CHAPTER 12

Integrating Training into the Design and Operation of Complex Systems

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12.1 INTRODUCTION

A challenging, new state of affairs is confronting public- and private-sector organizations engaged in the design and deployment of complex sociotechnical systems.[1] Chapter 1 aptly summarizes this by noting that systems and products that can be operated and repaired by fewer people, lesser skilled people, and/or people with less training will be in greater demand. It is not an impractical expectation for the military, and probably for many commercial areas as well, to demand human systems integration (HSI) designs that will allow reductions in all three areas—manpower, personnel, and training (MPT)—together.

If current trends hold, these organizations will be increasingly challenged to accomplish more with significantly diminished financial and personnel resources. Specifically, they will be called upon to develop and field systems that are "better" (more operationally effective) than their predecessors, even though their design and operation will be supported with fewer traditional resources (e.g., funding, manpower, etc.). Advanced military systems, such as the U.S. Navy's planned CVNX aircraft carrier, are already being approached with these expectations and constraints firmly in place. The CVNX is intended to be far more operationally effective than earlier Nimitz-class carriers but with an approximate 27 percent reduction in crew size (Smith and Driscoll, 2000). Similarly, the planned DD-X class of new naval destroyers is projected to operate with an even greater percentage reduction in crew size—and, again, with greatly improved performance capabilities. Indeed, it seems apparent that the U.S. military's strategic paradigm is shifting away from a reliance on overwhelming force (in terms of sheer numbers of personnel and weapons platforms) toward increased reliance on superior technology, stealth, flexibility, and speed. And while critical resources underlying system development and deployment may be diminishing, performance expectations certainly are not. Clearly, the development of large-scale military systems has entered an era in which intelligent, coordinated,

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multidisciplinary cooperation among design disciplines will be required to produce high-performance technologies.

An analogous shift is occurring in many nongovernment sectors of the economy, those in which some combination of personnel cutbacks, budgetary pressures, and increased performance demands are present.[2] The fact that these constraints are also typically accompanied by significant timeline pressures (e.g., bringing products to market before one's competitors in the private sector; adhering to aggressive timelines for system development and deployment in the public sector) has led to significant interest in the development and application of an efficient and effective means of designing and deploying new systems.

The HSI approach provides a set of effective guidelines for accomplishing these complex and frequently conflicting objectives. The principles and methods of the HSI approach reflect (1) an unwavering concentration on the user as the focal point of any sociotechnical system in order to achieve high levels of safe and effective system performance and (2) the application of a coordinated, multidisciplinary approach among the core elements of the systems engineering process during all phases of acquisition from concept formulation to deployment. As described elsewhere in this book (e.g., Chapter 18), the HSI approach has led to the development of effective and safe systems in a manner whose efficiency is reflected in the life-cycle cost savings as well as in enhanced usability and effectiveness of the systems themselves.

Despite several successful applications to date, the HSI model is still a new approach with a number of important areas remaining for growth and elaboration. Nowhere is this more evident than in enhancing training to reach its full potential as a critical HSI domain.

12.1.1 Role of Training in System Design and Deployment

The vital importance of training in supporting the effective performance of systems has long been recognized. Obviously, effective training has been, is, and will continue to be a critical element of successful systems for the foreseeable future and beyond. However, an HSI approach to systems acquisition affords an important, new role for training within the total context of an *integrated*, *multidisciplinary* approach to systems design and deployment. It also addresses the apparent workforce reality that resources for training will continue to experience significant pressure and the training community (like other systems engineering components) will continue to be called on to accomplish more with less.

The HSI design philosophy emphasizes three key aspects of training:

1. the role training plays in supporting the effective performance of deployed systems;
2. the role that training considerations and expertise play throughout all phases of the *design* and *test* of systems, well before they are deployed; and
3. the positive impact that the HSI approach can have on the training community itself, primarily by facilitating interactions with other domains whose concerns are principally with optimizing aspects of human performance.

The first point corresponds to training's traditional role—one in which a specific, fully developed system is taken as a starting point and within which training applies its trade toward equipping people with the knowledge, skills, and abilities (KSAs) and devices necessary to interact with the system. This is the area in which training specialists have most commonly devoted their time and attention. Adding the second and third points is the challenge posed by HSI.

As one of the oldest and most prestigious domains of applied psychology, training is an area of impressive scholarship and real-world accomplishment, and there are several excellent, contemporary reviews of this work (e.g., Patrick, 1992; Salas and Cannon-Bowers, 2001; Swezey and Andrews, 2001). While I will discuss some of the main elements of this literature and have relied heavily on these reviews throughout this chapter, my main interest will be to review several key areas of training research and development in order to analyze how the various issues and challenges relate to an HSI training approach. Specifically, how can we best apply the considerable expertise contained within the training community to better support the *entire* system design and deployment process? How can we intelligently design systems so that training requirements will not be as onerous once they are built and deployed, thereby enabling more efficient and effective use of limited training resources? And how can training itself be improved through more thorough integration with other HSI domains and procedures?

To approach this problem, we will need to examine the nature of the potential interactions between training and the other elements of the HSI approach and how the products of these interactions can be used to enhance the total system acquisition process. For instance, training and personnel selection are two areas with considerable functional overlap. Clearly, it is vital for training and personnel selection specialists to efficiently interact with one another—for instance, when training informs personnel of projected personnel attributes and characteristics that will be needed to support specific systems or when personnel informs training of a deficit of such people in the personnel assignment pool. However, it is also likely that training expertise and knowledge can inform and benefit the activities of human factors engineers, safety and health specialists, and others involved in the up-front development and testing of a new system. Similarly the expertise of these groups, in turn, can likely inform and benefit the activities of training experts.

One of the purposes of this chapter is to show examples where considerable benefits to the systems acquisition process can be derived from application of training expertise earlier in the process and through greater interaction with the other functional domains. These benefits can be expected not only in the form of cost and time savings through early anticipation of training problems but also through more innovative designs. It is not unreasonable to expect many creative ideas to appear when training specialists interact with other HSI professionals and systems engineering disciplines on a consistent, daily basis. The outcome of these synergistic processes will take the form of design and test insights that will, in all likelihood, significantly enhance the overall performance of new systems.

12.1.2 Overview of Chapter

The objective of this chapter is to discuss issues and challenges associated with effectively applying the training domain throughout the system life cycle using the HSI principles and methods described throughout this book.

The chapter covers the following topics:

1. *Traditional Training Model* This section covers the objectives and fundamental activities of training and provides an overview of the systems development process depicting the traditional training role.

2. *New HSI Training Model* A new training definition is provided, synergies between training and the other HSI domains are discussed, and considerations for integrating training within the systems development process are identified.
3. *Issues and Challenges* This section reviews some of the key issues that have been examined by training specialists over the years, identifies key challenges currently facing the training domain, and considers the relevance of these topics for an HSI approach to systems design.
4. *Conclusions and Recommendations* In order for training to be most effectively integrated within an HSI approach, a number of important research questions must be addressed. In addition, there are important issues more directly related to the culture and organization of complex systems design and deployment. The former topics are more empirical and scientific in nature, while the latter are more related to programmatic and administrative concerns. This section will describe issues and make some recommendations relevant to both types.

12.2 TRADITIONAL TRAINING MODEL

What is the purpose of training? At the most general level, this question is usually addressed by noting that training exists to promote the acquisition, retention, and transfer of specific sets of skills and abilities (e.g., Patrick, 1992, pp. 13–14). Training, it has often been noted, is not the same as education. The two domains have traditionally been differentiated by emphasizing training's concentration on very specifically defined sets of skills as opposed to education's more global purpose of "broadening the mind" and developing the intellect. However, as a result of the profound changes impacting the nature of contemporary work environments, the traditional differences between training and education are perhaps becoming less distinct and less meaningful than in the past. As we attempt to prepare individuals to become adept at coping with rapid and significant change in work environment characteristics, much may be gained by broadening the scope of training to include skills associated with "learning to learn."[3]

Clearly, one of the major purposes of training is to identify and devise practical methods and technologies for imparting the skills that people need to successfully function within complex systems. However, within an HSI perspective the objective of training is expanded to include a concern with the development of KSAs to handle *all* aspects of the sociotechnical system. Simply put, the new objective of training is to promote the design and operation of highly functional systems by

1. promoting awareness of training needs and requirements at all phases of the system acquisition process and
2. incorporating knowledge from other technical domains within its conception of system training requirements and approaches.

12.2.1 Fundamental Training Activities

Figure 12.1 provides a conceptual illustration of the role of training in the systems design process implied by the traditional definition. Four fundamental activities are seen as

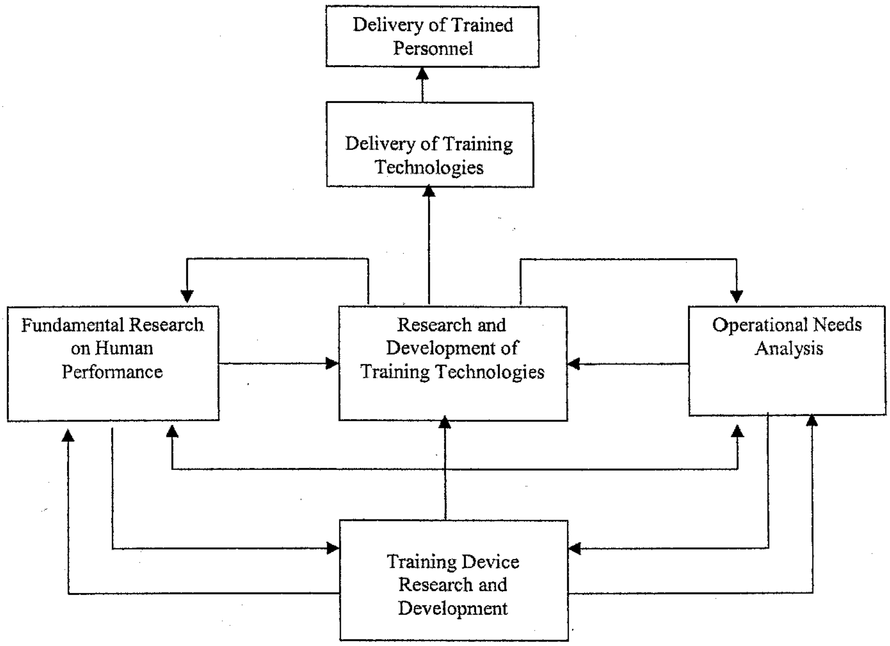

Figure 12.1 Schematic diagram representing traditional flow of training expertise within systems design and deployment process.

forming the basis of the role of training in complex systems design and deployment, particularly with respect to large-scale military procurements:

1. *Fundamental Research on Human Performance* Research within the broad area of human performance, including domains such as cognition, learning, problem solving, decision making, psychomotor performance, etc., plays an important role in the identification of (1) the types of cognitive, perceptual, and motor abilities that underlie skilled performance; (2) the means by which humans acquire these skills; and (3) the means by which the presence or absence of these abilities can be reliably assessed. In the realm of training research and practice, these are perhaps the most scientifically based areas of investigation.

2. *Operational Needs Analysis* This analysis is an empirical determination of system performance requirements, particularly with respect to the nature of the role played by human operators. Techniques such as cognitive work analysis, hierarchical task analysis, knowledge mapping, etc., are widely used to extract information about global characteristics of operators' tasks as well as more detailed information such as the timing of information delivery and corresponding human performance requirements in operational environments.

3. *Training Device Research and Development* This activity reflects the engineering and human factors research conducted on the design and application of new technical approaches to training (e.g., advanced simulation devices, virtual environment systems, etc.). Typically, this area of training research and practice is devoted to the development of new training hardware and software for eventual deployment into the operational training

environment and includes work in the area of simulation and virtual environment systems as well as technologies for delivering training during system deployment.

4. *Training Technology Research and Development* The output of the above three activities is manifest in the form of training technologies—specifically, training concepts, curricula, and devices that best represent current knowledge about training needs, training devices, and human skills acquisition. When combined with specific knowledge about the operational needs and constraints of the targeted training environment, the output of this area of training research and practice is the delivery of training technologies to the operational community.

As depicted in Figure 12.1, none of these areas operate independently of one another. Nor is there (or should there be) a strictly linear relationship between these activities. One does not feed directly into another without some reciprocal influence. Certainly it is in the best interest of large-scale training programs to have all these areas effectively interacting with one another. Particularly in an era of reduced research and development (R&D) budgets it would be wise, for example, for activities within the *fundamental research on human performance* area to be closely linked with current and future requirements identified by the *operational needs analysis* area. Otherwise, the former risks becoming estranged from the real-world requirements identified by the latter.

Figure 12.1 illustrates a model that makes sense and has worked well [particularly within large-scale Department of Defense (DoD) training programs], but it has a serious flaw with respect to the interaction of training programs with other disciplines involved in system development. Specifically, within the traditional model, training takes the form of a very "stovepiped" activity. In other words, while certainly not operating in a complete vacuum, training tends to be isolated from other mainstream system disciplines.[4]

12.2.2 Training in the System Development Process

Figure 12.2 provides a simplified schematic of the systems design and deployment process in which the traditional training role is depicted. Four major system acquisition cycle activities are illustrated:

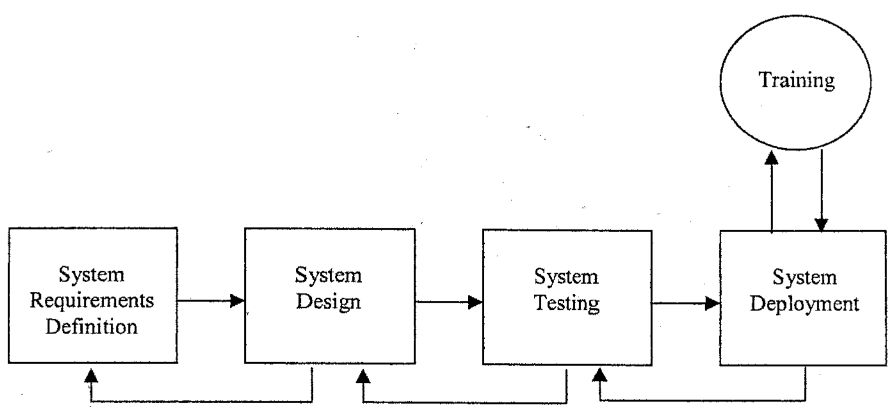

Figure 12.2 Schematic representation of system development process featuring the traditional role played by training.

1. *System Requirements Definition* The origin of any new system results from the establishment of some need in the user community. In the case of military systems, this need may arise from the level of the individual warfighter (e.g., a stated need for improved sighting mechanisms on small arms) or from a more strategic level (e.g., a stated need for a high-performance destroyer to operate in *littoral* environments with greatly reduced crew sizes—the DD-X). Quite often, of course, the identification of needs has relevance for both levels of analysis. It is in this stage that the overall objectives of the system are identified and performance specifications are determined.

2. *System Design* Once a need has been established and the necessary approval granted to proceed with development of candidate systems,[5] the design process can begin in earnest. With particularly transformational technologies (such as the U.S. Navy's DD-X and CVNX programs, the U.S. Air Force's F-22 program, and the multiservice Joint Strike Fighter program) this stage of the process quickly becomes extremely complex. Large-scale, *transformative* systems acquisition projects can lead to the initiation of extensive basic and applied R&D programs involving large teams of scientists, engineers, and management and support personnel. While these teams are often widely dispersed in a geographical and organizational sense (and are often in competition with one another for resources and influence), their overall mission is to produce a working prototype of the system under consideration.

3. *System Testing* While testing of system components is almost always conducted as part of the system design process, ultimately, a form of acceptance testing must be conducted to determine whether or not the entire finished product meets stated specifications. Acceptance testing of systems in the field typically includes assessment of overall system performance, generally assessed in terms of a battery of operationally relevant performance metrics, as well as a variety of tests of subsystem components.

4. *System Deployment* Following successful completion of the initial three phases of design, the system is ready to be deployed. At this point and throughout the system's effective life cycle, changes may occasionally be made based on changing strategic needs, advances in technology, etc. However, for all intents and purposes the design cycle is effectively ended once the system is deployed.

As the model in Figure 12.2 implies, input from the training community has traditionally been solicited only toward the end of the design cycle. In the worst-case scenario, training specialists are called upon to begin their work once a system has more or less reached its final design and is ready for deployment, at which point they obviously will not have had any input on requirements, design, and testing issues that may have facilitated the eventual design of training programs and enhanced the overall design of the system itself. In a somewhat less dire scenario, training inputs may have been solicited at these earlier stages in system development, but in a way that effectively isolated training specialists from other technical domains (i.e., stovepiping), thereby limiting the effectiveness of the system development process in ways described above.

12.3 HSI TRAINING MODEL

The most compelling feature of the traditional model is that training R&D efforts are devoted exclusively to very specific training objectives. In other words, training researchers and practitioners work on well-defined training issues to achieve very specific training objectives. On the face of it, this may not seem like such an unreasonable proposition; indeed, it is almost a tautology. One might also argue that concentrating on very specific training objectives should produce more sharply focused and effective solutions to training problems.

However, there are at least three major problems with this approach: (1) it perpetuates organizational stovepiping with its many associated problems, (2) it prevents other HSI domains from benefiting from training expertise, and (3) it cuts off training experts from benefits that could be gained from more regular interaction with other HSI domains.

The commonly understood objectives of training (i.e., supporting the effective and efficient acquisition and retention of functional KSAs) characterizes training as a process that is unnecessarily restricted to a narrow range of activities in the life cycle of a given sociotechnical system. The HSI approach encourages the incorporation of training expertise and requirements at all stages of the system development process.

12.3.1 New Training Definition

A new definition of training is proposed to take into account a broader, more integrated perspective: *Training* is concerned with promoting the safe and effective performance of sociotechnical systems by facilitating the acquisition, retention, and transfer of user KSAs through the design of effective curricula and training technologies and through influencing system design, development, test, and deployment in such a way as to effectively integrate knowledge about requisite user skills, abilities, and performance requirements throughout all phases of the system life cycle.

Figure 12.3 provides a conceptual illustration of the role of training in the systems development process as implied by the new definition of training. The figure illustrates the

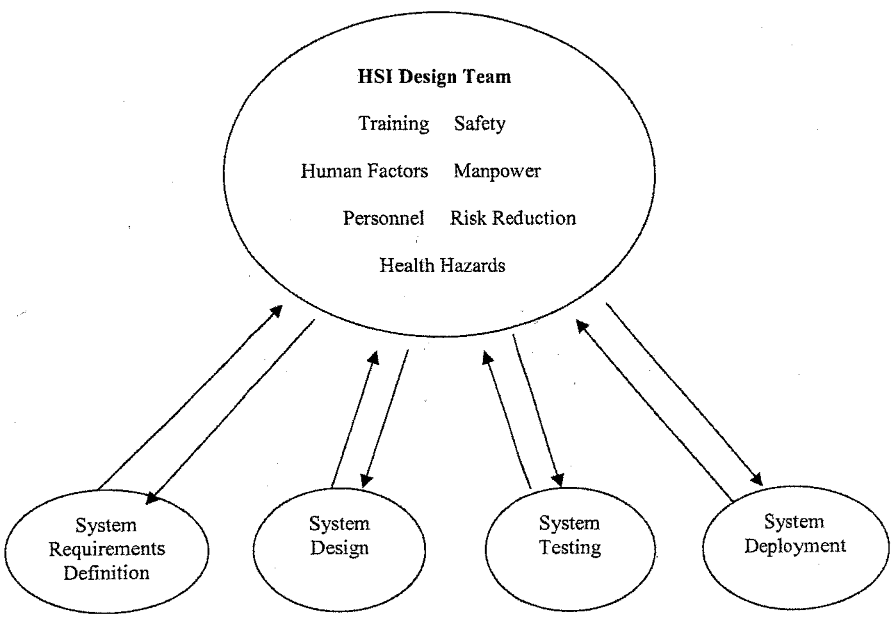

Figure 12.3 Schematic diagram representing flow of training expertise in HSI approach.

concept of training, along with the other HSI domains, working in close cooperation with one another throughout all major phases of system development.

The satisfactory application of HSI principles to complex system design requires not only that appropriate and up-to-date knowledge about designing and implementing training programs be employed but also that training considerations be factored into the discussions of system design at all stages and in conjunction with all of the other HSI disciplines. For example, although training research and practice have played a very important role in the successful application of human–machine technologies, its role has been unnecessarily restricted to already developed or nearly developed systems.

Also, many aspects of training, as traditionally conceived, can have a negative impact on overall system performance. These include poor training (e.g., training delivered by ineffective and/or poorly qualified individuals, training delivered using defective or outdated materials, etc.), inappropriate or nonfocused training (e.g., training delivered at an inappropriate level or with insufficient attention given to the specificity of the material to be covered or the desired outcome), training delivered at the wrong time, and many others.

These problems are all clearly *risk factors* in designing training for any given sociotechnical system. However, they are more than just training risks and are best understood as *system risks*, because to the extent that such risks are present, the functionality of the entire system will be adversely affected. Training, it might be said, is too important to be left to training specialists alone—just as human factors, personnel selection, safety and health, etc., are too important to be left to their respective specialists alone. The implications of risks not being adequately addressed in any of these areas have profound consequences for an entire system, and therefore, a systems approach such as the HSI methodology is needed.

12.3.2 Synergies between Training and Other HSI Domains

One of the main areas of emphasis of the HSI approach is the need for all functional entities within the system development process to work together in a consistent and coordinated fashion. This is critical not only from the perspective of eliminating costly redundancies or discrepancies in effort and other negative effects of misunderstanding and miscommunication but also to enhance the introduction of creative, user-centered approaches to system design. In order to better appreciate the benefits of such synergies, several examples of interactions between training specialists and those from the personnel selection, human factors, and safety and health domains are provided below.

Training and Personnel Selection As noted earlier in the chapter, the synergistic relation between the domains of training and personnel selection is one of the most clearly evident. To a great extent, the primary mission of each of these areas is largely identical—providing individuals who are well suited to operate systems safely and effectively. The difference, of course, is that one group has primary responsibility for selecting individuals from the pool of possible candidates while the other group has primary responsibility for providing these individuals with the necessary KSAs to perform their assigned tasks.

One can easily imagine the inefficiencies that can result when these two groups operate in relative isolation from one another. From a more positive perspective, however, the benefits of these groups working in close coordination are also clear. Those responsible for personnel selection concern themselves on a daily basis with the nature of the pool of candidates from which they must select those individuals who will eventually, following training, be called upon to operate and/or function within the various systems that comprise a given organization. Consistent interaction between these specialists and those with training responsibility can help the latter prepare training technologies and curricula that are optimally suited to the types of trainees that are most likely to be made available to them. Conversely, personnel selection specialists will come away from this regular interaction with a much more accurate concept of the types of KSAs that are going to be required for recruits, job candidates, etc., to succeed in the work environment.

Training and Human Factors Engineering Training and human factors specialists approach system design problems in ways that often seem largely complementary to one another. Human factors engineering (HFE) attempts to design human–machine systems that are sufficiently intuitive and functional so that the need for extensive training is diminished. Training specialists design training methods to compensate for the inability of HFE to perfectly achieve its goal. While interactions between these groups are certainly far from uncommon, to the extent that they are kept separate within the context of stovepiped system development efforts, many potential design and training benefits can still be lost.

For instance, since a large part of training's traditional role involves preparing individuals to successfully operate human–machine systems, it would be advantageous for training personnel to have the opportunity to provide inputs on the design of these systems. For all of the various reasons described above—expertise in human performance, skill acquisition (e.g., what has and has not "worked" in the past), and analysis and assessment of tasks—training personnel bring a unique perspective to human–machine interface design problems. Similarly, human factors specialists can reciprocate with their insights on how humans interact with novel technologies and the types of human performance failures (and successes) that they have observed as part of their human–machine system design process. Additionally, if training specialists are assigned a meaningful role along with human factors engineers (and hardware and software specialists, etc.) in the early design of human–machine system concepts, then the possibility of designing in effective "on-duty" training technologies is greatly enhanced. By permitting operators to exercise opportunities for training using the very human–machine systems they use to perform their tasks, greater efficiencies in the use of training resources (time and money) can be achieved. Greater training effectiveness and personnel readiness can also be achieved as needs for training are identified by means of on-line performance assessment followed by carefully targeted training to address performance deficits as they are identified.

Training and Personnel Safety and Health Personnel safety and health specialists concern themselves with all aspects of system design and operation that impact on operators' physical and psychological well-being. Within large-scale industrial settings, such as the oil and chemical industries, the day-to-day work of training specialists is nearly always very directly concerned with safety and health issues, and the same is also true of military settings. However, personnel and health specialists often find themselves in the same situation as their training counterparts—they are called upon to deal with the constraints of a system well after it has reached the final stages of development. To the extent that these two groups work with one another at all stages of the development process, their complementary insights on the acquisition of safe and effective work procedures are likely to shed significant light on how such systems should be designed originally.

Each of the discussions above is analogous to what might be referred to as a *two-way interaction* statistical analysis. Two-way interactions are useful in illustrating the HSI concept, but it should be understood that three-, four-, five-, and six-way (and more) interactions can occur, providing even finer synergies when all HSI disciplines interact consistently with one another.

12.3.3 Integrating Training within the HSI Approach

The key challenges involved in overcoming the inherent limitations in the model depicted in Figure 12.3 include establishing organizational structures that

1. overcome the effects of stovepiping,
2. facilitate consistent and close coordination between all HSI disciplines, and
3. assure a lead HSI administrator/engineer serves at a very high level within the design team's organization.

Although HSI administrators need not be training specialists, they must report directly to the overall program manager and have people responsible for all HSI areas reporting directly to them. As Chapter 1 notes, without ongoing commitment to and participation of HSI at the very highest organization levels, the support and performance of specific HSI tasks will suffer. In other words, it is absolutely critical that the structure of the system development organization be such that an overall HSI leader is positioned at a very high level reporting directly to the program manager.

Another challenge involves changing the traditional organizational mindset or "culture" to reflect a greater commitment to the sort of coordinated "systems" approach reflected in the HSI model. A systems approach to training is not a new idea among training experts themselves. For example, Patrick (1992) states, "training . . . can be viewed as a system which interacts with other systems, such as personnel selection, ergonomics, etc." (p. 14). However, as things currently stand outside the training community, training considerations, as well as those of other HSI domains particularly with regard to their integration, are all too rarely taken into account during the early phases of complex system development. Nevertheless, it is at this stage that the implications of alternative designs can be examined with respect to trade-offs between personnel requirements, human–machine interface design characteristics, and training requirements while there is still time to influence key, early acquisition cycle decisions.

Effective and thorough integration is key to the successful application of HSI methodology and, ultimately, to successful system design, deployment, and maintenance. As with many other organizational entities whose strength lies in the synthesis of partially independent, partially overlapping areas, the "whole" of HSI is much greater than the sum of its parts. As Chapter 1 points out, HSI is a technical *and* managerial concept (emphasis mine). One of the greatest challenges to successful incorporation of an HSI approach therefore involves overcoming the many organizational and managerial sorts of obstacles that stand in its way.

Organizations will occasionally attempt to conduct an *HSI approach* to the design of a new system, particularly when explicitly instructed to do so by their customers (e.g., the government), but fail to grasp that unless there is strong coordination and near daily interaction between *all* of the various elements that make up the HSI approach, then much of its potential benefit will be lost. Therefore, it is not sufficient to have one group working on "training issues" while another independent group works on "human factors" or "personnel selection" issues. There must be integration of these efforts, and they must be coordinated from the highest organizational levels. What is lost if integration is not successfully accomplished are the types of synergistic insights that can arise when people of quasi-independent areas of expertise come together with a common focus—in this case, efficient and effective human-centered systems design. A related problem, particularly common in complex system development projects performed by large and (often) geographically far-flung organizations comprised of numerous system specialties, involves the significant probability of miscommunication and wasted or duplicated effort.

How can we tailor training to better support overall system goals of effective and timely performance? More importantly, how can we effectively *integrate* training with other aspects of an HSI approach to design? The model depicted in Figure 12.4 is proposed as an approach to overcoming the types of problems and limitations in current system development models that have been described throughout this chapter. It is also proposed as a means to facilitate the types of economic and synergistic benefits, also described above, of adopting a more comprehensive user-centered HSI approach to system development.

Figure 12.4 actually presents an overview of a fully integrated HSI approach to system development from the point of view of the training community. Specifically, training is involved with all phases of the system development process and interacts on a continual, day-to-day basis with each of the other user-centered HSI domains. Issues and advantages of this approach with respect to each of the four key areas of system development are described below.

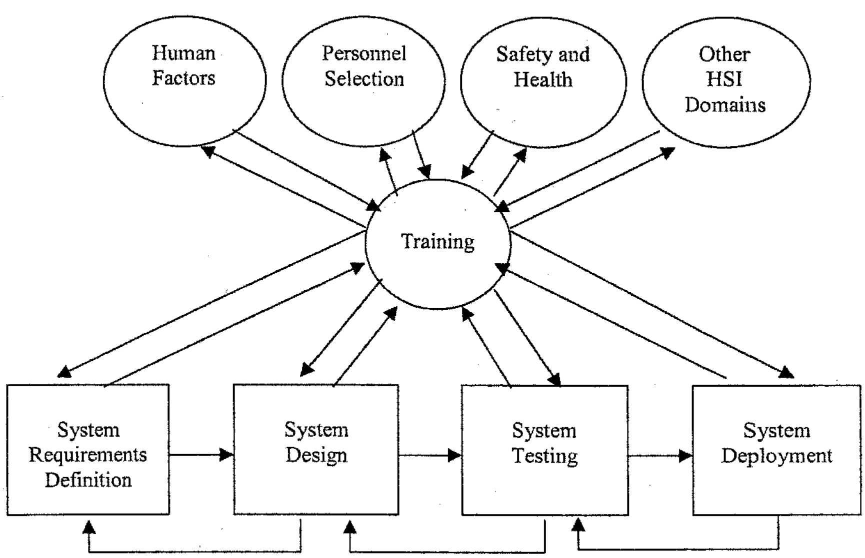

Figure 12.4 Schematic representation of system development process featuring expanded role for training.

System Requirements Definition Training expertise is required in the earliest phase of systems design—system requirements definition—in order to accomplish several specific objectives. First, it is important for training personnel to begin to anticipate any unusual training demands that might be forecast as a result of emerging characteristics of the new system. For instance, early on in the DD-X system definition process it became clear that greatly reduced crew size was going to be one of the most radical new features of this system. After decades of training crews of 300 or more to perform destroyer-based tasks, suddenly the training community was faced with being required to do the same with a crew size closer to 100. Given the enormous challenges that this represents, it is vital that training personnel are involved at this phase in order to (1) begin to prepare themselves to meet the challenge sooner rather than later, (2) avoid delays in the system development process, and (3) advise other elements of the system design process of the feasibility of being able to meet new challenges of this sort.

The advantage of having not only training personnel present in this phase but also training personnel interacting directly and consistently with all other user-centered and technical domains is that problems in the early system definition problem can be approached from a multidisciplinary perspective, providing a more creative approach to defining a system that has a chance of success. For instance, given the greatly reduced crew size requirement of the DD-X and CVNX, what looks like an insurmountable training problem at first might become much less so when training and human factors personnel interact. Such interaction could perhaps design onboard human–machine systems that can carry much of the training load that might otherwise need to be assumed by traditional on-shore training centers.

System Design The system design phase refers to the phase of design in which work begins to develop concrete designs, prototypes, concept demonstrations, etc., to provide concrete but innovative approaches to meeting the specifications and requirements of the system as specified in the system definition phase. Traditionally, system design has been heavily dominated by engineering considerations, with HSI concerns either treated as something of an afterthought or relegated to a lower level within the system development hierarchy. Chapter 6 and Chapter 20 address problems associated with this traditional design paradigm and discuss methods for overcoming it. Within the HSI approach, it is important to specify the role that each user-centered discipline plays at this stage of system development and define how they can optimally integrate with one another. This is largely an organizational issue and requires that an administrative structure be put in place that (1) recognizes HSI as a discipline on an equal setting with all other design disciplines and (2) mandates the consistent, daily interaction of all HSI domains—working in close cooperation with engineering design elements to produce design concepts.

What, specifically, does it mean to incorporate training requirements and expertise into the design process? First, it means defining the constellation of KSAs that operators will need to acquire in order to successfully use the system. This knowledge emerges as characteristics of the system's human–machine components begin to emerge and allows training specialists to begin to structure their related technologies and curricula accordingly. However, it also enables training specialists to provide designers of human–machine systems with information about these KSAs for the purpose of helping to (1) design some of these features "into the system" in order to decrease training requirements on the human,[6] and (2) examine methods of designing training technologies and curricula that are embedded in the human–machine systems, enabling on-duty training to take place.

At this stage of system development training specialists must also assess the ability of the *training system* (e.g., the training centers and schools, the simulation technologies, etc., that support training) to support the needed skill acquisition. Can the system handle it? If not, what is needed to get the training system up to speed so that deployment of the operational system is not delayed?

System Testing Complex systems undergo testing at many different levels and at many different periods of time during their life cycle. When initially designed, systems are tested to ensure that they meet the functional specifications set for them earlier in the system development process. Later, as new subsystems are developed and used to replace older legacy subsystems, testing is often repeated to ensure that these new elements conform to expectations and specifications.

For any system or subsystem that requires human intervention at some point in its life cycle (either in the form of regular operational intervention—as in the case of a control room display panel—or in the form of maintenance or repair), training is a concern. In preparation for initial system testing, training specialists will need to focus on several key tasks. First, initial training procedures will need to be developed in order to prepare a crew to exercise either the entire system or subcomponents of the system. Clearly, this is a daunting task that is most efficiently approached using a multidisciplinary approach such as that proposed by the HSI model. The importance of a smooth development of the test procedure (in terms of maximizing the effectiveness of resources expended) is just as important in the test phase as in the other phases of system development. Therefore, it is very important that training preparations reflect the full input of all other relevant operational domains.

System tests also afford the opportunity to collect human performance data that are of interest. For example, such data can shed light on the effectiveness of the design of human–machine interfaces and can also provide information about the effectiveness of training procedures (including any innovative on-line/on-duty training procedures). The collection of human performance data is vital at this stage to evaluate the effectiveness of many aspects of the system design, including the training technologies and curricula.

System Deployment Training has always had its broadest and most important application at the system deployment stage, and in spite of the value it can add at earlier phases, this will probably be the case for many years to come. Once a system is deployed, it is the responsibility of the training community, in conjunction with their colleagues in the personnel selection domain, to supply a steady stream of qualified individuals to operate and/or function within it. While there is nothing new in this requirement, there are new ways that the training community can accomplish this important objective provided they have been able to participate in the early system design stages. This may, for example, include the development of novel training technologies that can be "embedded" within the design of human–machine systems. Continued progress in the area of human performance assessment (an area in which collaboration between training and human factors specialists would be beneficial) could hasten the development of "adaptive" training technologies in which individualized training regimens can be designed and applied on an as-needed basis as a function of deficits in operators' task performance.

In the current operational environment, the biggest challenge facing training is operating at this final stage of the system life cycle with reduced resources and enlarged expectations. This challenge, along with the several others identified in this chapter, can best be met by a more thorough integration of training expertise at all levels of the system development process, especially by helping to design system components and procedures that require less training for operators to master while at the same time incorporating required training elements into their design.

12.4 ISSUES AND CHALLENGES

Because of the immaturity of the training domain at influencing system design, a major objective of this chapter is to provide a state-of-the-art review of training from an HSI perspective. Such a review was found necessary in order to provide a basis for better understanding what needs to be involved culturally, organizationally, and technically to bring the training domain into an effective, efficient HSI discipline. This section, therefore, presents the findings of that review. The categories considered are

- dominant themes in the history of training research and practice,
- emerging issues in training research and practice,
- technical challenges, and
- cultural changes.

12.4.1 Dominant Themes in the History of Training Research and Practice

The scholarly and technical literature on training is vast and daunting. A thorough review of this literature is beyond the scope of this chapter, but it is important to examine several of the major themes in this body of work. The reasons for doing so are (1) to examine the relevance of this knowledge base to the broader "design team" philosophy underlying the HSI approach to system development and (2) to examine the extent to which the proposed broader definition of training and its role in the system development process may require the field to expand upon the principles and knowledge contained within these areas. Indeed, in many cases, very important new sets of questions and research issues for the training community may appear.

The themes from the training literature briefly reviewed are (1) individual versus team training, (2) measurement of training effectiveness, (3) the analysis of tasks and related aspects of skill, and (4) the design of training programs. These topics by no means comprise an exhaustive list of themes from the training literature of potential relevance to the HSI design philosophy; they merely represent an exemplary sampling of topics whose discussion is intended to highlight the relevance of the area as a whole to all aspects of complex system design and deployment.

Individual versus Team Training In recent years the attention of training specialists and researchers has increasingly turned from considerations of training *individuals* to a more concentrated focus on training *groups* of individuals or *team training* (e.g., Cannon-Bowers and Salas, 1997, 1998; Entin and Serfaty, 1999; Salas and Cannon-Bowers, 2000; Swezey and Salas, 1992). In the human factors and training literature, a team is defined as a set of two or more individuals who must interact and adapt to achieve specified, shared, and valued objectives (Salas et al., 1992). Team training is clearly a key issue in the development and successful application of sociotechnical systems whose successful operation relies on the skilled performance of coordinated groups of operators. It is becoming increasingly rare for operators to perform functions within complex systems that have little or no direct relevance for the activities of other operators. Therefore, the training of efficient group or team skills is becoming increasingly important.

For many years researchers seemed to avoid studying team training, perhaps because the problems involved in training and reliably assessing the performance of *individuals* were daunting enough, let alone *teams* of individuals. Nevertheless, this area has begun to receive extensive research attention in recent years, and the work that has been accomplished to date has significant implications for all aspects of system development. The concerns that face training specialists in designing approaches to team training and the knowledge they have obtained from studying the problem are of great potential value to other design team members. Conversely, the training community's understanding of team training is likely to be greatly aided by the inputs of others who deal with teams in settings other than training.

For example, a topic of great current interest in the team training field involves the concept of the *shared mental model* (e.g., Kraut et al., 1999; Stout et al., 1996). Simply put, this notion reflects the hypothesis that a team's performance is likely to be significantly enhanced to the extent that individuals within the team share common concepts (mental models) relating to the factors that underlie their work performance. In other words, in order to function cohesively and effectively, it is generally thought that team members should share a very similar set of functional concepts about (1) the team's long- and short-term objectives within any given situation and (2) the means for accomplishing them. Additionally, of course, individual team members must possess the requisite sets of skills needed to successfully achieve these objectives.[7] To perform at a high level, individuals within teams should be able to accurately and easily perceive and comprehend the current operational state of affairs with respect to the performance of the team and their role within it. Furthermore, they must also be able to accurately anticipate the state of affairs in the operationally relevant near future. In short, the team should share a common, high-level *situation awareness* (e.g., Endsley, 1999) in order to function effectively.

Clearly, training must concentrate on developing the sets of skills and abilities that will produce effective team performance, and much work remains to be done to refine the methods needed to accomplish this important goal. The identification of team-based KSAs as well as the design of methods with which to impart them through training continues to be a topic of intensive research in the training community. However, by factoring these training considerations into the design phase of system development, it should be possible to design human–machine systems that will facilitate team training and team performance objectives while simultaneously reducing the overall demand on training resources.[8] By doing so, overall system performance objectives can be enhanced within a more efficient and cost-effective design setting.

A few relevant skeptical questions at this point might be: In operational terms, in terms of the success or failure of the total system, how vitally important is this concept of a shared mental model? Does it make sense to devote a significant portion of our limited resources to fostering it? Will it really make a difference in terms of the overall performance of the system? The answers to these questions are not always clear and are likely to be heavily situation dependent,[9] although evidence (much of it from the commercial aviation literature) strongly suggests that many accidents occur as a result of breakdown in team coordination (e.g., Helmreich and Foushee, 1993). In general, however, if the answer to the first question is that it is very important to promote effective team performance and to contribute to this goal by doing what we can to create a consistent, shared cognitive mission perspective, then it is critical that the development of a shared mental model among team members become a broad rather than a narrow concern.

In general, one might say that this is true of all such human performance issues. If the system cost associated with a breakdown in human performance is high, and if factors can be identified that might lead to such a breakdown, then it is vitally important for the broad design team as a whole to be concerned with them and not just one narrow subdiscipline. For instance, while training experts have become increasingly familiar with the shared mental model concept, others involved in different aspects of system design have not. Therefore, in a stovepiped approach to system design, this potentially critical issue becomes little more than a *training* objective when in fact it must be a total *system* objective.

What can be done to address this organizational deficiency? Involving training personnel in the system design phase, as a start, can help place emphasis on the design of human–machine systems that facilitate the acquisition and maintenance of shared mental models. This can be accomplished through the design of displays that provide individual team members with intuitive information concerning the activity of the team and the team's role in the overall structure of ongoing events. Consistent interaction (early in the system design phase) between training, human factors, and human–machine systems design personnel is an obvious first step toward obtaining the objective of "designing" in shared mental models. A failure to take a coordinated approach of this type means that training personnel must take whatever they are given in the way of a completed system design and work with it to promote effective team training. Without their inputs in the design phase, this will almost certainly be a more arduous and time-consuming (and, in the end, less effective) process.

To revisit an important theme, in the HSI approach to system design, the focus of the design team is first and foremost on the *user* of the system. The goal of system design is shifted away from a primary emphasis of achieving purely *engineering* objectives to achieving *system performance* objectives on the assumption that the human user is the most critical element of the system. This can only be successfully accomplished by incorporating those with knowledge of human performance requirements at all phases of the system design process. As illustrated above, such an approach can result in more functional systems that achieve their objectives in a coordinated and efficient manner.

Measurement of Training Effectiveness The ability to reliably assess the effectiveness of training has long been an area of central concern to the training community. When substantial time and resources are devoted to the development of training techniques and technologies, it is important to be able to determine if they are achieving their objectives. Training researchers have devoted substantial attention to identifying valid and reliable metrics of training effectiveness (how *well* task-relevant KSAs are acquired and retained) and efficiency (how *quickly* they are acquired and with what level of resource commitment) (e.g. Damos, 1988; Lintern, 1991). Consumers of training technologies are of course very interested in being able to gauge their return on investment for training resources spent.

Training involves ongoing changes in underlying cognitive skills but also manifests itself as behavioral change (e.g., Salas et al., 1999). In other words, effective training enables trainees to *think* more effectively about their jobs, and it also enables them to *perform* those jobs more effectively. Therefore, a key challenge faced by training researchers has been to devise measures of training effectiveness that tap into both of these key outcomes.

The ability to determine training effectiveness relies heavily on the more fundamental ability to reliably assess the dimensions of human performance that underlie the KSAs of interest. In other words, metrics (usually quantitative) of human performance are used to assess the effectiveness of training and allow researchers, trainers, and consumers to make informed decisions on the adequacy of various training approaches and technologies.

Given the progress that has been made in assessing the human performance of complex tasks (e.g., Boff et al., 1986; Lane, 1987), a logical extension of the training domain within the HSI approach might involve the implementation of on-line human performance assessment to indicate when an operator or user of a system may need further training in one or more specific areas. Once a particular performance deficit has been identified, appropriate individualized training could then be prescribed for the operator. In essence, then, a continual monitoring or sampling of operator performance (particularly in tasks where the costs associated with human error are high, such as those involved in managing complex weapons systems or nuclear power plant control) can be conducted to assess the degree to which a particular operator requires additional or refresher training.

While the measurement of training effectiveness with respect to individuals remains a critical research area, an even more complex challenge involves the determination of factors influencing the effectiveness of team training. The determination of appropriate team performance metrics could also lead to the same sort of possibilities for real-time/on-line assessment of team performance and subsequent identification of just-in-time or refresher training requirements. In either case, the key point is that system designers can build on this important training research to develop human–machine systems that possess the capability to effectively monitor the performance of individuals and teams, identify performance deficits, and prescribe and deliver training to address those deficits.

Additionally, knowledge about desired human/team performance outcomes is (or ought to be) critical in the early phases of system design. Human performance metrics should be among the most carefully examined factors when designing and evaluating human–machine components of complex systems. Clearly, the role of training experts in this phase of the system development process is vital as they represent a significant portion of a design team's expertise on the topic of targeted human performance "goals" that the system must meet in order to achieve success.

Analysis of Tasks and Related Aspects of Skill Many methods have been developed over the years in an attempt to describe the tasks that people execute when performing a given job and to identify the underlying KSAs needed to successfully perform those tasks. The most common and best known are generally referred to as job or task analysis techniques (e.g., Schraagen et al., 2000) and are based on the observation of work and the interviewing of subject matter experts (e.g., workers, operators, supervisors, etc.), resulting in the production of detailed, schematic representations of the spatiotemporal characteristics of the work environment as well as the perceptual, cognitive, and motor requirements associated with task performance. *Cognitive work analysis* (e.g., Roth and Woods, 1989; Vicente, 1999) and *cognitive task analysis* (e.g., Schraagen et al., 2000) represent more recent variants on traditional task analysis and are more focused on identifying and understanding perceptual and cognitive tasks as they relate to the costs and constraints of the task environment. Other related techniques include *knowledge mapping* or *concept mapping* (e.g., McNeese et al., 1995), techniques that seek to explicitly delineate the hypothesized connections between events, costs, and constraints of the task environment and the operator's related cognitive and perceptual tasks.

These techniques have been used over the years to help identify requisite KSAs underlying the performance of operational tasks in support of the development and application of training technologies and programs. Clearly, in order to train effectively, one must have a focused awareness of the aspects of skilled performance that are relevant in any given situation, and task analysis techniques are specialized for uncovering this type of information. However, the utility of a detailed specification of cognitive, perceptual, and motor task requirements understood with relation to the operational environment of interest extends far beyond the training domain. For example, as exemplified by the role that cognitive task analysis has played in *ecological interface design*, there is a significant role for this type of information in the design of human–machine interfaces (Vicente and Rasmussen, 1992). The utility of this type of information in other domains such as manpower and personnel selection is also clear.

Three areas of training research and practice—team training, the assessment of training effectiveness, and the analysis of tasks and related aspects of skill—exemplify the types of expertise characteristic of training that have much broader application within the total system development process. These areas provide a baseline of existing training information that should be continually examined for extension to broader system questions beyond the traditional applications.

12.4.2 Emerging Issues in Training Research and Practice

Having reviewed some of the major issues from the literature on training for potential relevance to HSI in system development, we can now examine several emerging issues for training. The purpose of this section is to illustrate the nature of some of the key challenges that the training domain can expect to face in the near future and how an HSI approach to system development can facilitate their solution.

Environments within which people perform their jobs have changed dramatically over the past several decades, and the pace of change appears to be continually accelerating (e.g., Gleick, 1999). Clearly, the technology has changed immensely, primarily in the direction of providing individuals and organizations with greatly enhanced "power" in terms of the ability to extract, process, display, and act upon information. Powerful and portable computers, the Internet, widespread wireless telecommunications, advanced display and control technologies (e.g., virtual environments), personal digital assistants, and many other information-based technologies are commonplace tools that in many cases were still in the conceptual phase no more than 10 years ago.

However, many important social, economic, and political trends have accompanied the so-called information revolution, most notably (for purposes of this chapter) many that relate to the structure of the work environment.[10] Downsizing, increased workload, and increased requirements for multitasking and concomitant multiple skill sets are several of the emerging realities of workplaces (military or otherwise) that impact strongly on training and the relationship of training to other elements of system development.

The ubiquitous nature of significant technical and societal change has profound significance for all aspects of complex system development, including training. How, for instance, can training technologies and curricula be designed and implemented to retain relevance for more than a short period of time? How can we train individuals to accommodate to and thrive within a rapidly changing sociotechnical environment? And how can we incorporate knowledge from research on these questions into more efficient design of complex systems? These and many other questions must be successfully resolved to ensure that training fulfills the important role implied in the expanded definition of the field used in this chapter. Before proposing approaches that might answer some of these questions, it will be helpful to consider how training has accommodated similar circumstances in the past.

The military has been interested in systematic, large-scale training for a long time, perhaps longer than any other area of human endeavor.[11] For instance, the development of fundamental fighting skills and abilities (handling a spear, swordsmanship, archery, etc.) has been a subject of military interest since ancient times. However, coincident with the onset of World War I, the emphasis on military training began to dramatically shift in at least two important ways. First, training (and related disciplines such as personnel selection) began to transform its focus from the development of as many competent foot soldiers as possible toward the more challenging need to prepare individuals to deal with human–machine systems (e.g., airplanes, tanks, increasingly complex artillery systems, etc.) whose complexity and sophistication were much greater than anything previously encountered. Second, the nature of training began to be a topic of serious scientific inquiry, particularly among applied psychologists of the day. Training moved from being a purely "seat-of-the-pants" enterprise practiced more or less along the lines of the journeyman-apprentice model to a much more scientifically based approach. This change of focus was partly necessitated by the requirement to train large numbers of people in a hurry and concomitant increased government funding of training research. In essence, training was forced to change in order to accommodate to the vast strategic, technical, and scientific changes characteristic of the time, which it must again do now.

Obviously, a great deal has changed since World War I, although many demands and constraints on the training community remain very much the same. Training still largely focuses on preparing large numbers of individuals to become skilled users of complex human–machine systems, and the level of involvement of psychological scientists in matters of training is still high. However, the human–machine systems themselves as well as the situations under which they are used have changed dramatically.

The two emerging areas of greatest concern for the future of training are (1) effects of new technologies on sociotechnical system performance and (2) cultural changes, including the effects of personnel downsizing on system performance.

Among the many emerging challenges facing training and systems development in general, the remarkably rapid change in the technological capabilities of systems is certainly one of the most daunting. As the number of years that it takes to transition from one "generation" of technology to the next continues to decrease, workers and military personnel are continually at risk of finding that their hard-earned KSAs that were appropriate in one technical "era" have become obsolete. Those responsible for the smooth life-cycle operation of large-scale systems (i.e., some military weapons platforms are designed with the goal of being operable for 30 years or more) must concern themselves not only with the periodic upgrading of technology but also with the ability of training programs to be able to smoothly transition personnel from one generation of technology to the next. In addition, many new technologies present challenges (and opportunities) for the training community in that they may require new forms of skilled human performance that have received little attention in the past. Some of these technologies are described in Section 12.4.3.

The second major emerging challenge relates to general concerns with changes in the "culture" of work and in particular the effects of downsizing. Downsizing in and of itself does not necessarily guarantee a negative impact on overall system performance. Whether it does or not, and the degree to which it does or not, depends strongly on (1) organizational expectations concerning the impact of personnel downsizing on system performance (i.e., is organizational "output" expected to decrease in a manner commensurate with the loss of personnel, remain at a constant, pre-downsizing level, or even increase in spite of the loss of personnel resources?) and (2) whether or not technical tools and other resources are introduced to offset the loss of personnel resources. Indeed, the general area of *resource downsizing* is a related, major area of concern as not only personnel but also budgets and key resources are cut back.

Those who must successfully operate a particular system with fewer colleagues frequently experience the collateral effects of personnel downsizing. Increased demands in the form of multitasking and the need to perform under conditions of potentially increased stress and fatigue are among the challenges they face. What role does training have in preparing individuals to cope with these changes characteristic of the workplace?

These areas of technical and socioeconomic change are hardly independent. The nature of their interactions is important for the training and larger system development community, as will be discussed in Section 12.4.4. Before that, however, we will examine a number of technical challenges facing the training community.

12.4.3 Technical Challenges

Currently there are four technical challenges that are particularly critical to the progress of training in an HSI environment:

1. increased reliance on automation,
2. novel human–machine interface technologies,
3. enhanced functionality of legacy systems, and
4. complexity.

Increased Reliance on Automation In order to enhance the overall performance of sociotechnical systems in the face of reduced manpower, it is apparent that machines will be called upon to accomplish more tasks (that were previously performed by humans) and to do so with increased speed and reliability. The increased use of automation is one system design strategy that will be heavily relied upon to accomplish this goal. As has been frequently noted (e.g., Wickens, 1999), as automation becomes a more ubiquitous characteristic of sociotechnical systems, the role of the human increasingly shifts from one of active operator to one more accurately described as active monitor. As has also frequently been noted, automation is a double-edged sword (e.g., Funk et al., 1996). Assuming that automation is introduced into a system for reasons other that, economic cost savings (i.e., there is strong reason to expect increased safety and/or effectiveness of system performance), there are still many potential design and training problems that interact with one another. For instance, if automation is not designed properly, then it may lack the functionality or performance desired by operators in all relevant situations, necessitating "workarounds" when it fails to perform as anticipated. Automation may not control processes or systems the way an operator might, which suggests that the gap between the operator's mental model of the system and the actual system model itself must be successfully bridged to avoid potential difficulties associated with the operator being "out of the loop" when a problem arises.

Obviously, to the extent that the design of automation is not “human centered,” the demands on training will be greatly increased. However, even under ideal design conditions training has to be able to address the unique human performance demands of this new role of the human in the functioning of sociotechnical systems.

Introduction of Novel Human–Machine Interface Technologies Another method of enhancing the overall performance effectiveness of current and future systems is to introduce effective, new human–machine interface technologies. Emerging concepts such as virtual environment technology (e.g., Durlach and Mavor, 1994) and adaptive interface technology (e.g., Bennett et al., 2001) hold a great deal of promise for developing more effective systems by producing human–machine interfaces that are far more intuitive than current approaches. However, the introduction of such novel technologies raises a number of issues for system developers that require the application of training expertise.

First, the design and functional integration of new technologies such as virtual and adaptive interfaces are best approached from a user-centered design framework, one in which the technical aspects of the design are in close alignment with the needs, capabilities, and limitations of the user. As discussed earlier, the training domain has developed significant expertise over the years in domains such as individual and team performance assessment, task analysis, and assessment of the impact of novel technologies on human performance and skill acquisition. Along with human factors specialists, training personnel have a great deal to offer in helping to design technologies to match the needs of the user.

Second, novel technologies present novel challenges for training specialists within their more traditional role of providing trainees with the KSAs needed to safely and effectively interact with them. Early, direct, and consistent involvement of training personnel with technology development and testing will result in greater training effectiveness and efficiency by allowing training specialists to (1) anticipate training requirements of new technologies early enough to permit training to take place as soon as possible upon system deployment and (2) participate in the development of the technology itself, specifically with an eye toward helping to build in on-line just-in-time/refresher training capabilities into the technologies while they are still in the design phase.

Finally, it should be pointed out that these technologies offer significant new opportunities for training (Durlach and Mavor, 1994). This topic will be discussed more fully in Section 12.5.

Enhanced Functionality of Legacy Systems While in many cases operators may perform their tasks at workstations that are not appreciably different from legacy systems in terms of the amount, type, and appearance of the equipment involved, the equipment itself may be enhanced to control a significantly increased number of processes and subsystems. The greater amount of activity to be performed by an operator in the same unit period of time is a significant factor to be accounted for in the design of these systems and in training operators to use them.

Complexity One of the most profound technical issues impacting the future effectiveness of systems and one that each element of the system development process will be called upon to address is complexity, a phenomenon that cuts across all aspects of the technical challenges discussed above. As stated by Pool (1997), the safety and effectiveness of complex systems depend not just on their physical characteristics but also on the people and organizations operating them. Complexity creates uncertainty, and uncertainty demands human judgment (a problematic situation for applications of automation). As noted by Perrow (1984) and others, complex systems can be very sensitive to even small changes or perturbations, so that a minor mistake or malfunction can quickly deteriorate into a major accident. As Pool (1997, p. 250) notes: “Such uncertainty and sensitivity make it impossible to write out procedures for every possible situation—and attempts to do so can backfire. Operators who are trained to always go by the book may freeze up when an unexpected situation arises. Or worse, they may misinterpret the situation as something they’re familiar with and take exactly the wrong action.”

Training individuals to cope with complexity, particularly in the operation of high-risk systems such as weapons platforms, oil and chemical refineries, and nuclear technologies, presents challenges that, in the end, almost certainly cannot be addressed by training alone. Indeed, the technical issues described above present significant challenges not only for training but also for all aspects of complex sociotechnical system development. However, adding the overall level of complication is another emerging set of trends whose individual elements can perhaps best be classified under the umbrella of *sociocultural* change.

12.4.4 Cultural Changes

A number of sociocultural trends were described above whose presence represents an emerging challenge for training as traditionally conceived and training as recast within the HSI approach to system development. Chief among these in terms of the breadth of its influence is downsizing, the reduction of manpower/personnel that has characterized both the public and private sectors in recent years and is anticipated to continue at least into the foreseeable future. Downsizing results in a number of issues for training and system design, challenges that require extensive coordination between HSI domains in order to be satisfactorily met. Among these are the increased need for cross training and the need to train individuals to accommodate to and thrive within an environment of change.

Increased Need for Cross Training and Multitasking A key challenge in downsized and reduced manpower environments is the need for cross training and, analogously, the requirement for individuals to be able to perform well in a multitasking environment. As with the emerging technical issues described above, an efficient and satisfactory approach to this problem will require a multidisciplinary approach involving training, human factors, and personnel selection specialists at a minimum. While each field, if it were to attempt to address the problem in isolation, would undoubtedly develop useful approaches and concepts, it is very likely that a combined approach would result in a more satisfactory, cost-effective solution.[12]

Training to Adapt to Change There is little doubt that the environment and overall culture within which people live and work have changed dramatically within the course of the last several generations. One of the most central features of our current culture is the ubiquity and rapidity of *change.* This sociocultural characteristic has important implications for the design of training approaches and technologies as well as their integration within an overall system development approach.

Levy (1998) has noted that society’s relationship to information and knowledge has changed dramatically since World War II and to an even greater extent since the seventies: “Until the second half of the twentieth century, a person could utilize skills learned during his youth throughout his career. More important, he was able to transmit this knowledge, nearly unchanged, to his children or apprentices. Today this pattern has become obsolete" (Levy, 1998, p. 70). Many people, perhaps the majority, are now required to change their skills several times throughout their life. As observed by Levy, even within a given "trade," knowledge has an increasingly shorter life span (e.g., three years or less in computer technology). It has therefore become difficult to design and train "basic" skills in a given field. The relevance and importance of KSAs are now far less durable than at any time in the past, being subject to change as a function of the emergence of new technologies (e.g., the personal computer) or new socioeconomic conditions (e.g., downsized work environments). As a result, society appears to have made a transition from the dominance of stable skill sets to what Levy refers to as "a condition of permanent apprenticeship."

12.5 CONCLUSIONS AND RECOMMENDATIONS

Despite its importance and the many decades of work devoted to understanding it, there is still a great deal of misunderstanding about training. Salas et al. (1999) have recently summarized many of the current "myths, misconceptions, and mistaken assumptions" about training, and their discussion is well worth studying. Perhaps the greatest myth about training is that its applicability is limited to the design of training technologies and procedures. Those who accept the HSI approach to systems integration have little doubt that training expertise can significantly enhance other key aspects of user-centered system design and that such interaction is vital to achieve enhanced system performance in a reduced resource environment.

A key point emphasized in this chapter is that training considerations need to be thoroughly interwoven with all other HSI considerations throughout the life cycle of major systems. The means of determining how to do this is perhaps much less an empirical or scientific question than a socioeconomic-political question. As noted in Chapter 1 and elsewhere in this book, it is incumbent upon HSI professionals to effectively "sell" the HSI approach to those in charge of major programs. In addition, there is a need to develop a systematic approach to incorporating training as part of a total life-cycle approach to system procurement. This process must involve systematic and periodic reexamination of mission requirements, task requirements, personnel requirements, etc.

However, there are also many technical areas in which the area of training must continue to develop to meet the challenges of system design in the twenty-first century. For instance, as noted by Patrick (1992), there is still considerable work to be done to identify principles that will permit the development of training programs that are not problem specific but that generalize across a range of training problems. This is a critical area in light of the reduced resource constraint. While there will always be a need to tailor training approaches to specific system requirements, there is little doubt that funding agencies and organizations are going to continue to exert pressure on the training community to develop generalized training paradigms and methodologies that can transfer relatively easily from one domain to another.

As these pressures mount and both system developers and training communities recognize the need to make better use of HSI principles throughout systems acquisition, strategies to address the following considerations will become more important.

1. *Recognize the Change in Focus for Training Specialists* Clearly, the types of suggestions raised in this chapter, were they to be implemented, would involve many profound changes in the traditional role of the training specialist. Chief among these is the much broader role to be played throughout the entire system design process. The realization of this broader, more interactive role will require the pursuit of new avenues of research and new developments in theoretical approaches to training.

The primary challenge will be to envision a much broader role for today's *training specialist* as tomorrow's *system design specialist* with particular expertise in user knowledge, skill, and ability acquisition and retention. This change in focus amounts to a fundamental redefinition of the role of the training expert within the system design process, one that acknowledges the relevance of training expertise at each stage of system acquisition and that also acknowledges the reciprocal influence of all other HSI domains on training.

2. *Explore the Question "Can We Train People to Adapt?"* In past centuries, people could apprentice themselves to a master of some trade or craft and very effectively learn a skill, safe in the knowledge that its basic components would not change appreciably over the course of their lifetime or career. Obviously this is no longer the case. The ubiquity of rapid technical change in nearly all career fields—indeed, the rapid appearance and disappearance of entire job specialties—requires that successful individuals be able to adapt quickly and effectively to changing sociotechnical work environments.

The author has observed control room operators in oil refineries who were either unwilling or unable to fully adapt to the presence of computer-based control and/or maintenance request systems that had recently been introduced to replace more traditional and familiar systems. There appeared to be many factors underlying operators' apprehensive approach to these systems, but for the most part they related to a compelling sense of discomfort with change on the job in general as well as the introduction of requirements for new skills that some operators felt they could not easily master. In response to such situations, a variety of coping behaviors may be adopted, e.g., delaying actions until there is "enough time" to sit down and devote the necessary attention to the task or asking someone more adept with the new technology to perform the task. In either case, these coping mechanisms can obviously produce performance and safety problems.

It is insufficient to merely train operators in the specifics of new technologies and new systems every time one comes along. Rarely is it the case that an entire work environment is replaced or upgraded; rather, individual components or subsystems of the work environment tend to get replaced. The rapidity and unpredictability of such change in itself create training challenges for operators. In addition, the possibility that new subsystems may not function predictably or well with existing components creates training and performance challenges of a different sort. Training specialists must concentrate on developing approaches to enable operators to cope with change. Furthermore, training specialists must be continually involved in the evolutionary development and upgrading of existing systems in order to help assure that new components and subsystems will function well within existing operator skill sets.

3. *Consider the Effects of Downsizing* As noted above, downsizing is one of the most compelling of the "new realities" facing designers of new systems as well as those responsible for the smooth and safe operation of existing systems. There is little doubt that significant reductions in the number of individuals available to operate aircraft carriers, oil and chemical refineries, and other complex and risky technologies will pose tremendous challenges for those responsible for their design and operation. Responsible approaches to

downsizing must be based on examining the trade-offs involved in reducing personnel while maintaining overall system performance at effective and safe levels. Tools for performing these sorts of analyses do not currently exist, and the training community must be called upon to provide reliable inputs on changes in training that will be needed to empower a smaller workforce to perform at an acceptable level.

4. *Explore the Effects of New Human–Machine Technologies* Many radically new approaches to human–machine technology are being developed and can soon be expected to appear more frequently in major systems. For instance, the development of virtual environments, adaptive interface, and alternative control technologies (to name just a few) will radically change the relationship between the operator and mechanical/computer system being controlled (e.g., Durlach and Mavor, 1994). In each case, these technologies present new challenges in terms of identifying new skills that need to be trained, new training regimens, etc. However, they also present exciting new opportunities to promote more effective training. For instance, the increased computational power that makes such technologies possible, combined with their underlying requirement to monitor human performance in real time, can provide training specialists with highly detailed, up-to-the-minute profiles of operator performance and skill levels. Virtual environments, in particular, can provide very versatile and realistic training environments, but exactly how these new technologies can best be utilized in training personnel remains to be demonstrated.

5. *Measure Team Performance* Cannon-Bowers and Salas (1997), in noting the importance that team training has assumed within recent years, state that the issue of team performance *measurement* has also grown in importance: “Without accurate, reliable measures of team performance, it is difficult to select or train team members or to manage team performance. Unfortunately, little research exists that provides theoretically based guidance to those interested in assessing team performance” (p. 45).

The need to consider team training in the development of modern sociotechnical systems is clear. This need is not limited to the training of teams but extends to the design of the very systems that teams use in the performance of their tasks. However, in order to realize the many potential benefits of training and designing for well-coordinated teams, their performance must be measured in a valid and reliable fashion. Without this ability, the impact of our interventions will remain unclear.

NOTES

1. This chapter refers to a variety of systems, each of which involves humans interacting with technology and/or with one another. For the sake of convenience these are called *sociotechnical* systems. The use of this term is intended to emphasize that in each case the system under consideration is characterized by complex interactions between humans and machines as well as humans and other humans.
2. The medical field is a prime example. In spite of persistent budgetary problems and personnel shortages in key areas such as nursing, there is tremendous pressure to develop and implement sociotechnical systems that improve overall system performance, particularly with respect to the reduction of medical error and the promotion of greater cost and performance efficiency.
3. The goal of an undergraduate and graduate education is often described in terms of developing the student’s ability to learn, rather than simply “loading the student up with facts and figures.” As the

author's graduate school advisor once opined: "Having a Ph.D. doesn't prove you are smart, it proves you are educable." To the extent that training begins to focus on broad "skills" associated with learning, then perhaps a similar criterion can be applied to identify successful trainees.

4. The problem of stovepiping is one that is widely acknowledged as contributing to cost and timeline inefficiencies in the development of complex sociotechnical systems. Inefficiencies attributable to stovepiping include conflict between ostensibly coordinated but often in fact competitive organizations over resources and scheduling priorities, a lack of cohesive awareness of large-scale organizational goals and plans, and severe constraints on communication resulting in further inefficiencies. A large portion of the HSI design philosophy is geared toward the elimination of stovepiping and its negative effects on complex system development.
5. This "approval" process is in itself, of course, a highly complex and treacherous process characterized by generally Byzantine political and economic machinations. It is also one that persists throughout the entire system acquisition cycle as programs can be terminated or radically redirected at any point. While I do not want to minimize the fundamental importance of these processes, they are beyond the author's expertise and scope of this chapter.
6. For example, designing in automation features that can perform specific role functions faster and more accurately than humans can, offloading performance responsibility from the operator and diminishing overall training load.
7. Often the required skills of one team member are complementary to those of others on the team, which is just one of the factors that make holistic assessment of team performance and training so difficult.
8. Conversely, the early design of human–machine systems intended to support operational teams (e.g., the command center of a destroyer) can be assessed and, if necessary, modified on the basis of the assessment of team performance during design-phase simulation tests of prototypes.
9. One rule-of-thumb answer might be as follows: To the extent that the cost associated with a breakdown in effective team performance is high (i.e., results in the creation of dangerous or catastrophic conditions), the importance attached to creating and maintaining a consistent, shared mental model should be high.
10. The degree to which these societal changes have in fact been caused by the proliferation of information technology is a matter of debate outside the scope of this chapter. For our purposes, it is sufficient to note that these vastly influential trends have occurred at the same time.
11. While other areas, such as agriculture, medicine, the arts, and preindustrial trades (metallurgy, weaving, etc.), also have long training histories, the military domain has been historically unique in its need to train large groups at the same time and to train them to work as coordinated, unified entities.
12. *Cost effective* in this sense refers to cost savings associated with (1) a more efficient problem solution process and (2) a more efficient and durable solution.

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