CHAPTER 1

THE DISCIPLINE OF HUMAN FACTORS AND ERGONOMICS

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The purpose of science is mastery over nature.

F. Bacon (*Novum Organum,* 1620)

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1 INTRODUCTION

Over the last 60 years human factors, a term that is used here synonymously with ergonomics [and denoted as human factors ergonomics (HFE)], has been evolving as a unique and independent discipline that focuses on the nature of human–artifact interactions, viewed from the unified perspective of the science, engineering, design, technology, and management of human-compatible systems, including a variety of natural and artificial products, processes, and living environments (Karwowski, 2005). The various dimensions of such defined ergonomics discipline are shown in Figure 1. The International Ergonomics Association (IEA, 2003) defines ergonomics (or human factors) as the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance. Human factors professionals contribute to the design and evaluation of tasks, jobs, products, environments, and systems in order to make them compatible with the needs, abilities, and limitations of people. Ergonomics discipline promotes a holistic, human-centered approach to work systems design that considers the physical, cognitive, social, organizational, environmental, and other relevant factors (Grandjean, 1986; Wilson and Corlett, 1995; Sanders and McCormick, 1993; Chapanis, 1995, 1999; Salvendy, 1997; Karwowski, 2001; Vicente, 2004; Stanton et al., 2004).

Historically, *ergonomics* (*ergon* + *nomos*), or “the study of work,” was originally and proposed and defined by the Polish scientist B. W. Jastrzebowski (1857a-d) as the scientific discipline with a very broad scope and wide subject of interests and applications, encompassing all aspects of human activity, including labor, entertainment, reasoning, and dedication (Karwowski (1991, 2001). In his paper published in the journal *Nature and Industry* (1857), Jastrzebowski divided work into two main categories: the *useful work*, which brings improvement for the common good, and the *harmful work* that

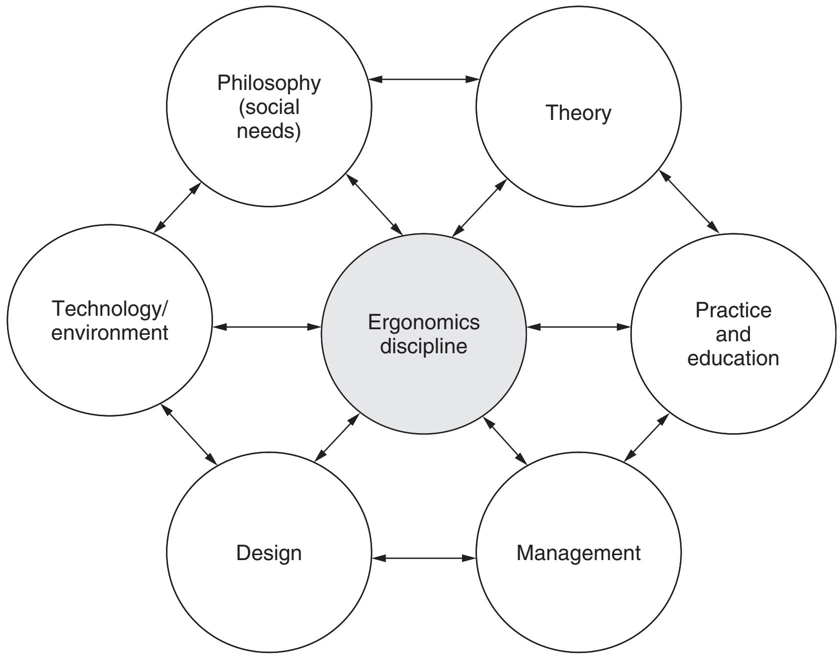


Figure 1 General dimensions of ergonomics discipline (after Karwowski, 2005).

brings deterioration (discreditable work). Useful work, which aims to improve things and people, is classified into physical, aesthetic, rational, and moral work. According to Jastrzebowski, such work requires utilization of the motor forces, sensory forces, forces of reason (thinking and reasoning), and the spiritual force. The four main benefits of the useful work are exemplified through the property, ability, perfection, and felicity.

The contemporary ergonomics discipline, independently introduced by Murrell in 1949 (Edholm and Murrell, 1973), was viewed at that time as an applied science, the technology, and sometimes both. The British scientists had founded the Ergonomics Research Society in 1949. The development of ergonomics internationally can be linked to a project initiated by the *European Productivity Agency* (EPA), a branch of the *Organization for European Economic Cooperation*, which first established a Human Factors Section in 1955 (Kuorinka, 2000). Under the EPA project, in 1956 specialists from European countries visited the United States to observe human factors research. In 1957 the EPA organized a technical seminar on "Fitting the Job to the Worker" at the University of Leiden, The Netherlands, during which a set of proposals was presented to form an international association of work scientists. A steering committee consisting of H.S. Belding, G.C.E. Burger, S. Forssman, E. Grandjean, G. Lehman, B. Metz, K.U. Smith, and R.G. Stansfield, was charged to develop specific proposal for such association. The committee decided to adopt the name International Ergonomics Association. At the meeting in Paris in 1958 it was decided to proceed with forming the new association. The steering committee designated itself as the Committee for the International Association of Ergonomic Scientists and elected G.C.E. Burger as its first president, K.U. Smith as treasurer, and E. Grandjean as secretary. The Committee for the International Association of Ergonomic Scientists met in Zurich in 1959 during a conference organized by the EPA and decided to retain the name International Ergonomics Association. On April 6, 1959, at the meeting in Oxford, England, E. Grandjean declared the founding of the IEA. The committee met again in Oxford, England, later in 1959 and agreed upon the set of bylaws or statutes of the IEA. These were formally approved by the IEA General Assembly at the first International Congress of Ergonomics held in Stockholm in 1961.

Traditionally, the most often cited domains of specialization within HFE are the physical, cognitive, and organizational ergonomics. Physical ergonomics is mainly concerned with human anatomical, anthropometric, physiological, and biomechanical characteristics as they relate to physical activity [Chaffin et al., 2006, Pheasant, 1986; Kroemer et al., 1994; Karwowski and Marras, 1999; National Research Council (NRC), 2001; Marras, 2008]. Cognitive ergonomics focuses on mental processes such as perception, memory, information processing, reasoning, and motor response as they affect interactions among humans and other elements of a system (Vicente, 1999; Hollnagel, 2003; Diaper and Stanton, 2004). Organizational ergonomics (also known as macroergonomics) is concerned with the optimization of sociotechnical systems, including their organizational structures, policies, and processes (Reason, 1997; Hendrick and Kleiner, 2002a,b; Hollman et al., 2003; Nemeth, 2004). Examples of the relevant topics include

Table 1 Exemplary Domains of Disciplines of Medicine, Psychology, and Human Factors

Medicine	Psychology	Human factors
Cardiology	Applied psychology	Physical ergonomics
Dermatology	Child psychology	Cognitive ergonomics
Gastroenterology	Clinical psychology	Macroergonomics
Neurology	Cognitive psychology	Knowledge ergonomics
Radiology	Community psychology	Rehabilitation ergonomics
Endocrinology	Counseling psychology	Participatory ergonomics
Pulmonology	Developmental psychology	Human–computer interaction
Gerontology	Experimental psychology	Neuroergonomics
Neuroscience	Educational psychology	Affective ergonomics
Nephrology	Environmental psychology	Ecological ergonomics
Oncology	Forensic psychology	Forensic ergonomics
Ophthalmology	Health psychology	Consumer ergonomics
Urology	Positive psychology	Human–systems integration
Psychiatry	Organizational psychology	Ergonomics of aging
Internal medicine	Social psychology	Information ergonomics
Community medicine	Quantitative psychology	Community ergonomics
Physical medicine	Social psychology	Nanoergonomics
		Service ergonomics

communication, crew resource management, design of working times, teamwork, participatory work design, community ergonomics, computer-supported cooperative work, new work paradigms, virtual organizations, telework, and quality management. The above traditional domains as well as new domains are listed in Table 1. According to the above discussion, the paramount objective of HFE is to understand the interactions between people and everything that surrounds us and based on such knowledge to optimize the human well-being and overall system performance. Table 2 provides a summary of the specific HFE objectives as discussed by Chapanis (1995). As recently pointed out by the National Academy of Engineering (NAE, 2004), in the future, ongoing developments in engineering will *expand toward tighter connections between technology and the human experience, including new products customized to the physical dimensions and capabilities of the user, and ergonomic design of engineered products*.

2 HUMAN–SYSTEM INTERACTIONS

While in the past ergonomics has been driven by technology (reactive design approach), in the future ergonomics should drive technology (proactive design approach). While technology is a product and a process involving both science and engineering, science aims to understand the "why" and "how" of nature through a process of scientific inquiry that generates knowledge about the natural world (Mitchem, 1994; NRC 2001). Engineering is the "design under constraints" of cost, reliability, safety, environmental impact, ease of use, available human and material resources, manufacturability, government regulations, laws, and politics (Wulf, 1998). Engineering, as a body of knowledge of design and creation of human-made products and a process for solving problems, seeks to shape the natural world to meet human needs and wants.

Table 2 Objectives of HFE Discipline

Basic Operational Objectives
Reduce errors
Increase safety
Improve system performance
Objectives Bearing on Reliability, Maintainability, and Availability (RMA) and Integrated Logistic Support (ILS)
Increase reliability
Improve maintainability
Reduce personnel requirements
Reduce training requirements
Objectives Affecting Users and Operators
Improve the working environment
Reduce fatigue and physical stress
Increase ease of use
Increase user acceptance
Increase aesthetic appearance
Other Objectives
Reduce losses of time and equipment
Increase economy of production

Source: Chapanis (1995).

Contemporary HFE discovers and applies information about human behavior, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use (Sanders and Mccormick, 1993; Helander, 1997). In this context, HFE deals with a broad scope of problems relevant to the design and evaluation of work systems, consumer products, and working environments, in which human–machine interactions affect human performance and product usability (Carayon, 2006; Dekker, (2007; Karwowski, 2006; Bedny and Karwowski, 2007; Weick and Sutcliffe, 2007; Sears and Jacko, 2009; Wogalter, 2006; Reason, 2008; Bisantz and Burns, 2009; Karwowski et al., 2010). The wide scope of issues addressed by the contemporary HFE discipline is presented in Table 3. Figure 2 illustrates the evolution of the scope of HFE with respect to the nature of human–system interactions and applications of human–system integration in a large variety of domains (Vicente, 2004; Karwowski, 2007; Lehto and Buck, 2007; Marras and Karwowski 2006a,b; Rouse, 2007; Guerin et al., 2007; Dekker, 2007; Schmorrow and Stanney, 2008; Pew and Mavor, 2008.; Cook and Durso, 2008; Zacharias et al., 2008; Salas et al., 2008; Marras, 2008, Chebbykin et al., 2008; Salvendy and Karwowski, 2010; Kaber and Boy, 2010; Marek et al., 2010).

Originally, HFE focused on the local human–machine interactions, while today the main focus is on the broadly defined human–technology interactions. In

Table 3 Classification Scheme for Human Factors/Ergonomics

1. General

Human Characteristics

2. Psychological aspects
3. Physiological and anatomical aspects
4. Group factors
5. Individual differences
6. Psychophysiological state variables
7. Task-related factors

Information Presentation and Communication

8. Visual communication
9. Auditory and other communication modalities
10. Choice of communication media
11. Person–machine dialogue mode
12. System feedback
13. Error prevention and recovery
14. Design of documents and procedures
15. User control features
16. Language design
17. Database organization and data retrieval
18. Programming, debugging, editing, and programming aids
19. Software performance and evaluation
20. Software design, maintenance, and reliability

Display and Control Design

21. Input devices and controls
22. Visual displays
23. Auditory displays
24. Other modality displays
25. Display and control characteristics

Table 3 (*continued*)

Workplace and Equipment Design

26. General workplace design and buildings
27. Workstation design
28. Equipment design

Environment

29. Illumination
30. Noise
31. Vibration
32. Whole-body movement
33. Climate
34. Altitude, depth, and space
35. Other environmental issues

System Characteristics

36. General system features

Work Design and Organization

37. Total system design and evaluation
38. Hours of work
39. Job attitudes and job satisfaction
40. Job design
41. Payment systems
42. Selection and screening
43. Training
44. Supervision
45. Use of support
46. Technological and ergonomic change

Health and Safety

47. General health and safety
48. Etiology
49. Injuries and illnesses
50. Prevention

Social and Economic Iimpact of the System

51. Trade unions
52. Employment, job security, and job sharing
53. Productivity
54. Women and work
55. Organizational design
56. Education
57. Law
58. Privacy
59. Family and home life
60. Quality of working life
61. Political comment and ethical considerations

Methods and Techniques

62. Approaches and methods
63. Techniques
64. Measures

Source: Ergonomics Abstracts (2004).

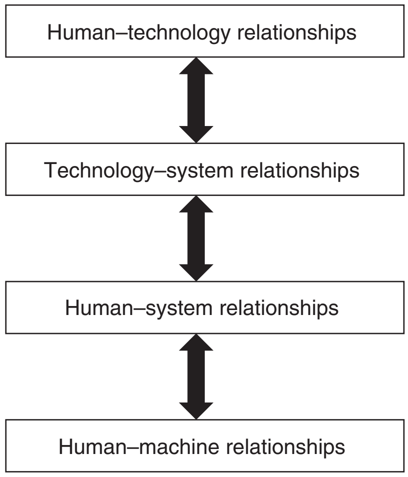


Figure 2 Expanded view of the human–technology relationships (modified after Meister, 1999).

this view, the HFE can also be called the discipline of *technological ecology*. Tables 4 and 5 present taxonomy of the human-related and technology-related components, respectively, which are of great importance to HFE discipline. According to Meister (1987), the traditional concept of the human–machine system is an organization of people and the machines they operate and maintain in order to perform assigned jobs that implement the purpose for which the system was developed (Meister, 1987). In this context, a system is a *construct* whose characteristics are manifested in physical and behavioral phenomena Meister (1991). The system is critical to HFE theorizing because it describes the substance of the human–technology relationship. General system variables of interest to HFE discipline are shown in Table 6.

The human functioning in human–machine systems can be described in terms of perception, information processing, decision making, memory, attention, feedback, and human response processes. Furthermore, the human work taxonomy can be used to describe five distinct levels of human functioning, ranging from primarily physical tasks to cognitive tasks (Karwowski, 1992a). These basic but universal human activities are (1) tasks that produce force (primarily muscular work),

Table 5 Taxonomy of HFE Elements: Technology

Technology Elements	Effects of Technology on the Human
Components	Changes in human role
Tools	Changes in human behavior
Equipments	
Systems	
Degree of Automation	Organization–Technology Relationships
Mechanization	Definition of organization
Computerization	Organizational variables
Artificial intelligence	
System Characteristics	
Dimensions	
Attributes	
Variables	

Source: Meister (1999).

Table 4 Taxonomy of HFE Elements: The Human Factor

Human Elements	Effects of the Human on Technology
Physical/sensory	Improvement in technology effectiveness
Cognitive	Absence of effect
Motivational/emotional	Reduction in technological effectiveness
Human Conceptualization	Human Operations in Technology
Stimulus–response orientation (limited)	Equipment operation
Stimulus–conceptual–response orientation (major)	Equipment maintenance
Stimulus–conceptual–motivational–response orientation (major)	System management
Human Technological Relationships	Type/degree of human involvement
Controller relationship	Direct (operation)
Partnership relationship	Indirect (recipient)
Client relationship	Extensive
Effects of Technology on the Human	Minimal
Performance effects	None
Goal accomplishment	
Goal nonaccomplishment	
Error/time discrepancies	
Feeling effect	
Technology acceptance	
Technology indifference	
Technology rejection	
Demand effects	
Resource mobilization	
Stress/trauma	

Source: Meister (1999).

Table 6 General System Variables

1. Requirement constraints imposed on the system
2. Resources required by the system
3. Nature of its internal components and processes
4. Functions and missions performed by the system
5. Nature, number, and specificity of goals
6. Structural and organizational characteristics of the system (e.g., its size, number of subsystems and units, communication channels, hierarchical levels, and amount of feedback)
7. Degree of automation
8. Nature of the environment in which the system functions
9. System attributes (e.g., complexity, sensitivity, flexibility, vulnerability, reliability, and determinacy)
10. Number and type of interdependencies (human–machine interactions) within the system and type of interaction (degree of dependency)
11. Nature of the system's terminal output(s) or mission effects

Source: Meister (1999).

(2) tasks of continuously coordinating sensorimonitor functions (e.g., assembling or tracking tasks), (3) tasks of converting information into motor actions (e.g., inspection tasks), (4) tasks of converting information into output information (e.g., required control tasks), and (5) tasks of producing information (primarily creative work) (Grandjean, 1986; Luczak et al., 1999). Any task in a human–machine system requires processing of information that is gathered based on perceived and interpreted relationships between system elements. The processed information may need to be stored by either a human or a machine for later use.

The scope of HFE factors that need to be considered in the design, testing, and evaluation of any human–system interactions is shown in Table 7 in the form of the exemplary ergonomics checklist. It should be noted that such checklists also reflect practical application of the discipline. According to the Board of Certification in Professional Ergonomics (BCPE), a practitioner of ergonomics is a person who (1) has a mastery of a body of ergonomics knowledge, (2) has a command of the methodologies used by ergonomists in applying that knowledge to the design of a product, system, job, or environment, and (3) has applied his or her knowledge to the analysis, design testing, and evaluation of products, systems, and environments. The areas of current practice in the field can be best described by examining the focus of Technical Groups of the Human Factors and Ergonomics Society, as illustrated in Table 8.

Table 7 Examples of Factors to Be Used in Ergonomics Checklists

I. Anthropometric, Biomechanical, and Physiological Factors

1. Are the differences in human body size accounted for by the design?
2. Have the right anthropometric tables been used for specific populations?
3. Are the body joints close to neutral positions?
4. Is the manual work performed close to the body?
5. Are there any forward-bending or twisted trunk postures involved?
6. Are sudden movements and force exertion present?
7. Is there a variation in worker postures and movements?
8. Is the duration of any continuous muscular effort limited?
9. Are the breaks of sufficient length and spread over the duration of the task?
10. Is the energy consumption for each manual task limited?

II. Factors Related to Posture (Sitting and Standing)

1. Is sitting/standing alternated with standing/sitting and walking?
2. Is the work height dependent on the task?
3. Is the height of the work table adjustable?
4. Are the height of the seat and backrest of the chair adjustable?
5. Is the number of chair adjustment possibilities limited?
6. Have good seating instructions been provided?
7. Is a footrest used where the work height is fixed?
8. Has the work above the shoulder or with hands behind the body been avoided?
9. Are excessive reaches avoided?
10. Is there enough room for the legs and feet?
11. Is there a sloping work surface for reading tasks?
12. Have the combined sit–stand workplaces been introduced?
13. Are handles of tools bent to allow for working with the straight wrists?

Table 7 (*continued*)

III. Factors Related to Manual Materials Handling (Lifting, Carrying, Pushing, and Pulling Loads)

1. Have tasks involving manual displacement of loads been limited?
2. Have optimum lifting conditions been achieved?
3. Is anybody required to lift more than 23 kg?
4. Have lifting tasks been assessed using the NIOSH (1991) method?
5. Are handgrips fitted to the loads to be lifted?
6. Is more than one person involved in lifting or carrying tasks?
7. Are there mechanical aids for lifting or carrying available and used?
8. Is the weight of the load carried limited according to the recognized guidelines?
9. Is the load held as close to the body as possible?
10. Are pulling and pushing forces limited?
11. Are trolleys fitted with appropriate handles and handgrips?

IV. Factors Related to Design of Tasks and Jobs

1. Does the job consist of more than one task?
2. Has a decision been made about allocating tasks between people and machines?
3. Do workers performing the tasks contribute to problem solving?
4. Are the difficult and easy tasks performed interchangeably?
5. Can workers decide independently on how the tasks are carried out?
6. Are there sufficient possibilities for communication between workers?
7. Is there sufficient information provided to control the assigned tasks?
8. Can the group take part in management decisions?
9. Are the shift workers given enough opportunities to recover?

V. Factors Related to Information and Control Tasks

Information

1. Has an appropriate method of displaying information been selected?
2. Is the information presentation as simple as possible?
3. Has the potential confusion between characters been avoided?
4. Has the correct character/letter size been chosen?
5. Have texts with capital letters only been avoided?
6. Have familiar typefaces been chosen?
7. Is the text/background contrast good?
8. Are the diagrams easy to understand?
9. Have the pictograms been properly used?
10. Are sound signals reserved for warning purposes?

Control

1. Is the sense of touch used for feedback from controls?
2. Are differences between controls distinguishable by touch?
3. Is the location of controls consistent and is sufficient spacing provided?
4. Have the requirements for the control-display compatibility been considered?
5. Is the type of cursor control suitable for the intended task?
6. Is the direction of control movements consistent with human expectations?
7. Are the control objectives clear from the position of the controls?
8. Are controls within easy reach of female workers?
9. Are labels or symbols identifying controls properly used?
10. Is the use of color in controls design limited?

(*continued overleaf*)

Table 7 (*continued*)

Human–Computer Interaction

1. Is the human–computer dialogue suitable for the intended task?
2. Is the dialogue self-descriptive and easy to control by the user?
3. Does the dialogue conform to the expectations on the part of the user?
4. Is the dialogue error tolerant and suitable for user learning?
5. Has command language been restricted to experienced users?
6. Have detailed menus been used for users with little knowledge and experience?
7. Is the type of help menu fitted to the level of the user's ability?
8. Has the QWERTY layout been selected for the keyboard?
9. Has a logical layout been chosen for the numerical keypad?
10. Is the number of function keys limited?
11. Have the limitations of speech in human–computer dialogue been considered?
12. Are touch screens used to facilitate operation by inexperienced users?

VI. Environmental Factors

Noise and Vibration

1. Is the noise level at work below 80 dBA?
2. Is there an adequate separation between workers and source of noise?
3. Is the ceiling used for noise absorption?
4. Are the acoustic screens used?
5. Are hearing conservation measures fitted to the user?
6. Is personal monitoring to noise/vibration used?
7. Are the sources of uncomfortable and damaging body vibration recognized?
8. Is the vibration problem being solved at the source?
9. Are machines regularly maintained?
10. Is the transmission of vibration prevented?

Illumination

1. Is the light intensity for normal activities in the range of 200–800 lux?
2. Are large brightness differences in the visual field avoided?
3. Are the brightness differences between task area, close surroundings, and wider surroundings limited?
4. Is the information easily legible?
5. Is ambient lighting combined with localized lighting?
6. Are light sources properly screened?
7. Can the light reflections, shadows, or flicker from the fluorescent tubes be prevented?

Climate

1. Are workers able to control the climate themselves?
2. Is the air temperature suited to the physical demands of the task?
3. Is the air prevented from becoming either too dry to too humid?
4. Are draughts prevented?
5. Are the materials/surfaces that have to be touched neither too cold nor too hot?
6. Are the physical demands of the task adjusted to the external climate?
7. Are undesirable hot and cold radiation prevented?
8. Is the time spent in hot or cold environments limited?

Source: Dul and Weerdmeester (1993).

Table 8 Subject Interests of Technical Groups of Human Factors and Ergonomics Society

Technical Group	Description/Areas of Concerns
Aerospace systems	Application of human factors to the development, design, certification, operation, and maintenance of human–machine systems in aviation and space environments. The group addresses issues for civilian and military systems in the realms of performance and safety.
Aging	Human factors applications appropriate to meeting the emerging needs of older people and special populations in a wide variety of life settings.
Augmented cognition	Fostering the development and application of real-time physiological and neurophysiological sensing technologies that can ascertain a human's cognitive state while interacting with computing-based systems; data classification and integration architectures that enable closed-loop system applications; mitigation (adaptive) strategies that enable efficient and effective system adaptation based on a user's dynamically changing cognitive state; individually tailored training systems.
Cognitive engineering and decision making	Research on human cognition and decision making and the application of this knowledge to the design of systems and training programs. Emphasis is on considerations of descriptive models, processes, and characteristics of human decision making, alone or in conjunction with other individuals or intelligent systems; factors that affect decision making and cognition in naturalistic task settings; technologies for assisting, modifying, or supplementing human decision making; and training strategies for assisting or influencing decision making.
Communications	All aspects of human-to-human communication, with an emphasis on communication mediated by telecommunications technology, including multimedia and collaborative communications, information services, and interactive broadband applications. Design and evaluation of both enabling technologies and infrastructure technologies in education, medicine, business productivity, and personal quality of life.
Computer systems	Human factors in the design of computer systems. This includes the user-centered design of hardware, software, applications, documentation, work activities, and the work environment. Practitioners and researchers in the CSTG community take a holistic, systems approach to the design and evaluation of all aspects of user–computer interactions. Some goals are to ensure that computer systems are useful, usable, safe, and, where possible, fun and to enhance the quality of work life and recreational/educational computer use by ensuring that computer interface, function, and job design are interesting and provide opportunities for personal and professional growth.
Consumer products	Development of consumer products that are useful, usable, safe, and desirable. Application of the principles and methods of human factors, consumer research, and industrial design to ensure market success.
Education	Education and training of human factors and ergonomics specialists. This includes undergraduate, graduate, and continuing education needs, issues, techniques, curricula, and resources. In addition, a forum is provided to discuss and resolve issues involving professional registration and accreditation
Environmental design	Relationship between human behavior and the designed environment. Common areas of research and interest include ergonomic and macroergonomic aspects of design within home, office, and industrial settings. An overall objective of this group is to foster and encourage the integration of ergonomics principles into the design of environments
Forensics professional	Application of human factors knowledge and technique to ''standards of care'' and accountability established within legislative, regulatory, and judicial systems. The emphasis on providing a scientific basis to issues being interpreted by legal theory.
Health care	Maximizing the contributions of human factors and ergonomics to medical systems effectiveness and the quality of life of people who are functionally impaired
Individual differences	A wide range of personality and individual difference variables that are believed to mediate performance.
Industrial ergonomics	Application of ergonomics data and principles for improving safety, productivity, and quality of work in industry. Concentration on service and manufacturing processes, operations, and environments.

(*continued overleaf*)

Table 8 (*continued*)

Technical Group	Description/Areas of Concerns
Internet	Human factor aspects of user interface design of Web content, Web-based applications, Web browsers, Webtops, Web-based user assistance, and Internet devices; behavioral and sociological phenomena associated with distributed network communication; human reliability in administration and maintenance of data networks; and accessibility of Web-based products.
Macroergonomics	Organizational design and management issues in human factors and ergonomics as well as work system design and human–organization interface technology. The Technical Group is committed to improving work system performance (e.g., productivity, quality, health and safety, quality of work life) by promoting work system analysis and design practice and the supporting empirical science concerned with the technological subsystem, personnel subsystem, external environment, organizational design, and their interactions.
Perception and performance	Perception and its relation to human performance. Areas of concern include the nature, content, and quantification of sensory information and the context in which it is displayed; the physics and psychophysics of information display; perceptual and cognitive representation and interpretation of displayed information; assessment of workload using tasks having a significant perceptual component; and actions and behaviors that are consequences of information presented to the various sensory systems.
Product design	Developing consumer products that are useful, usable, safe, and desirable. By applying the principles and methods of human factors, consumer research, and industrial design, the group works to ensure the success of products sold in the marketplace
Safety	Development and application of human factors technology as it relates to safety in all settings and attendant populations. These include, but are not limited to, aviation, transportation, industry, military, office, public building, recreation, and home environment
System development	Fostering research and exchanging information on the integration of human factors and ergonomics into the development of systems. Members are concerned with defining human factors/ergonomics activities and integrating them into the system development process in order to enable systems that meet user requirements. Specific topics of interest include the system development process itself; developing tools and methods for predicting and assessing human capabilities and limitations, notably modeling and simulation; creating principles that identify the role of humans in the use, operation, maintenance, and control of systems; applying human factors and ergonomics data and principles to the design of human–system interfaces; and the full integration of human requirements into system and product design through the application of HSI methods to ensure technical and programmatic integration of human considerations into systems acquisition and product development processes; the impact of increasing computerization and stress and workload effects on performance.
Surface transportation	Human factors related to the international surface transportation field. *Surface transportation* encompasses numerous mechanisms for conveying humans and resources: passenger, commercial, and military vehicles, on- and off-road; mass transit; maritime transportation; rail transit, including vessel traffic services (VTSs); pedestrian and bicycle traffic; and highway and infrastructure systems, including intelligent transportation systems (ITSs).
Test and evaluation	All aspects of human factors and ergonomics as applied to the evaluation of systems. Evaluation is a core skill for all human factors professionals and includes measuring performance, workload, situational awareness, safety, and acceptance of personnel engaged in operating and maintaining systems. Evaluation is conducted during system development when prototype equipment and systems are being introduced to operational usage and at intervals thereafter during the operational life of these systems.
Training	Fosters information and interchange among people interested in the fields of training and training research.
Virtual environment	Human factors issues associated with human–virtual environment interaction. These issues include maximizing human performance efficiency in virtual environments, ensuring health and safety, and circumventing potential social problems through proactive assessment. For VE/VR systems to be effective and well received by their users, researchers need to focus significant efforts on addressing human factors issues.

Source: www.hfes.org.

3 HFE AND ECOLOGICAL COMPATIBILITY

The HFE discipline advocates systematic use of the knowledge concerning relevant human characteristics in order to achieve compatibility in the design of interactive systems of people, machines, environments, and devices of all kinds to ensure specific goals [Human Factors and Ergonomics Society (HFES), 2003)]. Typically such goals include improved (system) effectiveness, productivity, safety, ease of performance, and the contribution to overall human well-being and quality of life. Although the term *compatibility* is a key word in the above definition, it has been mainly used in a narrow sense only, often in the context of the design of displays and controls, including the studies of spatial (location) compatibility or the intention–response–stimulus compatibility related to movement of controls (Wickens and Carswell, 1997). Karwowski and his co-workers (Karwowski et al., 1988; Karwowski, 1985, 1991) advocated the use of compatibility in a greater context of the ergonomics system. For example, Karwowski (1997) introduced the term *human-compatible systems* in order to focus on the need for comprehensive treatment of compatibility in the human factors discipline.

The *American Heritage Dictionary of English Language* (Morris, 1978) defines "compatible" as (1) capable of living or performing in harmonious, agreeable, or congenial combination with another or others and (2) capable of orderly, efficient integration and operation with other elements in a system. From the beginning of contemporary ergonomics, the measurements of compatibility between the system and the human and evaluation of the results of ergonomics interventions were based on the measures that best suited specific purposes (Karwowski, 2001). Such measures included the specific psychophysiological responses of the human body (example.g., heart rate, EMG, perceived human exertion, satisfaction, comfort or discomfort) as well as a number of indirect measures, such as the incidence of injury, economic losses or gains, system acceptance, or operational effectiveness, quality, or productivity. The lack of a universal matrix to quantify and measure human–system compatibility is an important obstacle in demonstrating the value of ergonomics science and profession (Karwowski, 1997). However, even though 20 years ago ergonomics was perceived by some (e.g., see Howell, 1986) as a highly unpredictable area of human scientific endeavor, today HFE has positioned itself as a unique, *design-oriented* discipline, independent of engineering and medicine (Moray, 1984; Sanders and McCormick, 1993; Helander, 1997; Karwowski, 1991, 2003).

Figure 3 illustrates the human–system compatibility approach to ergonomics in the context of quality of working life and system (an enterprise or business entity) performance. This approach reflects the nature of complex compatibility relationships between the human operator (human capacities and limitations), technology (in terms of products, machines, devices, processes, and computer-based systems), and the broadly defined environment (business processes, organizational structure, nature of work systems, and effects of work-related multiple stressors). The operator's performance is an outcome of the compatibility matching between individual human characteristics (capacities and limitations) and the requirements and affordances of both the technology

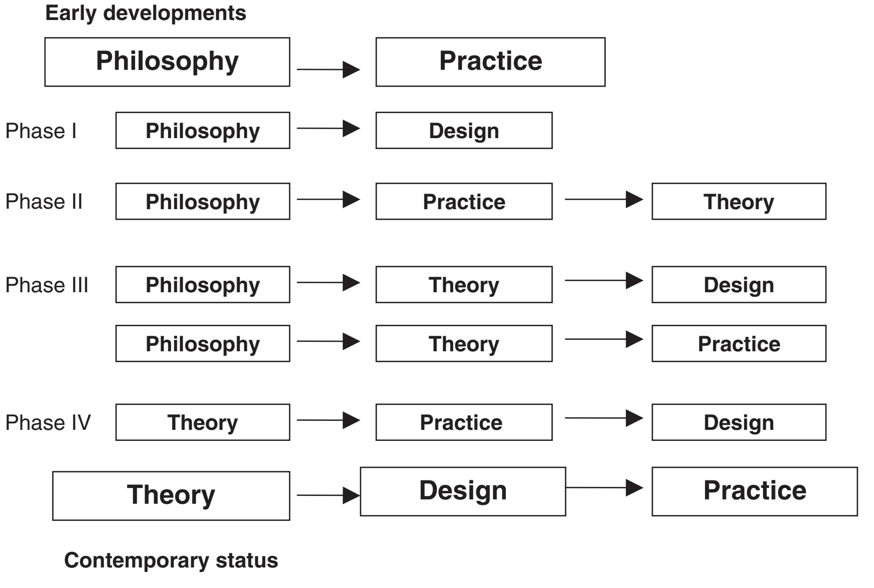


Figure 3 Evolution in development of HFE discipline (after Karwowski, 2005).

and environment. The quality of working life and the system (enterprise) performance is affected by matching the positive and negative outcomes of the complex compatibility relationships between the human operator, technology, and environment. Positive outcomes include such measures as work productivity, performance times, product quality, and subjective psychological (desirable) behavioral outcomes such as job satisfaction, employee morale, human well-being, and commitment. The negative outcomes include both human and system-related errors, loss of productivity, low quality, accidents, injuries, physiological stresses, and subjective psychological (undesirable) behavioral outcomes such as job dissatisfaction, job/occupational stress, and discomfort.

4 DISTINGUISHING FEATURES OF CONTEMPORARY HFE DISCIPLINE AND PROFESSION

The main focus of the HFE discipline in the twenty-first century will be the design and management of systems that satisfy customer demands in terms of human compatibility requirements. Karwowski (2005) has discussed 10 characteristics of contemporary HFE discipline and profession. Some of the distinguishing features are as follows:

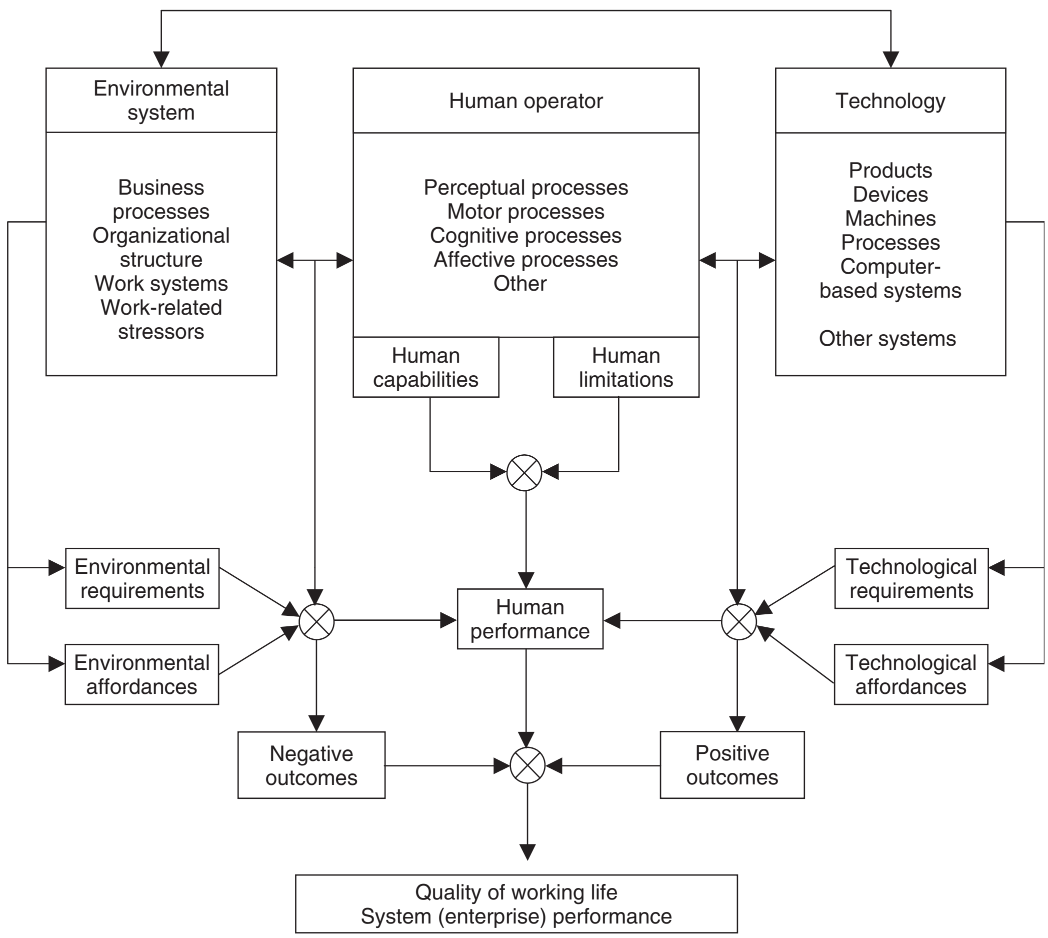
- HFE experiences continuing evolution of its "fit" philosophy, including diverse and ever-expanding human-centered design criteria (from safety to comfort, productivity, usability, or affective needs like job satisfaction or life happiness).
- HFE covers extremely diverse subject matters, similarly to medicine, engineering, and psychology (see Table 1).
- HFE deals with very complex phenomena that are not easily understood and cannot be simplified by making nondefendable assumptions about their nature.
- Historically, HFE has been developing from the "philosophy of fit" toward practice. Today, HFE is developing a sound theoretical basis for design and practical applications (see Figure 4).
- HFE attempts to "by-step" the need for the fundamental understanding of human–system interactions without separation from the consideration of knowledge utility for practical applications in the quest for immediate and useful solutions (also see Figure 5).
- HFE has limited recognition by decisionmakers, the general public, and politicians as to its value that it can bring to a global society at large, especially in the context of facilitating the socioeconomic development.
- HFE has a relatively limited professional educational base.
- The impact of HFE is affected by the ergonomics illiteracy of the students and professionals in other disciplines, the mass media, and the public at large.

Theoretical ergonomics is interested in the fundamental understanding of the interactions between people and their environments. Central to HFE interests is also an understanding of how human–system interactions should be designed. On the other hand, HFE also falls under the category of applied research. The taxonomy of research efforts with respect to the quest for a fundamental understanding and the consideration of use, originally proposed by Stokes (1997), allows for differentiation of the main categories of research dimensions as follows: (1) pure basic research, (2) use-inspired basic research, and (3) pure applied research. Figure 5 illustrates the interpretation of these categories for the HFE theory, design, and applications. Table 9 presents relevant specialties and subspecialties in HFE research as outlined by Meister (1999), who classified them into three main categories: (1) system/technology-oriented specialties, (2) process-oriented specialties, and (3) behaviorally oriented specialties. In addition, Table 10 presents a list of contemporary HFE research methods that can be used to advance the knowledge discovery and utilization through its practical applications.

5 PARADIGMS FOR ERGONOMICS DISCIPLINE

The paradigms for any scientific discipline include theory, abstraction, and design (Pearson and Young, 2002). Theory is a foundation of the mathematical sciences. Abstraction (modeling) is a foundation of the natural sciences, where progress is achieved by formulating hypotheses and systematically following the modeling process to verify and validate them. Design is the basis for engineering, where progress is achieved primarily by posing problems and systematically following the design process to construct systems that solve them.

In view of the above, Karwowski (2005) discussed the paradigms for HFE discipline: (1) ergonomics theory, (2) ergonomics abstraction, and (3) ergonomics design. Ergonomics theory is concerned with the ability to identify, describe, and evaluate human–system interactions. Ergonomics abstraction is concerned with the ability to use those interactions to make predictions that can be compared with the real world. Ergonomics design is concerned with the ability to implement knowledge about those interactions and use them to develop systems that satisfy customer needs and relevant human compatibility requirements. Furthermore, the pillars for any scientific discipline include a definition, a teaching paradigm, and an educational base (NRC, 2001). A definition of the ergonomics discipline and profession adopted by the IEA (2003) emphasizes fundamental questions and significant accomplishments, recognizing that the HFE field is constantly changing. A teaching paradigm for ergonomics should conform to established scientific standards, emphasize the development of competence in the field, and integrate theory, experimentation, design, and practice. Finally, an introductory course sequence in ergonomics should be based on the curriculum model and the disciplinary description.



Note: ⊗—Matching of compatibility relationships

Figure 4 Human–system compatibility approach to ergonomics (Karwowski, 2005).

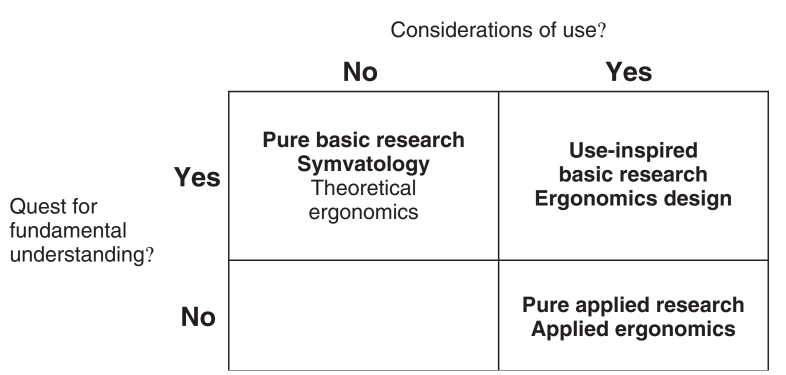


Figure 5 Considerations of fundamental understanding and use in ergonomics research (Karwowski 2005).

Table 9 Specialties and Subspecialties in HFE Research

System/Technology-Oriented Specialties

1. Aerospace: civilian and military aviation and outer space activities.
2. Automotive: automobiles, buses, railroads, transportation functions (e.g., highway design, traffic signs, ships).
3. Communication: telephone, telegraph, radio, direct personnel communication in a technological context.
4. Computers: anything associated with the hardware and software of computers.
5. Consumer products: other than computers and automobiles, any commercial product sold to the general public (e.g., pens, watches, TV).
6. Displays: equipment used to present information to operators (e.g., HMO, HUD, meters, scales).
7. Environmental factors/design: the environment in which human–machine system functions are performed (e.g., offices, noise, lighting).
8. Special environment: this turns out to be underwater.

Process-Oriented. Specialties

The emphasis is on how human functions are performed and methods of improving or analyzing that performance:

1. Biomechanics: human physical strength as it is manifested in such activities as lifting, pulling, and so on.
2. Industrial ergonomics (IE): papers related primarily to manufacturing; processes and resultant problems (e.g., carpal tunnel syndrome).
3. Methodology/measurement: papers that emphasize ways of answering HFE questions or solving HFE problems.
4. Safety: closely related to IE but with a major emphasis on analysis and prevention of accidents.
5. System design/development: papers related to the processes of analyzing, creating, and developing systems.
6. Training: papers describing how personnel are taught to perform functions/tasks in the human–machine system.

Behaviorally Oriented Specialties

1. Aging: the effect of this process on technological performance.
2. Human functions: emphasizes perceptual-motor and cognitive functions. The latter differs from training in the sense that training also involves cognition but is the process of implementing cognitive capabilities. (The HFE specialty called *cognitive ergonomics/decision making* has been categorized.)
3. Visual performance: how people see. They differ from displays in that the latter relate to equipment for seeing, whereas the former deals with the human capability and function of seeing.

Source: Meister (1999).

6 ERGONOMICS COMPETENCY AND LITERACY

As pointed out by the National Academy of Engineering (Pearson and Young, 2002), many consumer products and services promise to make people's lives easier, more enjoyable, more efficient, or healthier but very often do not deliver on this promise. Design of interactions with technological artifacts and work systems requires involvement of ergonomically competent people—people with ergonomics proficiency in a certain area, although not generally in other areas of application, similarly to medicine or engineering.

One of the critical issues in this context is the ability of users to understand the utility and limitations of technological artifacts. Ergonomics literacy prepares individuals to perform their roles in the workplace and outside the working environment. Ergonomically literate people can learn enough about how technological systems operate to protect themselves by making informed choices and making use of beneficial affordances of the artifacts and environment. People trained in ergonomics typically possess a high level of knowledge and skill related to one or more specific area of ergonomics application. Ergonomics literacy is a prerequisite to ergonomics competency. The following can be proposed as dimensions for ergonomics literacy:

1. *Ergonomics Knowledge and Skills*. An individual has the basic knowledge of the philosophy of human-centered design and principles for accommodating human limitations.
2. *Ways of Thinking and Acting*. An individual seeks information about benefits and risks of artifacts and systems (consumer products, services, etc.) and participates in decisions about purchasing and use and/or development of artifacts/systems
3. *Practical Ergonomics Capabilities*. An individual can identify and solve simple task (job)-related design problems at work or home and can apply basic concepts of ergonomics to make informed judgments about usability of artifacts and the related risks and benefits of their use.

Table 11 presents a list of 10 standards for ergonomics literacy which were proposed by Karwowski (2003) in parallel to a model of technological literacy reported by the NAE (Pearson and Young, 2002). Eight of these standards are related to developing an

Table 10 Contemporary HFE Research Methods

Physical Methods
PLIBEL: method assigned for identification of ergonomic hazards musculoskeletal discomfort surveys used at NIOSH
Dutch musculoskeletal questionnaire (DMQ)
Quick exposure checklist (QEC) for assessment of workplace risks for work-related musculoskeletal disorders (WMSDs)
Rapid upper limb assessment (RULA)
Rapid entire body assessment
Strain index
Posture checklist using personal digital assistant (PDA) technology
Scaling experiences during work: perceived exertion and difficulty
Muscle fatigue assessment: functional job analysis technique
Psychophysical tables: lifting, lowering, pushing, pulling, and carrying
Lumbar motion monitor
Occupational repetitive-action (OCRA) methods: OCRA index and OCRA checklist
Assessment of exposure to manual patient handling in hospital wards: MAPO index (movement and assistance of hospital patients)
Psychophysiological Methods
Electrodermal measurement
Electromyography (EMG)
Estimating mental effort using heart rate and heart rate variability
Ambulatory EEG methods and sleepiness
Assessing brain function and mental chronometry with event-related potentials (ERPs)
EMG and functional magnetic resonance imaging (fMRI)
Ambulatory assessment of blood pressure to evaluate workload
Monitoring alertness by eyelid closure
Measurement of respiration in applied human factors and ergonomics research
Behavioral and Cognitive Methods
Observation
Heuristics
Applying interviews to usability assessment
Verbal protocol analysis
Repertory grid for product evaluation
Focus groups
Hierarchical task analysis (HTA)
Allocation of functions
Critical decision method
Applied cognitive work analysis (ACWA)
Systematic human error reduction and prediction approach (SHERPA)
Predictive human error analysis (PHEA)
Hierarchical task analysis
Mental workload
Multiple resource time sharing
Critical path analysis for multimodal activity
Situation awareness measurement and situation awareness
Keystroke level model (KLM)
GOMS
Link analysis
Global assessment technique

(*continued overleaf*)

Table 10 (*continued*)

Team Methods
Team training
Distributed simulation training for teams
Synthetic task environments for teams: CERTTs UAV-STE
Event-based approach to training (EBAT)
Team building
Measuring team knowledge
Team communications analysis
Questionnaires for distributed assessment of team mutual awareness
Team decision requirement exercise: making team decision requirements explicit
Targeted acceptable responses to generated events or tasks (TARGETs)
Behavioral observation scales (BOS)
Team situation assessment training for adaptive coordination
Team task analysis
Team workload
Social network analysis
Environmental Methods
Thermal conditions measurement
Cold stress indices
Heat stress indices
Thermal comfort indices
Indoor air quality: chemical exposures
Indoor air quality: biological/particulate-phase contaminant
Exposure assessment methods
Olfactometry: human nose as detection instrument
Context and foundation of lighting practice
Photometric characterization of luminous environment
Evaluating office lighting
Rapid sound quality assessment of background noise
Noise reaction indices and assessment
Noise and human behavior
Occupational vibration: concise perspective
Habitability measurement in space vehicles and Earth analogs
Macroergonomic Methods
Macroergonomic organizational questionnaire survey (MOQS)
Interview method
Focus groups
Laboratory experiment
Field study and field experiment
Participatory ergonomics (PE)
Cognitive walk-through method (CWM)
Kansei Engineering
HITOP analysis TM
TOP-Modeler C
CIMOP System C
Anthropotechnology
Systems analysis tool (SAT)
Macroergonomic analysis of structure (MAS)
Macroergonomic analysis and design (MEAD)

Source: Stanton et al. (2004).

Table 11 Standards for Ergonomics Literacy: Ergonomics and Technology

An understanding of:
Standard 1: characteristics and scope of ergonomics
Standard 2: core concepts of ergonomics
Standard 3: connections between ergonomics and other fields of study and relationships among technology, environment, industry, and society
Standard 4: cultural, social, economic, and political effects of ergonomics
Standard 5: role of society in the development and use of technology
Standard 6: effects of technology on the environment
Standard 7: attributes of ergonomics design
Standard 8: role of ergonomics research, development, invention, and experimentation
Abilities to:
Standard 9: apply the ergonomics design process
Standard 10: assess the impact of products and systems on human health, well-being, system performance, and safety

Source: Karwowski (2007).

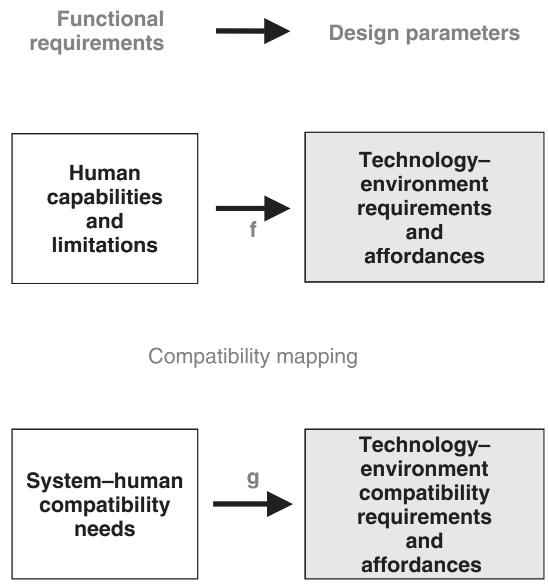


Figure 6 Ergonomics design process: compatibility mapping (Karwowski 2005).

understanding of the nature, scope, attributes, and role of the HFE discipline in modern society, while two of them refer to the need for developing the abilities to apply the ergonomics design process and evaluate the impact of artifacts on human safety and well-being.

7 ERGONOMICS DESIGN

Ergonomics is the design-oriented discipline. However, as discussed by Karwowski (2005), ergonomists do not design systems; rather HFE professionals design the interactions between the artifact systems and humans. One of the fundamental problems involved in such a design is that typically there are multiple functional system–human compatibility requirements that must be satisfied at the same time. In order to address this issue, structured design methods for complex human–artifact systems are needed. In such a perspective, ergonomics design can be defined in general as mapping from the human capabilities and limitations to system (technology–environment) requirements and affordances (Figure 6), or, more specifically, from system–human compatibility needs to relevant human–system interactions.

Suh (1990, 2001) proposed a framework for axiomatic design which utilizes four different domains that reflect mapping between the identified needs ("what one wants to achieve") and the ways to achieve them ("how to satisfy the stated needs"). These domains include (1) customer requirements (customer needs or desired attributes), (2) the functional domain (functional requirements and constraints), (3) the physical domain (physical design parameters), and (4) the processes domain (processes and resources). Karwowski (2003) conceptualized the above domains for ergonomics design purposes as illustrated in Figure 7 using the concept of compatibility requirements and compatibility mappings between the domains of (1) HFE requirements (goals in terms of human needs and system performance), (2) functional requirements and constraints expressed in terms of human capabilities and limitations, (3) the physical domain in terms of design of compatibility, expressed through the human–system interactions and specific work system design solutions, and (4) the processes domain, defined as management of compatibility (see Figure 8).

7.1 Axiomatic Design: Design Axioms

The axiomatic design process is described by the mapping process from functional requirements (FRs) to design parameters (DPs). The relationship between the two vectors FR and DP is as follows:

$$\{FR\} = [\mathbf{A}]\{DP\}$$

where $[\mathbf{A}]$ is the design matrix that characterizes the product design. The design matrix $[\mathbf{A}]$ for three functional domains (FRs) and three physical domains (DPs) is shown below:

$$[\mathbf{A}] = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

The following two design axioms, proposed by Suh (1991), are the basis for the formal methodology of design: (1) the independence axiom and (2) the information axiom.

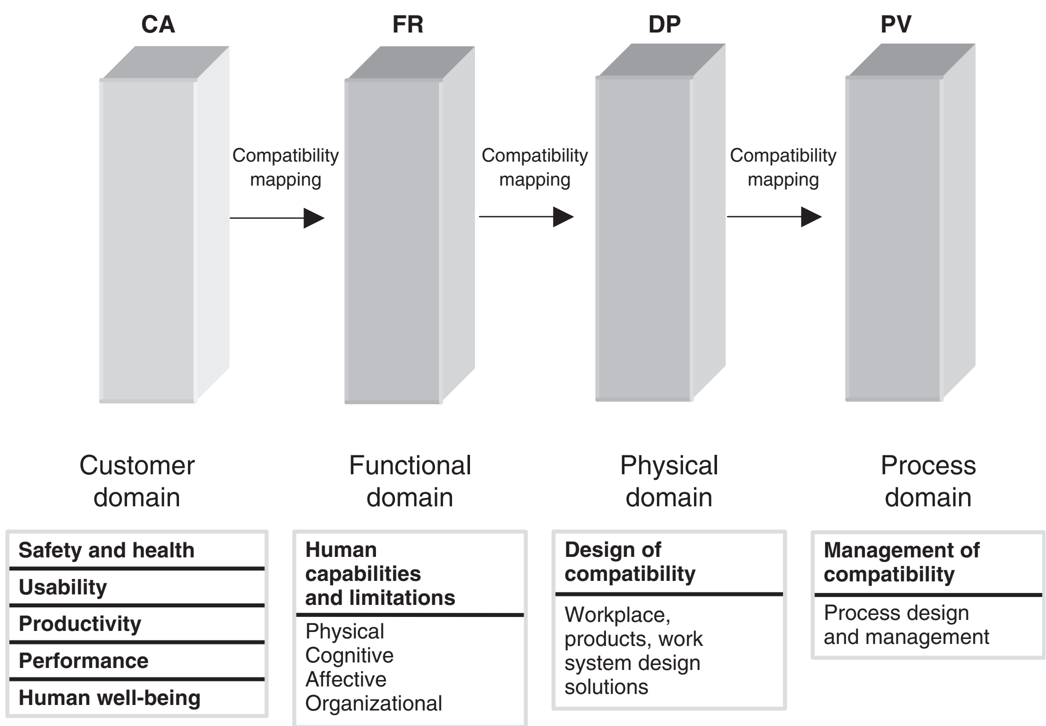


Figure 7 Four domains of design in ergonomics (Karwowski, 2003).

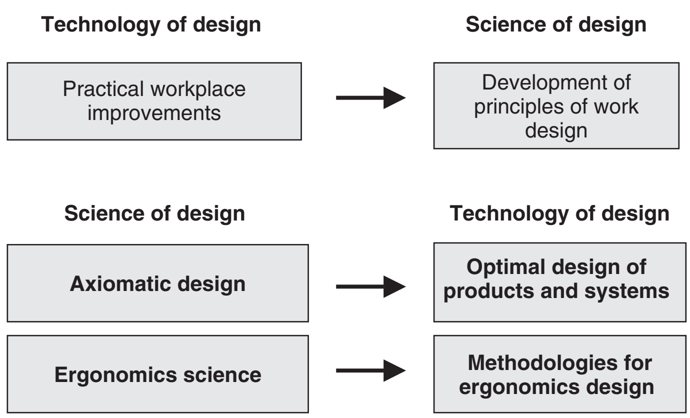


Figure 8 Axiomatic approach to ergonomics design (Karwowski, 2003).

7.1.1 Axiom 1: The Independence Axiom

This axiom stipulates a need for independence of the FRs, which are defined as the minimum set of independent requirements that characterize the design goals (defined by DPs).

7.1.2 Axiom 2: The Information Axiom

This axiom stipulates minimizing the information content of the design. Among those designs that satisfy the *independence axiom*, the design that has the smallest information content is the best design.

According to the second design axiom, the information content of the design should be minimized. The information content I_i for a given functional requirement (FR_i) is defined in terms of the probability P_i of satisfying FR_i:

$$I_i = \log_2(1/P_i) = -\log_2 P_i \text{ bits}$$

The information content will be additive when there are many functional requirements that must be satisfied simultaneously. In the general case of m number of FRs, the information content for the entire system I_{sys} is

$$I_{sys} = -\log_2 C_{\{m\}}$$

where $C_{\{m\}}$ is the joint probability that all m FRs are satisfied.

The above axioms can be adapted for ergonomics design purposes as follows:

7.1.3 Axiom 1: The Independence Axiom

This axiom stipulates a need for independence of the functional compatibility requirements (FCRs), which are defined as the minimum set of independent compatibility requirements that characterize the design goals (defined by ergonomics design parameters, EDPs).

7.1.4 Axiom 2: The Human Incompatibility Axiom

This axiom stipulates a need to minimize the incompatibility content of the design. Among those designs that satisfy the independence axiom, the design that has the smallest incompatibility content is the best design.

As discussed by Karwowski (2001, 2003), in ergonomics design, the above axiom can be interpreted as follows. The human incompatibility content of the design I_i for a given functional requirement (FR_i) is defined in terms of the compatibility C_i index satisfying FR_i:

$$I_i = \log_2(1/C_i) = -\log_2 C_i \text{ ints}$$

where I denotes the incompatibility content of a design.

7.2 Theory of Axiomatic Design in Ergonomics

As discussed by Karwowski 1991, 2001, 2003), a need to remove the system–human incompatibility (or ergonomics entropy) plays the central role in ergonomics design. In view of such discussion, the second axiomatic design axiom can be adopted for the purpose of ergonomics theory as follows.

The incompatibilty content of the design, I_i for a given functional compatibility requirement (FCR_i), is defined in terms of the compatibility C_i index that satisfies this FCR_i:

$$I_i = \log_2(1/C_i) = -\log_2 C_i \text{ [ints]}$$

where I denotes the incompatibility content of a design, while the compatibility index $\boldsymbol{C_i}$ $[0 < C < 1]$ is defined depending on the specific design goals,that is, the applicable or relevant ergonomics design criterion used for system design or evaluation.

In order to minimize system–human incompatibility, one can (1) minimize exposure to the negative (undesirable) influence of a given design parameter on the system–human compatibility or (2) maximize the positive influence of the desirable design parameter (adaptability) on system–human compatibility. The first design scenario, that is, a need to minimize exposure to the negative (undesirable) influence of a given design parameter (A_i), typically occurs when A_i exceeds some maximum exposure value of R_i, for example, when the compressive force on the human spine (lumbosacral joint) due to manual lifting of loads exceeds the accepted (maximum) reference value. It should be noted that if $A_i < R_i$, then C can be set to 1, and the related incompatibility due to the considered design variable will be zero.

The second design scenario, that is, the need to maximize the positive influence (adaptability) of the desirable feature (design parameter A_i) on system human compatibility), typically occurs when A_i is less than or below some desired or required value of R_i (i.e., minimum reference value). For example, when the range of chair height adjustability is less than the recommended (reference) range of adjustability to accommodate 90% of the mixed (male/female) population. It should be noted that if $A_i > R_i$, then C can be set to 1, and the related incompatibility due to the considered design variable will be zero. In both of the above described cases, the human–system incompatibility content can be assessed as discussed below.

1. *Ergonomics Design Criterion. Minimize exposure* when $A_i > R_i$.

The compatibility index C_i is defined by the ratio R_i/A_i where R_i = maximum exposure (standard) for design parameter i and A_i = actual value of a given design parameter i:

$$C_i = R_i/A_i$$

and hence

$$I_i = -\log_2 C_i = -\log_2(R_i/A_i) = \log_2(A_i/R_i) \text{ ints}$$

Note that if $A_i < R_i$, then C can be set to 1, and incompatibility content I_i is zero.

2. *Ergonomics Design Criterion. Maximize adaptability* when $A_i < R_i$.

The compatibility index C_i is defined by the ratio A_i/R_i, where A_i = actual value of a given design parameter i and R_i = desired reference or required (ideal) design parameter standard i:

$$C_i = A_i/R_i$$

Hence

$$I_i = -\log_2 C_i = -\log_2(A_i/R_i) = \log_2(R_i/A_i) \text{ ints}$$

Note that if $A_i > R_i$, then C can be set to 1 and incompatibility content I_i is zero.

As discussed by Karwowski (2005), the proposed units of measurement for system–human incompatibility (ints) are parallel and numerically identical to the measure of information (bits). The information content of the design in expressed in terms of the (ergonomics) incompatibility of design parameters with the optimal, ideal, or desired reference values, expressed in terms of ergonomics design parameters, such as range of table height or chair height adjustability, maximum acceptable load of lift, maximum compression on the spins, optimal number of choices, maximum number of hand repetitions per cycle time on a production line, minimum required decision time, and maximum heat load exposure per unit of time.

The general relationships between technology of design and science of design are illustrated in Figure 8. Furthermore, Figure 9 depicts such relationships for the HFE discipline. In the context of axiomatic design in ergonomics, the functional requirements are the human–system compatibility requirements, while the design parameters are the human–system interactions. Therefore, ergonomics design can be defined as mapping from the human–system compatibility requirements to the human–system interactions. More generally, HFE can be defined as the science of design, testing, evaluation, and management of human–system interactions according to the human–system compatibility requirements.

7.3 Axiomatic Design Approach in Ergonomics: Applications

Helander (1994, 1995) was first to provide a conceptualization of the second design axiom in ergonomics by considering selection of a chair based on the information content of specific chair design parameters. Recently, Karwowski (2003) introduced the concept of system incompatibility measurements and the measure on incompatibility for ergonomics design and evaluation. Furthermore, Karwowski (2003) has also illustrated an application of the first design axiom adapted to the needs of ergonomics design using an example of the design of the rear-light system utilized to provide information about application of brakes in a passenger car. The rear-light system is illustrated in Figure 10. In this highway safety-related example, the FRs of the rear-lighting (braking display) system were defined in terms

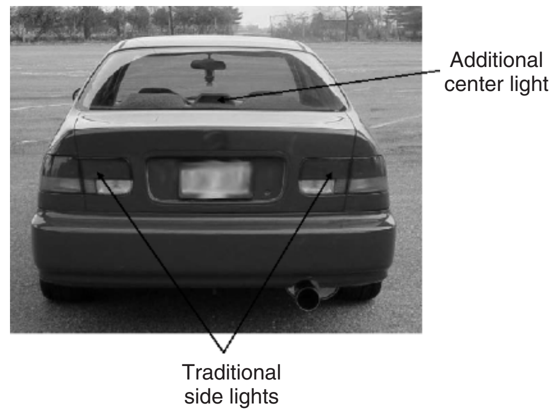


Figure 10 Illustration of redesigned rear-light system of an automobile.

of FRs and DPs as follows:

FR_1 = Provide early warning to maximize lead response time (MLRT) (information about the car in front that is applying brakes)
FR_2 = Assure safe braking (ASB)

The traditional (old) design solution is based on two DPs:

DP_1 = Two rear brake lights on the sides (TRLS)
DP_2 = Efficient braking mechanism (EBM)

The design matrix of the traditional rear-lighting system (TRLS) is as follows:

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{pmatrix} X & 0 \\ X & X \end{pmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix}$$

MLRT	X	0	TRLS
ASB	X	X	EBM

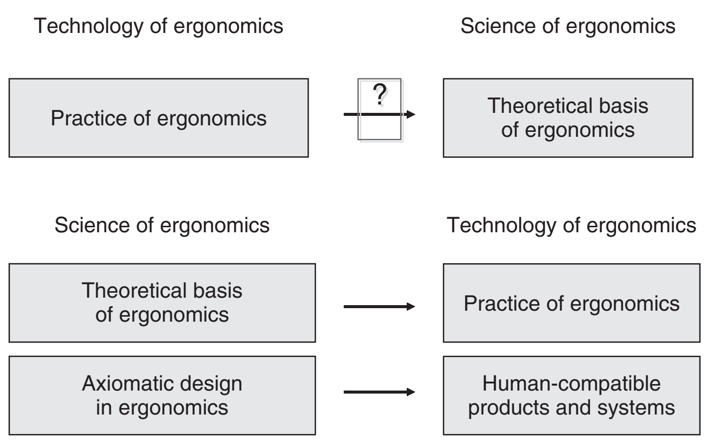


Figure 9 Science, technology, and design in ergonomics (Karwowski, 2003).

This rear-lighting warning system (old solution) can be classified as a *decoupled design* and is not an optimal design. The reason for such classification is that, even with the efficient braking mechanism, one cannot compensate for the lack of time in the driver's response to braking of the car in front due to a sudden traffic slowdown. In other words, this rear-lighting system does not provide early warning that would allow the driver to maximize his or her lead response time (MLRT) to braking.

The solution that was implemented two decades ago utilizes a new concept for the rear lighting of the braking system (NRLS). The new design is based on addition of the third braking light, positioned in the center and at a height that allows this light to be seen through the windshields of the car proceeding the car immediately in front. This new design solution has two DPs:

DP1 = A new rear-lighting system (NRLS)
DP2 = Efficient braking mechanism) (EBM) (the same as before)

The formal design classification of the new solution is an uncoupled design. The design matrix for this new design is as follows:

MLRT	X	0	NRLS
ASB	0	X	EBM

It should be noted that the original (traditional) rear-lighting system (TRLS) can be classified as decoupled design. This old design [$DP_{1,O}$] does not compensate for the lack of early warning that would allow to maximize a driver's lead response time (MLRT) whenever braking is needed and, therefore, violates the second functional requirement (FR_2) of safe beaking. The design matrix for new system (NRLS) is an *uncoupled design* that satisfies the independence of functional requirements (independence axiom). This uncoupled design, [$DP_{1,N}$], fulfills the requirement of maximizing lead response time (MLRT) whenever braking is needed and does not violate the FR_2 (safe braking requirement).

8 THEORETICAL ERGONOMICS: SYMVATOLOGY

It should be noted that the system–human interactions often represent complex phenomena with dynamic compatibility requirements. They are often nonlinear and can be unstable (chaotic) phenomena, the modeling of which requires a specialized approach. Karwowski (2001) indicated a need for symvatology as a corroborative science to ergonomics that can help in developing solid foundations for the ergonomics science. The proposed subdiscipline is called *symvatology*, or the science of the artifact–human (system) compatibility. Symvatology aims to discover laws of the artifact–human compatibility, proposes theories of the artifact–human compatibility, and develops a quantitative matrix for measurement of such compatibility. Karwowski (2001) coined the term symvatology, by joining two Greek words: *symvatotis* (compatibility) and *logos* (logic, or reasoning about). Symvatology is the systematic study (which includes theory, analysis, design, implementation, and application) of interaction processes that define, transform, and control compatibility relationships between artifacts (systems) and people. An *artifact system* is defined as a set of all artifacts (meaning objects made by human work) as well as natural elements of the environment, and their interactions occurring in time and space afforded by nature. A human system is defined as the human (or humans) with all the characteristics (physical, perceptual, cognitive, emotional, etc.) which are relevant to an interaction with the artifact system.

To optimize both the human and system well-being and performance, system–human compatibility should be considered at all levels, including the physical, perceptual, cognitive, emotional, social, organizational, managerial, environmental, and political. This requires a way to measure the inputs and outputs that characterize the set of system–human interactions (Karwowski, 1991). The goal of quantifying artifact–human compatibility can only be realized if we understand its nature. Symvatology aims to observe, identify, describe, and perform empirical investigations and produce theoretical explanations of the natural phenomena of artifact–human compatibility. As such, symvatology should help to advance the progress of the ergonomics discipline by providing a methodology for the design for compatibility as well as the design of compatibility between artificial systems (technology) and humans. In the above perspective, the goal of ergonomics should be to optimize both the human and system well-being and their mutually dependent performance. As pointed out by Hancock (1997), it is not enough to assure the well-being of the human, as one must also optimize the well-being of a system (i.e., the artifacts-based technology and nature) to make the proper uses of life.

Due to the nature of the interactions, an artifact system is often a dynamic system with a high level of complexity, and it exhibits a nonlinear behavior. The *American Heritage Dictionary of English Language* (Morris, 1978) defines "complex" as consisting of interconnected or interwoven parts. Karwowski et al. (1988) proposed to represent the artifact–human system (S) as a construct which contains the human subsystem (H), an artifact subsystem (A), an environmental subsystem (E), and a set of interactions (I) occurring between different elements of these subsystems over time (t). In the above framework, compatibility is a dynamic, natural phenomenon that is affected by the artifact–human system structure, its inherent complexity, and its entropy or the level of incompatibility between the system's elements. Since the structure of system interactions (I) determines the complexity and related compatibility relationships in a given system, compatibility should be considered in relation to the system's complexity.

The system space, denoted here as an ordered set [(complexity, compatibility)], is defined by the four pairs as follows [(high, high), (high, low), (low, high), (low, low)]. Under the best scenario, that is, under the most optimal state of system design, the artifact–human system exhibits high compatibility and low complexity levels. It should be noted that the transition from high to low level of system complexity does not necessarily lead to improved (higher) level of system compatibility. Also, it is often the case in most of the artifact–human systems that an improved (higher) system's compatibility can only be achieved at the expense of increasing the system's complexity.

As discussed by Karwowski et al. (1988), the lack of compatibility, or ergonomics incompatibility (EI), defined as degradation (disintegration) of the artifact–human system, is reflected in the system's measurable inefficiency and associated human losses. In order to express the innate relationship between the systems's complexity and compatibility, Karwowski et al. (1988, 1991) proposed the *complexity–incompatibility principle,* which can be stated as follows: *As the* (*artifact–human*) *system complexity increases, the incompatibility between the system elements, as expressed through their ergonomic interactions at all system levels, also increases, leading to greater ergonomic* (*nonreducible*) *entropy of the system and decreasing the potential for effective ergonomic intervention.* The above principle was illustrated by Karwowski (1995) using as an example the design of an office chair (see Figure 11). Karwowski (1992a) also discussed the complexity–compatibility paradigm in the context of organizational design. It should be noted that the above principle reflects the natural phenomena that others in the field have described in terms of difficulties encountered in humans interacting with consumer products and technology in general. For example, according to Norman (1988), the paradox of technology is that added functionality to an artifact typically comes with the trade-off of increased complexity. These added complexities often lead to increase human difficulty and frustration when interacting with these artifacts. One of the reasons for the above is that technology which has more features also has less feedback. Moreover, Norman noted that the added complexity cannot be avoided when functions are added and can only be minimized with good design that follows natural mapping between the system elements (i.e., the control-display compatibility). Following Ashby's (1964) law of requisite variety, Karwowski (1995) proposed the corresponding law, called the "law of requisite complexity," which states that only design complexity can reduce system complexity. The above means that only the added complexity of the regulator (R = re/design), expressed by the system compatibility requirements (CR), can be used to reduce the ergonomics system entropy (S), that is, reduce overall artifact–human system incompatibility.

9 CONGRUENCE BETWEEN MANAGEMENT AND ERGONOMICS

Advanced technologies with which humans interact toady constitute complex systems that require a high level of integration from both the *design and management* perspectives. *Design integration* typically focuses on the interactions between hardware (computer-based

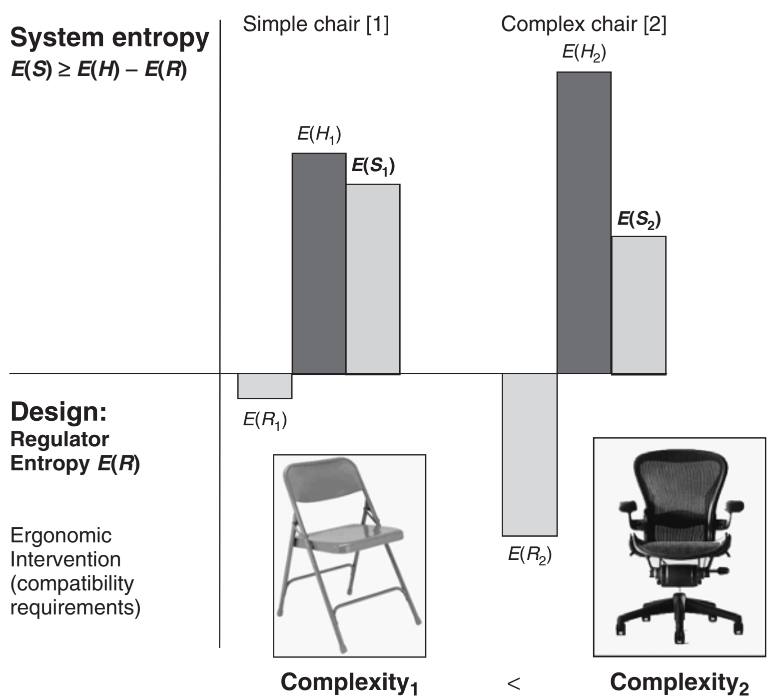


Figure 11 System entropy determination: example of a chair design (after Karwowski, 1995).

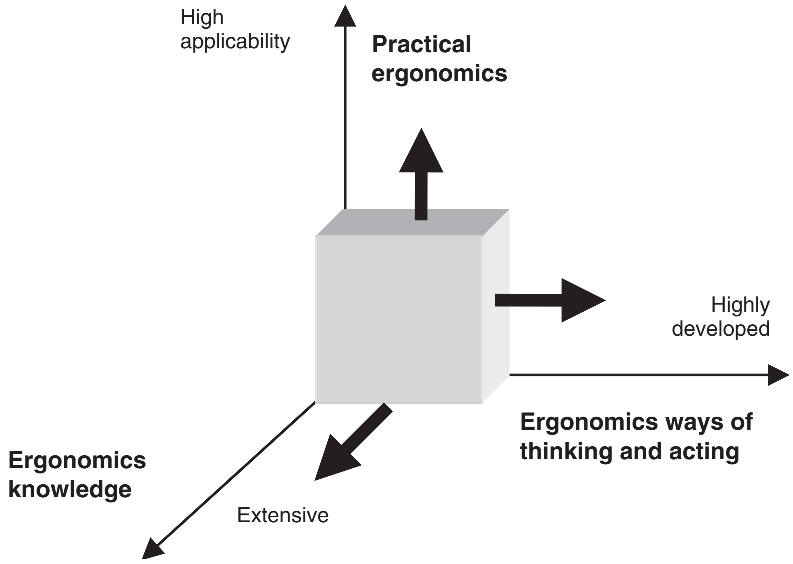


Figure 12 Desired goals for ergonomics literacy (Karwowski, 2003).

technology), organization (organizational structure), information system, and people (human skills, training, and expertise). *Management integration* refers to the interactions between various system elements across the process and product quality, workplace and work system design, occupational safety and health programs, and corporate environmental protection policies. As stated by Hamel (2007), "Probably for the first time since the Industrial Revolution, you cannot compete unless you are able to get the best out of people . . . ." Hamel also pointed out: "You cannot build a company that is fit for the future, unless you build a company that is fit for human beings." Unfortunately, the knowledge base of human factors and its principles of human-centered design have not yet been fully explored and applied in the area of business management. (See Figure 12.)

The scientific management originated with the work by Frederick W. Taylor (1911), who studied, among other problems, *how jobs were designed* and how workers could be trained to perform these jobs. The natural congruence between contemporary management and HFE can be described in the context of the respective definitions of these two disciplines. Management is defined today as a set of activities, including (1) planning and decision making, (2) organizing, (3) leading, and (4) controlling, directed at an organization's resources (human, financial, physical, and information) with the aim of achieving organizational goals in an efficient and effective manner (Griffin, 2001). The main elements of the management definition presented above and central to ergonomics are the following: (1) *organizing*, (2) *human resource planning*, and (3) *effective and efficient achievement of organizational goals*. In the description of these elements, the original terms proposed by the Griffin (2001) are applied in order to ensure precision of the used concepts and terminology. *Organizing* is deciding which is the best way to group organizational elements. The *job design* is the basic building block of an organizational structure. Job design focuses on identification and determination of the tasks and activities for which the particular workers are responsible.

It should be noted that the basic ideas of management (i.e., planning and decision making, organizing, leading, and controlling) are also essential to HFE. An example of the mapping between the management knowledge (planning function) and human factors knowledge is shown in Figure 13. Specifically, common to management and ergonomics are the issues of job design and job analysis. Job design is widely considered to be the first building block of an organizational structure. Job analysis as a systematic analysis of jobs within an organization allows us to determine an individual's work-related responsibilities. The *human resource planning* is an integral part of the human resource management. The starting point for this business function is a *job analysis*, that is, a systematic analysis of the workplace in the organization. *Job analysis* consists of two parts: (1) *job description* and (2) *job specification*. Job description should include description of the task demands and the work environment conditions, such as work tools, materials, and machines needed to perform specific tasks. Job specification determines abilities, skills, and other worker characteristics necessary for *effective and efficient* tasks performance in a particular job.

The discipline of management also considers important human factors that play a role in *achieving organizational goals in an effective and efficient way*. Such factors include (1) work stress in the context of individual workers' behavior and (2) human resource management in the context of safety and health

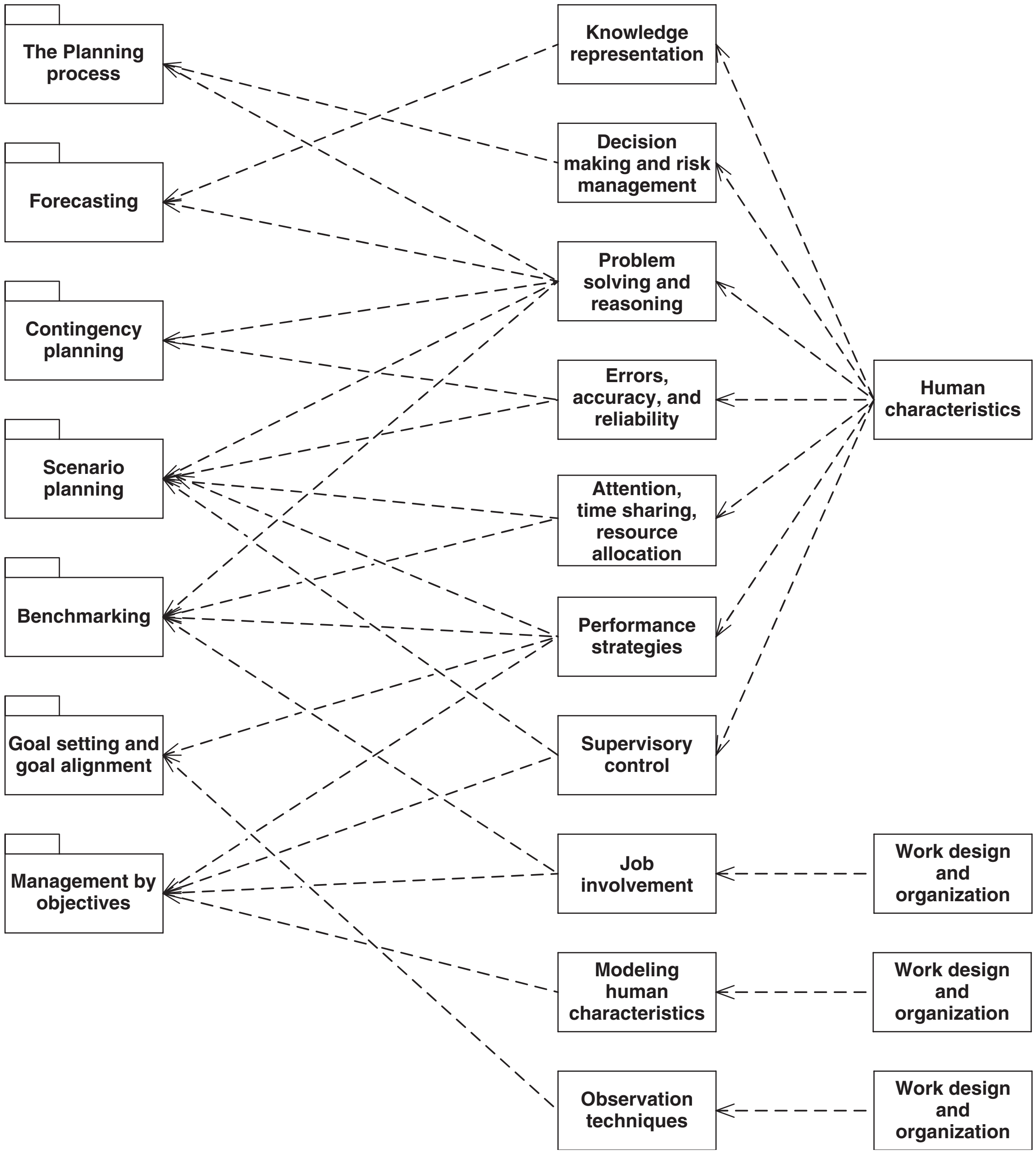


Figure 13 Human factors knowledge mapping: planning processes (left side) related to organizational design as part of business management and relevant human characteristics (middle and right sides).

management. The work stress may be caused by the four categories of the organizational and individual factors: (1) decision related to the *task demands*; (2) *work environment demands*, including physical, perceptional, and cognitive task demands, as well as quality of the work environment, that is, adjustment of the tools and machines to the human characteristics and capabilities; (3) *role demands* related to the relations with supervisor and co-workers; and (4) *interpersonal demands*, which can cause conflict between workers, for example, management style and group pressure. The human resource management includes provision of the safe work conditions and environment at each workstation, in the workplace, and in the entire organization.

It should also be noted that the elements of the management discipline described above, such as *job design, human resource planning* (job analysis and job specification), *work stress management,* and *safety and health management*, are essential components of the HFE subdiscipline often called industrial ergonomics. Industrial ergonomics, which investigates the human–system relationships at the individual workplace (workstation) level or at the work system level, embraces the knowledge that is also of central interest to management. From this point of view, industrial ergonomics in congruence with management is focusing on the organization and management at the workplace level (work system level) through the design and assessment (testing and evaluation) of job tasks, tools, machines, and work environments in order to adapt these to the capabilities and needs of the workers.

Another important subdiscipline of HFE with respect to the central focus of the management discipline is macroergonomics. According to Hendrick and Kleiner (2001), macroergonomics is concerned with the analysis, design, and evaluation of work systems. Work denotes any form of human effort or activity. System refers to *sociotechnical* systems, which range from a single individual to a complex multinational organization. A *work system* consists of people interacting with some form of (1) job design (work modules, tasks, knowledge, and skill requirements), (2) hardware (machines or tools) and/or software, (3) the internal environment (physical parameters and psychosocial factors), (4) the external environment (political, cultural, and economic factors), and (5) an organizational design (i.e., the work system's structure and processes used to accomplish desired functions).

The unique technology of HFE is the *human–system interface technology.* The human–system interface technology can be classified into five subparts, each with a related design focus (Hendrick, 1997; Hendrick & Kleiner, 2001):

1. *Human–machine* interface technology or hardware ergonomics
2. *Human–environment* interface technology or environmental ergonomics
3. *Human–software* interface technology or cognitive ergonomics
4. *Human–job* interface technology, or work design ergonomics
5. *Human–organization* interface technology or macroergonomics In this context, as disussed by (Hendrick and Kleiner, 2001), the HFE discipline discovers knowledge about human performance capabilities, limitations, and other human characteristics in order to develop human–system interface (HSI) technology, which includes the interface design principles, methods, and guidelines. Finally, the HFE profession applies the HSI technology to the design, analysis, test and evaluation, standardization, and control of systems.

10 HUMAN-CENTERED DESIGN OF SERVICE SYSTEMS

An important area of interest to the contemporary HFE discipline is the development and operation of service systems that employ today more than 60% of the workforce in the United States, Japan, and Germany (Salvendy and Karwowski, 2010). The major components in most service operations are people, infrastructure, and technology (Bitran and Pedrosa, 1998). Contemporary service systems can be characterized into four main dimensions (Fähnrich and Meiren, 2007):

- *Structure*: human, material, information, communication, technology, resources, and operating facilities
- *Processes*: process model, service provision
- *Outcomes*: product model, service content, consequences, quality, performance and standards
- *Markets*: requirement model, market requirements, and customer needs

Service system design extends the basic design concepts to include the experience that clients have with products and services. It also applies to the processes, strategies, and systems that are behind the experiences (Moritz, 2005). The key principles of customer-centered service system (CSS) design are characterized by the relationship between knowledge and technology. CSS involves the knowledge that is required to deliver the service, whether it is invested in the technology of the service or in the service provider (Hulshoff et al., 1998; McDermott et al., 2001).

Knowledge requirements in service systems design and modeling have been categorized into three main categories: knowledge based, knowledge embedded, and knowledge separated (McDermott et al., 2001). A knowledge-based service system such as teaching depends on customer knowledge to deliver the service. This knowledge may become embedded in a product that makes the services accessible to more people. An example of this is logistics providers, where the technology of package delivery is embedded in service system computers that schedule and route the delivery of packages. The delivery personnel contribute to critical components of both delivery and pickup. Their knowledge is crucial to satisfying customers and providing quality services. The CSS approach contributes to systems development processes rather than replaces them. Key principles of customer-centered service systems have been identified:

- *Clear Understanding of User and Task Requirements*. Key strengths of customer-centered service systems design are the spontaneous and active involvement of service users and the understanding of their task requirements. Involving end users will improve service system acceptance and increase commitment to the success of the new service.
- *Consistent Allocation of Functions between Users and Service System*. Allocation of

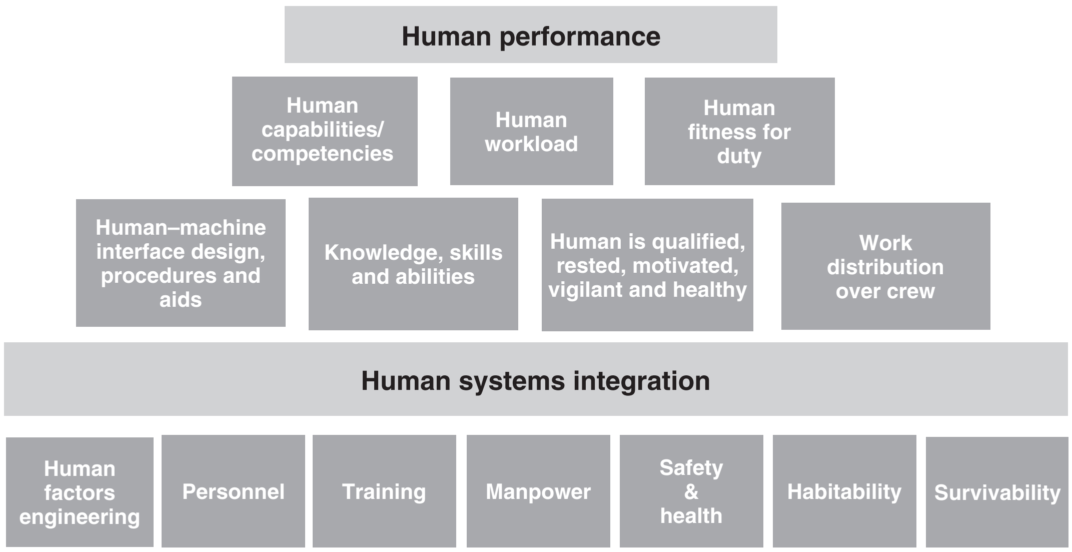


Figure 14 Domains of human systems integration (adapted from Air Force, 2005).

functions should be based on full understanding of customer capabilities, limitations, and task demands.

- *Iterative Service System Design Approach*. Iterative service system design solutions include processing responses and feedback from service users after their use of proposed design solutions. Design solutions could range from simple paper prototypes to high-fidelity service systems mock-ups.
- *Multidisciplinary Design Teams*. Customer-centered service system design is a multitask collaborative process that involves multidisciplinary design teams. It is crucial that the service system design team comprise professionals and experts with suitable skills and interests in the proposed service system design. Such a team might include end users, service handlers (front-stage service system designers), managers, usability specialists, software engineers (back-stage service system designers), interaction designers, user experience architects, and training support professionals.

11 HUMAN–SYSTEMS INTEGRATION

The HFE knowledge is also being used for the purpose of human–systems integration (HSI), especially in the context of applying systems engineering to the design and development of large-scale, complex technological systems, such as those for the defense and space exploration industries (Malone and Carson, 2003; Handley and Smillie, 2008; Hardman et al., 2008; Folds et al., 2008). The knowledge management human domains have been identified internationally and are shown in Figure 14. These include human factors engineering, manpower, personnel, training, safety and health hazards, habitability, and survivability. As discussed by Ahram and Karwowski (2009a, 2009b), these domains are the foundational human-centered domains of HSI and can be described as follows (Air Force, 2005, 2008, 2009):

Manpower Manpower addresses the number and type of personnel in the various occupational specialties required and potentially available to train, operate, maintain, and support the deployed system based on work and workload analyses. The manpower community promotes the pursuit of engineering designs that optimize the efficient and economic use of manpower, keeping human resource costs at affordable levels. Program managers and decision makers, who determine which manpower positions are required, must recognize the evolving demands on humans (cognitive, physical, and physiological) and consider the impact that technology can make on humans integrated into a system, both positive and negative.

Personnel The personnel domain considers the type of human knowledge, skills, abilities, experience levels, and human aptitudes (i.e., cognitive, physical, and sensory capabilities) required to operate, maintain, and support a system and the means to provide (recruit and retain) such people. System requirements drive personnel recruitment, testing, qualification, and selection. Personnel population characteristics can impact manpower and training as well as drive design requirements.

Human Factors Engineering Human factors engineering involves understanding and comprehensive integration of human capabilities (cognitive, physical, sensory, and team dynamics) into a system design, starting with conceptualization and continuing through system disposal. The primary concern for human factors engineering is to effectively integrate human–system interfaces to achieve optimal total system performance (use, operation, maintenance, support, and sustainment). Human factors engineering, through comprehensive task analyses (including cognitive), helps define system functions and then allocates those functions to meet system requirements.

Environment Environment considers conditions within and around the system that affect the human's ability to function as part of the system. Steps taken to protect the total system (human, hardware, and software) from the environment as well as the environment (water, air, land, space, cyberspace, markets, organizations, and all living things and systems) from the systems design, development, manufacturing, operation, sustainment, and disposal activities are considered here. Environmental considerations may affect the concept of operations and requirements.

Safety and Occupational Health Safety promotes system design characteristics and procedures that minimize the potential for accidents or mishaps that cause death or injury to operators, maintainers, and support personnel as well as stakeholders and bystanders. The operation of the system itself is considered as well as prohibiting cascading failures in other systems. Using safety analyses and lessons learned from prior systems (if they exist), the safety community prompts design features to prevent safety hazards where possible and to manage safety hazards that cannot be avoided. The focus is on designs that have redundancy and, where an interface with humans exists, alerting the operators and users alike when problems arise and also help to avoid and recover from errors. Occupational health promotes system design features and procedures that minimize the risk of injury, acute or chronic illness, and disability and enhance job performance of personnel who operate, maintain, or support the system. The occupational health community seeks to prevent health hazards where possible and recommends personal protective equipment, protective enclosures, or mitigation measures where health hazards cannot be avoided. However, a balance must be found between providing too much information, thus increasing workload to unsafe levels, and mitigating minor concerns (i.e., providing too much information on faults such that managing this information becomes a task in of itself).

Habitability Habitability involves the characteristics of system living and working conditions such as lighting, ventilation, adequate space, vibration, noise, temperature control, availability of medical care, food and drink services, suitable sleeping quarters, sanitation, and personnel hygiene facilities. Such characteristics are necessary to sustain high levels of personnel morale, motivation, quality of life, safety, health, and comfort, contributing directly to personnel effectiveness and overall system performance. These habitability characteristics also directly impact personnel recruitment and retention.

Survivability Survivability addresses the characteristics of a system (e.g., life support, personal protective equipment, shielding, egress or ejection equipment, air bags, seat belts, electronic shielding) that reduce susceptibility of the total system to operational degradation or termination, to injury or loss of life, and to a partial or complete loss of the system or any of its components. These issues must be considered in the context of the full spectrum of anticipated operations and operational environments and for all people who will interact with the system (e.g., users/customers, operators, maintainers, or other support personnel). Adequate protection and escape systems must provide for personnel and system survivability when they are threatened with harm.

Malone and Carson (2003) stated the goal of the HSI paradigm as "to develop a system where the human and machine synergistically and interactively cooperate to conduct the mission." They state that the "low hanging fruit" of performance improvement lies in the human–machine interface block. The basic steps for the HSI approach can be summarized as follows (Karwowski and Ahram, 2009):

- *Human–Systems Integration Process*. Apply a standardized HSI approach that is integrated with systems processes.
- *Top-Down Requirements Analysis*. Conduct this type of analysis at the beginning and at appropriate points to decide which steps to take to optimize manpower and system performance.
- *Human–Systems Integration Strategy*. Incorporate HSI inputs into system processes throughout the life cycle, starting from the beginning of the concept and continuing through the operational life of the system.
- *Human–Systems Integration Plan*. Prepare and update this plan regularly to facilitate HSI activities.
- *Human–Systems Integration Risks*. Identify, prioritize, track, and mitigate factors that will adversely affect human performance.
- *Human–Systems Integration Metrics*. Implement practical metrics in specifications and operating procedures to evaluate progress continually.
- *Human Interfaces*. Assess the relationships between the individual and the equipment, between the individual and other individuals, and between the individual (or organization) and the organization to optimize physiological, cognitive, or sociotechnical operations.
- *Modeling*. Use simulation and modeling tools to evaluate trade-offs.

12 COMMITTEE ON HUMAN–SYSTEMS INTEGRATION OF THE NATIONAL RESEARCH COUNCIL

As described by the NRC (2010), the Committee on Human Factors was originally created in 1980 at the request of the U.S. Army, Navy, and Air Force to assist them in addressing various military issues. This committee was renamed in 2008 as the Committee on Human-Systems Integration (COHSI) and has expanded its scope of activities to include nonmilitary issues, such as human factors engineering, physical ergonomics, training, occupational health and safety, health care,

Table 12 Membership of the International Ergonomics Association

Federated Societies	Society name	Initials	Website
Argentina	Argentinian Ergonomics Society	ADEA	www.adeargentina.org.ar
Australia	Human Factors and Ergonomics Society of Australia	HFESA	http://www.ergonomics.org.au
Austria	Austrian Ergonomics Society	OAE	www.imw.tuwien.ac.at/oeae
Belgium	Belgian Ergonomics Society	BES	http://www.emploi.belique.be
Brazil	Brazilian Ergonomics Society	ABERGO	www.abergo.org.br
Canada	Association of Canadian Ergonomists	ACE	www.ace-ergocanada.ca
Chile	Chilean Ergonomics Society	SOCHERGO	http://www.sochergo.cl/
China	Chinese Ergonomics Society	ChES	n/a
Columbia	Colombian Ergonomics Society	SCE	http://www.sociedadcolombianadeergonomia.com/
Croatia	Croatian Ergonomics Society	CrES	n/a
Czech Republic	Czech Ergonomics Society	CzES	http://www.bozpinfo.cz/
Ecuador	Ecuador Ergonomics Society	AEERGO	n/a
Francophone Society	French Language Ergonomics Society	SELF	http://www.ergonomie-self.org/
Germany	German Ergonomics Society	GFA	www.gfa-online.de
Greece	Hellenic Ergonomics Society	HES	www.ergonomics.gr
Hong Kong	Hong Kong Ergonomics Society	HKES	http://www.ergonomics.org.hk/
Hungary	Hungarian Ergonomics Society	MES	http://www.met.ergonomiavilaga.hu/subsites/index_eng.htm
India	Indian Society of Ergonomics	ISE	http://www.ise.org.in/
Indonesia	Indonesian Ergonomics Society	PEI	http://www.iesnet.org
Iran	Iranian Ergonomics Society	IES	www.modares.ac.ir/ies
Ireland	Irish Ergonomics Society	IrES	http://www.ergonomics.ie/IES.html
Israel	Israel Ergonomics Association	IEA	http://www.ergonomicsisrael.org
Italy	Italian Society of Ergonomics	SIA	www.societadiergonomia.it
Japan	Japan Ergonomics Society	JES	http://www.ergonomics.jp
Latvia	Latvian Ergonomics Society		http://www.ergonomika.lv
Mexico	Mexican Ergonomics Society	SEM	http://www.semac.org.mx
Netherlands	Dutch Ergonomics Society	NVVE	www.ergonoom.nl
New Zealand	New Zealand Ergonomics Society	NZES	www.ergonomics.org.nz
Nordic countries	Nordic Ergonomics Society	NES	http://www.nordicergonomics.org/
Philippines	Philippines Ergonomics Society	PHILERGO	n/a
Poland	Polish Ergonomics Society	PES	http://ergonomia-polska.com
Portugal	Portuguese Ergonomics Association	APERGO	n/a
Russia	Inter-Regional Ergonomics Association	IREA	n/a
Serbia	Ergonomics Society of Serbia	ESS	n/a
Singapore	Ergonomics Society of Singapore	ERGOSS	http://www.ergoss.org/
Slovakia	Slovak Ergonomics Association	SEA	n/a
South Africa	Ergonomics Society of South Africa	ESSA	www.ergonomicssa.com
South Korea	Ergonomics Society of Korea	ESK	http://esk.or.kr
Spain	Spanish Ergonomics Association	AEE	http://www.ergonomos.es
Switzerland	Swiss Society for Ergonomics	SSE	http://www.swissergo.ch/de/index.php
Taiwan	Ergonomics Society of Taiwan	EST	www.est.org.tw
Thailand	Ergonomics Society of Thailand	EST	www.est.or.th
Tunisia	Tunisian Ergonomics Society	STE	http://www.st-ergonomie.org/
Turkey	Turkish Ergonomics Society	TES	

Table 12 (*continued*)

Federated Societies	Society name	Initials	Website
Ukraine	All-Ukrainian Ergonomics Association	AUEA	http://ergotech.org.ua
United Kingdom	Institute of Ergonomics and Human Factors	ES	http://www.ergonomics.org.uk/
United States	Human Factors and Ergonomics Society	HFES	http://hfes.org
Affiliated Societies			
Japan	Human Ergology Society	HES	http://www.humanergology.com
Nigeria	Ergonomics Society of Nigeria	ESN	www.esnig.org
IEA Networks			
	South-East Asia Network of Ergonomics Societies	SEANES	http://www.seanes.org/index1_type.html
	Federation of European Ergonomics Societies	FEES	www.fees-network.org
	Union of Latin-American Ergonomics Societies	ULAERGO	www.ulaergo.net

Note: n/a = not available in public domain.
Source: www.iea.cc.

product design, and macroergonomics. The main objective of the committee is *to provide new perspectives on theoretical and methodological issues concerning the relationship of individuals and organizations to technology and the environment; identify critical issues in the design, test, evaluation, and use of new human-centered technologies; and advise committee sponsors on the research needed to expand the scientific and technical bases for effectively designing new technology and training employees*. Currently, the meetings and activities of the COHSI are sponsored by the Agency for Healthcare Research and Quality, Federal Aviation Administration, the Human Factors and Ergonomics Society, the National Institute on Disability and Rehabilitation Research, Office of Naval Research, the U.S. Army Research Laboratory, and the U.S. Air Force Research Laboratory.

13 THE INTERNATIONAL ERGONOMICS ASSOCIATION (WW.IEA.CC)

Over the last 30 years, ergonomics as a scientific discipline and as a profession has been rapidly growing, expanding its scope and breadth of theoretical inquiries, methodological basis, and practical applications (Meister 1997, 1999; Chapanis, 1999; Stanton and Young, 1999; Kuorinka, 2000; Karwowski, 2001; IEA 2003). As a profession, the field of ergonomics has seen development of formal organizational structures (i.e., the national and cross-national ergonomics societies and networks) in support of HFE discipline and professionals internationally. As of 2010, the IEA consisted of 47 member (federated) societies plus 2 affiliated societies and 3 IEA networks, representing over 18,000 HFE members worldwide (see Table 12). The main goals of the IEA are to elaborate and advance the science and practice of ergonomics at an international level and to improve the quality of life by expanding the scope of ergonomics applications and contributions to the global society. A list of current IEA technical committees is shown in Table 13.

Some past IEA activities have focused on development of programs and guidelines in order to facilitate the discipline and profession of ergonomics worldwide. Examples of such activities include an international directory of ergonomics programs, core competencies in ergonomics, criteria for IEA endorsement of certifying bodies in professional ergonomics, guidelines for a process of endorsing a certification body in professional ergonomics, guidelines on standards for accreditation of ergonomics education programs at tertiary (university) level, or ergonomics quality in design (EQUID) programs. More information about these programs can be found on the IEA websire (www.ie.cc). In addition to the above, the IEA endorses scientific journals in the field. A list of the core HFE journals is given in Table 14. A complete classification of the core and related HFE journals was proposed by Dul and Karwowski (2004).

The IEA has also developed several actions for stimulating development of HFE in industrially developing countries (IDCs). Such actions include the following elements:

- Cooperating with international agencies such as the ILO (International Labour Organisation), WHO (World Health Organisation), and professional scientific associations with which the IEA has signed formal agreements
- Working with major publishers of ergonomics journals and texts to extend their access to

Table 13 IEA Technical Committees

Activity Theories for Work Analysis and Design
Aerospace HFE
Affective Product Design
Aging
Agriculture
Anthropometry
Auditory Ergonomics
Building and Construction
Ergonomics for Children and Educational Environments
Ergonomics in Design
Ergonomics in Manufacturing
Gender and Work
Healthcare Ergonomics
Human Factors and Sustainable Development
Human Simulation and Virtual Environments
Mining
Musculoskeletal Disorders
Online Communities
Organizational Design and Management
Process Control
Psychophysiology in Ergonomics
Safety & Health
Slips, Trips and Falls
Transport
Visual Ergonomics
Work with Computing Systems (WWCS)

Source: www.iea.cc

federated societies, with particular focus on developing countries

- Development of support programs for developing countries to promote ergonomics and extend ergonomics training programs
- Promotion of workshops and training programs in developing countries through the supply of educational kits and visiting ergonomists
- Extending regional ergonomics "networks" of countries to countries with no ergonomics programs located in their region
- Supporting non-IEA member countries considering application for affiliation to the IEA in conjunction with the IEA Development Committee

14 FUTURE HFE CHALLENGES

The contemporary HFE discipline exhibits rapidly expanding application areas, continuing improvements in research methodologies, and increased contributions to fundamental knowledge as well as important applications to the needs of the society at large. For example, the subfield of neuroergonomics focuses on the neural control and brain manifestations of the perceptual, physical, cognitive, emotional, and so on, interrelationships in human work activities (Parasuraman, 2003). As the science of the brain and work environment, *neuroergonomics* aims to explore the premise of design of work to match the neural capacities and limitations of people. The potential benefits of this emerging branch of HFE are improvements of medical therapies and applications of more sophisticated workplace design principles. The near future will also see development of the entirely new HFE domain that can be called nanoergonomics. Nanoergonomics will address the issues of humans interacting with the devices and machines of extremely small dimensions and in general with the nanotechnology.

Finally, it should be noted that developments in technology and the socioeconomic dilemmas of the twenty-first century pose significant challenges for HFE discipline and profession. According to the report on major predictions for science and technology in the

Table 14 Core HFE Journals

Official IEA journal	*Ergonomics*[a]
IEA-endorsed Journals	*Applied Ergonomics*[a]
	Human Factors and Ergonomics in Manufacturing and Service Industries[a]
	International Journal of Industrial Ergonomics[a]
	International Journal of Human-Computer Interaction[a] *International Journal of Occupational Safety and Ergonomics*
	Theoretical Issues in Ergonomics Science
	Ergonomia: An International Journal of Ergonomics and Human Factors
Other core journals	*Human Factors*[a]
	Le Travail Human[a]
Non-ISI journals	*Asian Journal of Ergonomics*
	Japanese Journal of Ergonomics
	Occupational Ergonomics
	Tijdschrift voor Ergonomie
	Zeitschrift für Arbeitswissenschaft
	Zentralblatt für Arbeirsmedizin, Arbeitsschurz und Ergonomie

Source: Dul and Karwowski (2004).
[a]ISI (Institute for Scientific Information) ranked journals.

twenty-first century published by the Japan Ministry of Education, Culture, Sports, Science and Technology MEXT (2006), several issues will affect the future of our civilization, including developments in genetics (creation of an artificial life, extensive outer space exploration); developments in cognitive sciences (human cognitive processes through artificial systems); a revolution in medicine (cell and organ regeneration, nanorobotics for diagnostics and therapy, superprosthesis, artificial photosynthesis of foods, elimination of human starvation and malnutrition, and safe genetic foods manipulation); full recycling of resources and reusable energy (biomass and nanotechnology); changes in human habitat (100% underground manufacturing, separation of human habitat from natural environments); clean-up of the negative effects of the twentieth century (natural sources of clean energy); communication, transport, and travel (automated transport systems, revolution in supersonic small aircraft and supersonic travel, underwater ocean travel); and human safety (human error avoidance technology, control of the forces of nature, intelligent systems for safety in all forms of transport). The above issues will also affect the future direction in the development of human factors and ergonomics, as the discipline that focuses on the science, engineering, design, technology, and management of human-compatible systems.

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