to work with people. Finally, a recent review of Calder's work claimed he might have garnered greater respect if his work had not been so approachable; his work was too "user friendly." We hope this cover will inspire you to create similarly user friendly designs that focus on the user and not the technology.

In closing, we want your feedback. If you see omissions, mistakes, or opportunities for improvement, please contact us and share your suggestions.

No book is created only by the authors listed on the cover. Special thanks to Xiaoxia Lu for her help creating figures and to Hyo-Jeong Kang for designing the cover. We also enjoyed the benefit of many people who reviewed earlier drafts of this book. We thank all of the following for their helpful comments.

Your experience reading this book was greatly improved by the comments of the following people.

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R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https:// www. R-project.org/.

Contents

Chapter 1

Introduction

At the end of this chapter you will be able to...

1. prioritize the human factors design goals for high-risk systems, the workplace, and consumer products
2. describe how the understand, create, and evaluate elements of the human factors design cycle address the cognitive, physical, and organizational aspects of design
3. discuss the order of application of the six general human factors interventions that is typically most effective
4. explain the scope of human factors engineering in terms of application domains, interventions, and related disciplines
5. explain why technology that doesn't work for people doesn't work
6. explain why intuition is insufficient in designing for people

Figure 1.1 Moving pig iron at a Coltness Iron factory similar to Bethlehem Steel. Source: Coltness Iron Co. [1]

As a new manager at Bethlehem Steel, Fred Taylor was confronted with a problem: how to move pig iron out of storage faster (Figure 1.1). Taylor studied workers moving pig iron in detail, recording the time required for each motion and the amount of effort people could expend over the day. This detailed study made it possible to select the one in eight workers suited to the task and to specify the rest periods needed for the workers' muscles to recover. Enforcing these rest cycles improved capacity well beyond the rest periods that workers had chosen for themselves. By identifying the one best way to move pig iron, Taylor increased the amount of iron a worker could move from an average of 12.5 tons per day to 47 tons per day [1].

A B-25 C fully loaded with bombs and fuel was taking off from a 2500-foot runway. The pilots recounted: "We crossed the end of the runway at an altitude of 2 feet and were pulling up over the trees shortly ahead when I gave the wheels up signal. The airplane mushed and continued to brush the tree tops at a constant 125 mph speed with T.O. [Take Off] power." The co-pilot had pulled up the flaps instead of the wheels, almost causing a deadly crash. Paul Fitts and Richard Jones reviewed 460 such mishaps to identify design changes to prevent future mishaps, saving thousands of lives [2].

In 2007, Apple debuted a revolutionary design when it released the iPhone to compete with an already crowded market dominated by Blackberry. How did Blackberry go from having almost half of the smartphone market in 2010 to less than 1% in 2015? "By all rights the product should have failed, but it did not," said David Yach, [Research in Motion] RIM's chief technology officer. To Mr. Yach and other senior RIM executives, Apple changed the competitive landscape by shifting the raison d'être of smartphones from something that was functional to a product that was beautiful. 'I learned that beauty matters....RIM was caught incredulous that people wanted to buy this thing,' Mr. Yach says [3]." Blackberry ceased production in 2016, and Apple transformed the smartphone market with an intense focus on designing a beautiful product that provided an integrated experience.

1.1 What is Human Factors Engineering?

Human Factors Engineering makes technology work for people.

Human factors engineering aims to make technology work for people. This aim is very broad as shown by the three vignettes at the beginning of the chapter. These three vignettes also highlight the history of the field, with early developments focused on improving workplace productivity and efficiency. Taylor, the father of *"Scientific Management,"* introduced time studies and the scientific study of work in the early 1900s. He focused on increasing productivity, but not safety or satisfaction. During the Second World War more pilots died because of human error, as in the second vignette, than died in combat. Fitts and Jones studied these errors and identified the importance of designing for safe operations, which accelerated the growth of human factors engineering, and the field's role in the

Department of Defense and NASA. Blackberry's downfall underscores the importance of user satisfaction. The Apple design team demonstrated the importance of making products aesthetically pleasing and usable. The advent of the graphical user interface and the Internet have made computers a part of billions of lives and the value of creating products that satisfy and delight has become central to the success of many companies. The historical development of human factors engineering shows the importance of considering people in design and how neglecting human involvement invites disaster.

At 9:30 AM, the morning of July 5, 2006, a patient suffering from a strep infection arrived at St Mary's hospital in Madison, Wisconsin to deliver her baby. The patient was concerned about pain during delivery and so the nurse retrieved a bag of epidural pain medication from the dispensary down the hall. Epidural pain medication must be delivered to the space between the spine and the spinal cord, and is deadly if delivered into the bloodstream. As the nurse returned to the patient's room, another nurse handed her a bag of intravenous penicillin to treat the patient's strep infection. She connected the bag to the infusion pump, which began the flow of medication into the patient. Within minutes, the patient fell into cardiovascular collapse, and despite nearly an hour and a half of resuscitation efforts, the patient died. The nurse had confused similar-looking bags, and was able to connect the intravenous tubing to the epidural bag that allowed the epidural medication to flow through the infusion pump. Factors that contributed to the confusion included production pressure to prepare the room in advance of the anesthesiologist arriving to deliver the epidural medication, 16 hours of work the previous day, and distractions from family members. She was arrested and charged with a felony for her error [4].

While the first three vignettes highlight the positive contributions of human factors engineering, this fourth vignette highlights what can happen when human factors engineering is neglected. These four vignettes show the importance of human factors engineering. All systems include people and meeting their needs is the end goal of engineers and designers—*if a system doesn't work for people, it doesn't work*—human factors engineering makes technology work for people [5]. These vignettes show the benefits of tailoring technology to fit the capabilities and needs of people and how neglecting these considerations can lead to problems. When things go wrong, as in the tragedy at St Mary's hospital, people often call for a diagnosis and solution. Understanding these situations—rather than attributing the cause to human error and blaming the nurse—represents an important contribution of human factors to system design. Human factors engineering can also identify unrecognized needs that can help avoid such mishaps and even delight customers. *Human factors engineering* is a discipline that considers the cognitive, physical, and organizational influences on human behavior to improve human interaction with products and processes.

Human error is a symptom of a poor design.

1.2 Goals and Process of Human Factors Engineering

Human factors engineering improves people's lives by making technology work well for them. Most broadly, human factors engineering aims to improve human interaction with systems by enhancing:

- Safety: Reducing the risk of injury and death
- Performance: Increasing productivity, quality, and efficiency
- Satisfaction: Increasing acceptance, comfort, and well-being

In considering these goals, safety is always a critical concern, but the relative emphasis of each goal depends on the particular area of application: high-risk systems, such as a B787 cockpit; workplace design, such as a manufacturing assembly line; consumer products, such as an iPhone. Design of high-risk systems must focus on *safety*. In contrast, design of workplaces focuses more on *performance*, and design of consumer products focuses more on *satisfaction*. Figure 1.2 shows the relative emphasis of each of these goals for each application area .

There are clearly tradeoffs among these goals: it is not always possible to maximize both safety and performance. For example, performance is an all-encompassing term that may involve increasing the speed of production. Increasing speed may cause people to rush through assembly and inspections, which can lead to more operator errors and undermine safety. As another example, some companies may cut corners on time-consuming safety procedures to meet productivity goals.

Fortunately, good human factors designs can avoid these tradeoffs. Human factors interventions often can satisfy safety, performance, and satisfaction simultaneously. For example, one com-

Figure 1.2 The goals of human factors engineering and application areas. The lengths of the lines indicate the relative emphasis of each human factors goal.

pany that improved its workstation design reduced workers compensation losses from $400,000 to $94,000 [6]. Workers were able to work more (increasing performance), while greatly reducing the risk of injury (increasing safety), and increasing their engagement with work (satisfaction).

The three goals of human factors are accomplished through the human factors design cycle, shown in Figure 1.3. The design cycle begins with understanding the people and system they interact with, proceeds with creating a solution, and completes with evaluating how well the solution achieves the human factors goals. The outcome of this evaluation becomes an input to the cycle because it typically leads to a deeper understanding of what people need and identifies additional opportunities for improvement. Because designs are imperfect and people adapt to designs in unanticipated ways, the design process is iterative, repeating until a satisfactory design emerges, and continues even after the first version is released. This approach embodies the essence of *design thinking*: an empathetic focus on the person, iterative refinement, and integrative thinking that considers many aspects of design problems to arrive at novel solutions [7].

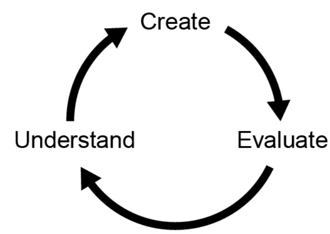

Figure 1.3 Understand, create, evaluate design cycle.

Understanding the people and system includes understanding the opportunities for a new product or process, or problems with existing systems. Most fundamentally, this understanding identifies a need that a design can satisfy. Understanding what people need must be coupled with an understanding of the cognitive, physical, and organizational issues involved. As an example, a human factors engineer would combine an analysis of the events that led up to the tragedy that occurred at St Mary's with an understanding of principles of communication (Chapter 6), decision making (Chapter 7), display design (Chapter 8), and performance degradation under stress (Chapter 15) to provide a more complete understanding of the causes of the St Mary's tragedy and offer recommendations for improvement.

This book contains four sections all focused on designing for people. The first describes methods for understanding people's needs and evaluating whether those needs are met. The following three sections address cognitive, physical, and social considerations in design. Figure 1.4 shows understanding at the start of the process and evaluation at the end. Chapter 2 describes methods for understanding people's needs, such as observation and task analysis. Chapter 3 discusses methods for evaluating systems, such as heuristic evaluation and usability testing. The center of Figure 1.4 shows six human factors design interventions [8]. Using these interventions depends on knowledge of the nature of the mind (its information-processing characteristics), the physical body (its size, shape, and strength),and limitations), and the social interactions as part of teams or larger organizations. The least effective of these design interventions are selection and training: design should fit technology to person rather than fit the person to the technology. In fact, design should strive to accommodate all people.

Consider training and selection after other interventions.

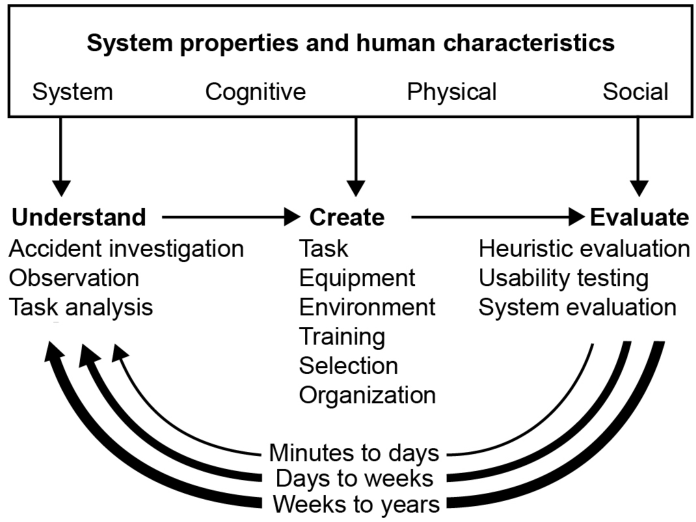

Figure 1.4 The human factors design cycle informed by human cognitive, physical and organizational characteristics and system properties. The process of understanding, creating and evaluating is repeated across days, weeks and years of a system's lifecycle.

Task design focuses more on changing what operators do than on changing the devices they use. A workstation for an assembly-line worker might be redesigned to eliminate manual lifting. Task design may involve assigning part or all of tasks to other workers or to automated components. For example, a robot might be designed to lift the component.

Equipment design changes the physical equipment that people work with. Apple's design of the iPhone hardware and software demonstrates how important a focus on equipment design can be to a product's success. The tubing that allowed the epidural bag to be connected to the intravenous pump in the St Mary's tragedy could be redesigned to prevent medication errors.

Environmental design changes the physical environment where the tasks are carried out. This can include improved lighting, temperature control, and reduced noise. Noise attenuating headsets can improve communication in a noisy cockpit.

Training enhances the knowledge and skills of people by preparing them for the job environment. This includes teaching and practicing the necessary physical or mental skills. Training is most applicable when there will be many repetitions of a task or a long involvement with the job. Periodic training is also important for those tasks that are rare, but where performance is critical, such as fire drills and emergency first aid.

Selection changes the makeup of the team or organization by picking people that are best suited to the job. Just as jobs differ in many ways, people differ from each other along almost every physical and mental dimension. Performance can be improved by selecting operators who have the best set of characteristics for the job. In our opening vignette, Taylor carefully selected the one person in eight that could move hundreds of 92-pound pieces of pig iron each day.

Team and organization design changes how groups of people communicate and relate to each other, and provides a broad view that includes the organizational climate where the work is performed. This might, for example, represent a change in management structure to allow workers more participation in implementing safety programs. Workers are healthier, happier, and more productive if they can control their work, which directly contradicts Taylor's approach of identifying the one best way of doing a task, sometimes known as "Taylorism". We return to this discussion in Chapter 17.

These six human factors design interventions show that design goes well beyond the interface and the objects that people might see and touch. Design includes redefining tasks, interaction, and overall environment. The opening vignette described how the RIM executives belatedly discovered the importance of beauty, but what was not mentioned was the additional value of Apple's *interaction design*, which made it possible for people to "touch" information on the iPhone screen; Apple's organizational design also enabled thousands of people outside Apple to develop apps for the iPhone.

Human Factors design includes the design of the interface, interaction, experience, and organization.

Historically, the role of human factors engineering has often focused on evaluation, such as usability testing, which is performed after the design is complete. This role is consistent with our discussion of fixing problems, such as those associated with St. Mary's hospital. The role of human factors engineering is just as relevant to designing systems that are effective and that avoid problems. Thus, the role of human factors in the design cycle can just as easily enter at the point of understanding people's needs rather than simply evaluating system design. Human factors engineers should be problem solvers as the design develops, not just problem finders and design fixers after the design is complete.

Considering human factors early in the design process can save considerable money and possibly human suffering. For example, early attention to equipment design could have prevented the medication error at St Mary's and many other similar errors that occur daily at other hospitals. The percentage cost to an organization of incorporating human factors in design grows from 1% of the total product cost when human factors is addressed at the earliest stages to more than 12% when human factors is addressed only in response to problems, after a product is in the manufacturing stage [9]. Ideally, the understand, create, and evaluate cycle would focus on early and rapid iterations shown in the center of Figure 1.4, and proceed to usability testing and overall system evaluation only after considerable attention to people's needs and capabilities. In Chapter 2 we talk in detail about the role of human factors in the design process.

Intervention	High-risk Aircraft cockpits, nuclear power plants, cars	Workplace Manufacturing lines, office workstations, cars	Consumer products Websites, games, smartphones, cars
Task Chapters 2, 10, 11	●	●	●
Equipment Chapters 2, 12, 13	●	●	●
Environment Chapters 15, 18	●	●	○
Training Chapter 17	●	◑	○
Selection Chapter 17	●	◑	○
Organization Chapter 18	●	○	○

Table 1.1 This matrix of human factors interventions and application areas where their application is most central (●) moderately central (◑) and less central (○).

1.3 Scope of Human Factors Engineering

Although the field of human factors engineering originally grew out of a fairly narrow concern for human interaction with physical devices (usually military or industrial), its scope has broadened greatly during the last few decades. Human factors engineering is not just concerned about making work more productive and safer, but also with improving the routines of daily life, such as cooking, and making the most out of leisure time.

The range of human factors applications leads to a huge range of career options. Options include working for software and computer companies in positions described as usability engineers or user experience designers. Human factors engineers also work to create safer workplaces in almost every large company by ensuring that offices are configured in an ergonomic fashion and manufacturing processes are safe. Human factors engineers also work for government agencies using human factors research to write regulations and guide industries towards safer and more efficient practices, such as in design of medical devices, cars, roads, tax forms, and aircraft. Human factors engineers also work in consulting and research companies conducting studies to understand how technology affects human behavior .

The priority of human goals and interventions depends on the application area.

Table 1.1 shows one way of understanding the roles of human factors professionals. Across the top of the matrix are major types of systems that human factors engineers aim to improve. Major categories include high-risk environments, the workplace, and consumer products. *High-risk* environments include nuclear power plants, chemical processes, and aircraft cockpits. The *workplace* includes manufacturing plants, customer service, assembly lines, and office work. *Consumer products* include watches, cameras, games, and smartphones. Some products and processes cut across multiple categories, such as cars. Cars are consumer products and so satisfaction is a critical design goal; they are also central for the work of many people, such as taxi drivers, and so performance is an important consideration, and cars are certainly part of a high-risk environment, where mishaps can cause severe injuries and deaths.

As we discussed earlier, these application areas often imply different human factors goals. These application areas also imply different priorities for human factors interventions. For example, selection and training are an important part of high-risk environments like aviation, but not so with most consumer products. The rows of Table 1.1 indicate the human factors approaches and the cells indicate the relative emphasis of the intervention. With consumer products, the focus tends to be the device and task, but with the workplace, environmental design (e.g., lighting and temperature) is more relevant. With high-risk systems, such as aviation, training, selection, and team design are critical; however, good task and equipment design can minimize or eliminate the need for training and selection, and so these human factors approaches should only be considered after the others. Table 1.1 highlights the prominence of equipment and task design—all categories of human factors product and process design should minimize the need for training and selection through careful design.

Lillian Gilbreth (1850-1946) Designer of the modern kitchen and pioneering industrial engineer. "The idea that housework is work now seems like a commonplace. We contract it out to housekeepers, laundromats, cleaning services, takeout places. We divvy it up: You cooked dinner, I'll do the dishes. We count it as a second shift, as well as primary employment. But it wasn't until the early part of the 20th century that first a literature, and then a science, developed about the best way to cook and clean.
The results of Gilbreth's research shape the way we treat housework today and defined our kitchens. She a design pattern for the kitchen (e.g., continuous countertop, built in sink, cabinets under the counter, and the island) that remains conceptually unchanged from the 1920s. [10].
Photo Source: Theodor Hyorydczak. [2]

A second way of looking at the scope of human factors is to consider its relationship to related domains of science and engineering, as shown in Figure 1.5. Items within the figure are placed close to other items to which they are related. The core discipline of human factors is shown at the center of the circle, and immediately surrounding it are various subdomains of study within human factors. Moving from the top to the bottom of this figure implies a shift of emphasis from the individual to team and organization. Moving from the left to the right implies a shift of emphasis from cognitive considerations to physical considerations. The six closely related human factors disciplines are shown as circles within the broad umbrella of human factors. Finally, outside of the circle are other disciplines that are likely to overlap with some aspects of human factors, particularly as members of a design team.

Fields closely related to human factors engineering include engineering psychology, ergonomics, human-systems integration, macroergonomics, cognitive engineering, and human-computer interaction. Historically, the study of ergonomics has focused on the aspect of human factors related to the workplace, particularly physical work: lifting, reaching, stress, and fatigue. This discipline is closely related to aspects of human physiology, hence its proximity to anatomy, physiology and biomedical engineering. Ergonomics has also been the preferred label in Europe to describe all aspects of human factors. However, in practice the domains of human factors and ergonomics have been sufficiently blended so that the distinction is often not maintained.

Engineering psychology is a discipline within psychology, whereas the study of human factors is a discipline within engineering. The distinction is clear: The ultimate goal of the study of human factors is system design, accounting for those factors, psychological and physical, that are properties of the human component. In contrast, the ultimate goal of engineering psychology is to understand the human mind as it relates to design [11].

Cognitive engineering, also closely related to human factors, but focuses on the cognitive considerations, particularly in the context of safety of complex systems, such as nuclear power plant [12, 13]. It focuses on how organizations and individuals manage such systems with the aid of sophisticated displays, decision aids, and automation, which is the focus of Chapters 7 and 11.

Human factors engineering includes cognitive, physical, and organizational considerations.

Macroergonomics, like cognitive engineering, takes complex systems as its focus. Macroergonomics addresses the need to consider not just the details of particular devices or processes, but the need to consider the overall work system. Macroergonomics takes a broad systems perspective and considers the design of teams and organizations, which is the focus of Chapters 16 through 18.

Human-systems integration takes an even broader view and considers how designs must consider how people interact with all systems, to the point of forecasting availability of qualified staff based on demographic trends and training requirements.

Human-computer interaction (HCI) is often linked to the field

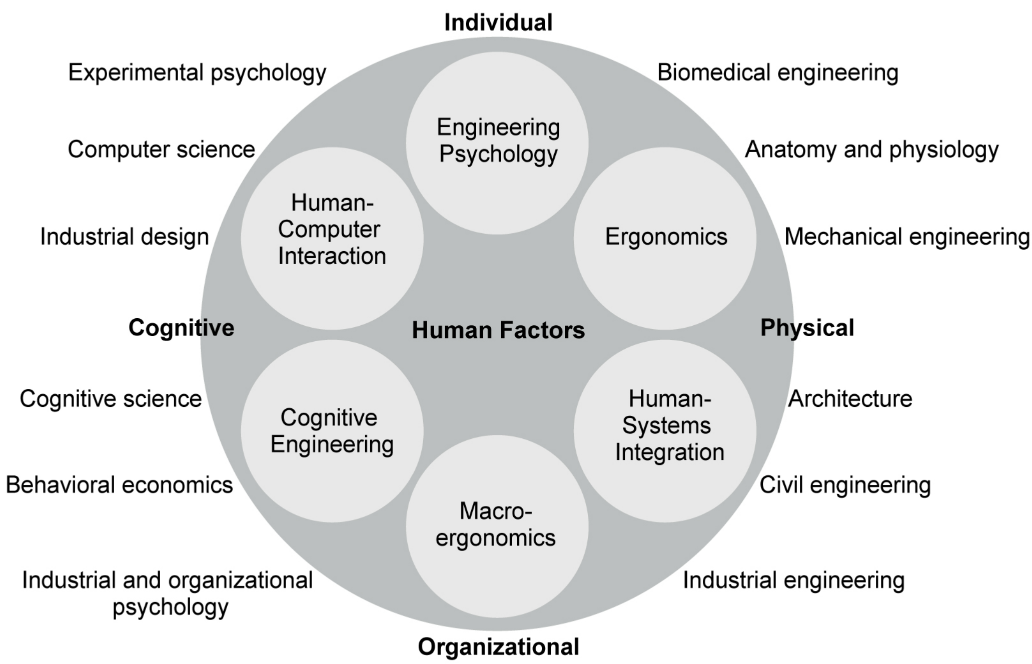

Figure 1.5 The domains of human factors.

of user experience and tends to focus more on software and less on the physical and organizational environment. Computers already touch many aspects of life, and the Internet of things, augmented reality, and wearable computers make it likely that we will soon be in nearly continuous interaction with computers. As a consequence, human-computer interaction and user experience increasingly overlap with other areas of human factors engineering. For example, as computers have been transformed from desktop machines to devices that are held in your hand or worn on your wrist, the physical aspects of reach and touch have become important.

1.4 Systems Thinking

Unlike the behavior of many components of a design, the behavior of people depends on the situation. This dependence makes systems thinking and systems engineering particularly important when designing for people [14]. Here we briefly highlight three elements of systems thinking: interconnection, adaptation, and environment.

Interconnection. Complex systems, such as hospitals and manufacturing plants, have many interconnected elements. Changing one element effects the others. For example, the introduction of sophisticated technology to improve coal mining failed because it did not consider the human side of the mining operation [15]. This failure led to the idea of *joint optimization*, where the focus is on improving the performance of the person *and* the technology, not just making the technology perform better [16]. Improving only the technology does not necessarily improve the performance of the overall system. Technology must work with people.

What is the purpose: As “why” five times to define why the system is being built.

The need to consider interconnections also applies to understanding mishaps. The interconnections of complex systems mean that there is no single cause for most mishaps. For design, the interconnections mean that design requires tradeoffs with many competing objectives and conflicting guidelines. The cover of this book highlights the need to consider such interconnections: touching one element moves the others.

What could go wrong? Ask "what" five times to explore what could happen that might not be expected

Adaptation. Technology often has *unanticipated consequences* that result from people adapting and changing their behavior in response to the technology—adaptation can lead good technology to have bad outcomes. For example, the introduction of the ski-doo to the Skolt-Lapp people in northern Finland would seem to be an unambiguous improvement over skis and sleds. The Skolt-Lapp people embraced the technology and adapted their hunting practices to kill more reindeer to pay for the ski-doos. This adaptation caused a collapse of the reindeer population and was a disaster for the Lapp society [17]. People’s adaption to technology often leads to outcomes the designers do not anticipate—how designers expect people to use a system rarely aligns perfectly with how people actually use it.

Environment. To a surprising degree our surroundings guide our behavior. Central to thinking about the relationship between environment and how it guides behavior is the idea of *affordances*—opportunities for action presented by the environment. Properly specified affordances lead people to effortless behave in an appropriate fashion. For example, pavement markings can slow drivers and the position of food in a restaurant buffet influences what people eat [18]. As a consequence, the following chapters on perception and cognition begin with a discussion of the relevant aspects of the environment as a context for discussing the characteristics of people.

The environment also determines the consequence of behavior. A perfectly good response in one situation could be disastrous in another. This means that good design is contingent on the environment in which the person uses the system [19]. Uncertainty and the changing nature of environments that people and companies find themselves in means that it is rarely possible to follow Taylor's lead and identify the one best way of doing something. Variability of the environment means that designs need to be flexible and support variety of responses. Often engineering solutions that strive to eliminate human error may improve routine performance, but diminish flexibility needed to respond to unusual situations [14]. For example, you might be able to find the optimal route and drive it to work every day. Taking only the optimal might make your commute more efficient, but might make you less resilient; less able to take a different route if your familiar route is closed for construction.

Systems thinking reminds us that any design combines many interacting elements that affect behavior in complex ways. In short, when asked how a person might respond to a particular feature the proper response is: It depends. The rest of this book helps describe what the response depends on.

1.5 Scientific Base of Human Factors Engineering

Using intuition to anticipate user preferences requires that you are representative of all your anticipated users and that you use the product in the same way they will.

Unlike other system components, engineers and designers do not require specialized training to have some intuition for the human component of a design. Everyone knows how people thing because they are people too, or so they think. Unfortunately, this intuition is often based on common sense and life experiences, and is not a solid base for design. Intuitions fail because people are not aware of how their minds and bodies operate: expectations change what people see, attention makes people blind to events that happen right in front of them, and default settings often make decisions for people. Intuition also fails to guide design because designers often differ substantially from end users: they have different needs, priorities, and preferences. Designers might also have a deep familiarity with technology, such as a computer mouse, which leads to *learned intuition* that might not be shared by those unfamiliar with computer technology, such as an 85-year-old who has never used a computer. Even if designers can sense people's preferences, it might not lead to the best design because what people prefer does not always produce the best performance. The science of human factors engineering addresses the limits of intuition and provides a solid basis for design.

Intuition is often a poor guide for design.

The scientific base of human factors engineering also makes it possible to link human characteristics to engineering specifications. How bright lighting needs to be for efficient reading?, how loud alarms need to be to capture attention?, and how much a person can safely lift?. Answers to these and many other questions have been quantified to guide design in a way that intuition cannot. This quantification is one instance of the more general ability of the human factors science base to support design [20]. In the problem understanding phase, investigators wish to *generalize* across classes of problems that may have common elements. As an example, the problems of communications between an air traffic control center and the aircraft may have the same elements as the communications problems between workers on a noisy factory floor or between doctors and nurses in an emergency room, thus enabling similar solutions to be applied to all three cases. Such generalization is more effective when it is based on a deep understanding of the physical and mental components of the human operator. It also is important to be able to *predict* that solutions designed to address good human factors issues will actually succeed when put into practice.

1.6 Overview of the Book

The forthcoming chapters are divided into four sections .

1. Design and evaluation methods are covered in Chapters 2 and 3, respectively.
2. Cognitive characteristics of people and their implications for design: visual and auditory and other sensory systems (Chapters 4 and 5), cognition (Chapter 6), macrocognition and decision making (Chapter 7), application to display (Chapter 8), and control design (Chapter 9). This section also addresses human computer interaction (Chapter 10) and automation (Chapter 11).
3. Physical characteristics of people and their implications for design: anthropometry and workspace layout (Chapter 12), biomechanics and materials handling (Chapter 13), physiology (Chapter 14), and stress (Chapter 15).
4. Social characteristics of people and organizations and their

implications for design: safety (Chapter 16), job design, training and selection (Chapter 17), and group and organizational design (Chapter 18).

Additional Resources

Several journals address human factors issues that may be of interest to readers. These journals provide more depth on the theory and applications introduced in this book. Some recommendations include: *Ergonomics*, *Human Factors*, *Ergonomics in Design*, *Computer Human Interaction (CHI)* conference proceedings, and *Accident Analysis and Prevention*.

Several books cover similar material as this book: Sanders and McCormick [21] and Proctor and Van Zandt [22] offer comprehensive coverage of human factors. Norman [23] examines human factors manifestations in the kinds of consumer systems that most of us encounter every day.

1. Sanders, M. S., McCormick, E. J., & Sanders, S. (1993). *Human Factors in Engineering and Design.* McGraw-Hill.
2. Proctor, R., & Van Zandt, T. (2008). *Human Factors in Simple and Complex Systems.* Taylor & Francis.
3. Norman, D. (2013). *The Design of Everyday Things: Revised and Expanded Edition.* Basic Books.

At a more advanced level, Wickens, Hollands, Banbury, and Parasuraman [11] provide coverage of engineering psychology, foregoing treatment of those human components that are not related to psychology (e.g., visibility, reach, and strength). In complementary fashion, Wilson and Corlett [24] and Chaffin, Andersson, and Martin [25] focus on the physical aspects of human factors. Finally, a comprehensive treatment of nearly all aspects of human factors can be found in the *Handbook of Human Factors and Ergonomics* [26], and issues of system integration can be found the *Handbook of Human-Systems Integration* [27].

1. Wickens, C. D., Hollands, J. G., Banbury, S., & Parasuraman, R. (2016). *Engineering Psychology and Human Performance* (Fourth edition). Routledge.
2. Wilson, J., & Sharples, S. (2015). *Evaluation of Human Work.* Taylor & Francis.
3. Chaffin, D. B., Andersson, J., G. B., & Martin, B. J. (2006). *Occupational Biomechanics* (Fourth edition). Wiley.
4. Salvendy, G. (2013). *Handbook of Human Factors and Ergonomics.* Wiley.
5. Boehm-Davis, D. A., Durso, F. T., & Lee, J. D. (2015). *APA Handbook of Human System Integration.* APA Press.

Questions

Questions for 1.1 What is Human Factors Engineering?

P1.1 What three general influences on human behavior are considered by human factors engineering in guiding design?

P1.2 What is “human error” a symptom of?

Questions for 1.2 Goals and Process of Human Factors Engineering

P1.3 What are the three goals of human factors engineering and what is their relative importance?

P1.4 How might the three goals of human factors engineering conflict with each other?

P1.5 How can potential conflicts in the goals of human factors engineering be resolved?

P1.6 What are three application areas that influence the priority of human factors engineering goals?

P1.7 How do the three goals of human factors engineering depend on the application area (e.g., high-risk, the workplace, and consumer products)?

P1.8 What are the three components of the human factors engineering design cycle?

P1.9 What activities comprise the “create” element of the human factors design cycle?

P1.10 What characteristics of people and systems make the evaluation element of the human factors design cycle essential?

P1.11 Why is it best to design with humans in mind from the start?

P1.12 Why are human factors interventions related to the task or equipment considered to be of greater importance than organization, training or selection?

P1.13 Why should training and selection be considered only after other human factors design interventions?

Questions for 1.3 Scope of Human Factors Engineering

P1.14 Explain why some human factors interventions, such as training and selection, are most relevant to the workplace and high-risk application areas?

P1.15 How do the two dimensions used to describe the scope of human factors relate to the organization of this textbook?

Questions for 1.5 Scientific Base of Human Factors Engineering

P1.16 Why is intuition insufficient to guide design?

P1.17 Why is it important to remember that preference does not always equal performance?

P1.18 Explain what the concept of learned intuition might mean for those designing for people in a developing country.