# Chapter 1
# Why This Book Has Been Written: Purpose and Structure of the Book

This book came about from my motivation to bring together research on the acquisition of knowledge and skills for performing complex tasks for controlling complex technical systems, research on the challenges of ergonomics in activities with high automation, and research on training design. My own roots lie in classical industrial and organisational psychology with a main emphasis on personnel and vocational training, personnel selection and human resources. In the year 2000, my empirical research into complex systems (summarised e.g. in Kluge and Schüler 2007; Kluge 2008) led me to a refinery in Southern Germany, where I was able to look at a refinery simulator. In the years that followed, I had the opportunity get to know the small group of committed refinery simulator trainers in the German-speaking area and to interview them in depth (Kluge 2007; Kluge et al. 2008/ZfA).

Inspired by these contacts and conversations, my research into the skill acquisition for complex technical activities developed away from abstract complex systems and artificial microworlds (Kluge 2007, 2008) and towards concrete application situations in so-called High Reliability Organisations (HROs, Weick and Sutcliffe 2003). HROs operate complex hazardous technologies and manage to remain accident-free "while simultaneously retaining their capacity to meet highly unpredictable and demanding production goals" (Shrivastava et al. 2009, p. 1362). HROs operate on a very high level of trust, because technical failures and slip-ups can have severe consequences for human beings and the environment if they are not identified and resolved immediately (Kluge et al. 2009; Hagemann et al. 2012). Chemical plants, refineries, and nuclear power plants (NPP) belong to the category of HROs. They are assumed to be of great size, both physically and conceptually, and face the presence of risk and a high level of hazard, based on interconnected real-time dynamics (Crossman 1974; Moray 1997).

HROs are assumed to be highly *complex*, tightly *coupled* systems (Table 1.1), which are vulnerable to catastrophic failure (Perrow 1984; Wickens et al. 2004, p. 493). Complexity, as outlined in detail in Chap. 2, is characterised by the number of interconnected subsystems (interconnectivity), further divided by Perrow (1984) into loose and tight coupling, invisible, sometimes unexpected interactions (Wickens et al. 2004), and dynamic effects (Funke 2010; Kluge 2008). Coupling

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**Table 1.1** Examples of industries in the clusters of combinations of complexity and coupling by Perrow (1984) and Shrivastava et al. (2009)

| | Low/loose coupling | High/tight coupling |
|---|---|---|
| Low complexity | Traditional manufacturing, assembly line production, single-goal agencies (post office) | Marine transport, rail transport, continuous processing |
| High complexity | Universities, government agencies, R&D firms, mining | Nuclear power plants, refineries, chemical plants, airplanes, space missions |

as defined by Perrow (1984) is defined by the degree of missing slack and tight connection between subsystems so that a disruption in one part of the system strongly affects other parts.

Coupling specifies the qualities of interconnectivity with regard to time and degrees of freedom. While loose coupling allows certain parts of the system to express themselves according to their own interest and/or logic, tight coupling restricts this. Loosely coupled systems tend to have flexible performance standards, while tightly coupled systems include more time-dependent processes: They cannot wait or stand by until they are attended to (Perrow 1984).

Insufficient training and experience also affects the perceived complexity of a system (Hollnagel and Woods 2005) by aggravating intransparency (see also Kluge 2004) in which incomplete understanding leads to an incorrect situation assessment and to problems in choosing or selecting an action. An operator must be able to identify or recognise what happens as well as to interpret it in a context, since not knowing what happens affects the ability to predict future events (Hollnagel and Woods 2005). Therefore, persons working in HROs who are of special interest in this book are *control room operators*, whose failures in performance might lead to high financial and safety costs (Woods et al. 1987). One might argue that there are (more important) groups of workers in the world who are more worthy of having a whole book devoted to them. However, I am convinced that from the training design for activities of process control, much can be transferred to other vocations and tasks which contain partial aspects of this specific activity and which can, in principle, be generalised.

The tasks of a *control room operator* are to monitor and control a complex technical system (as will be described later). Monitoring and controlling a complex technical system is not a challenge for human motor capabilities (Wickens and Hollands 2000). Rather, it challenges *human factors* aspects, such as attention allocation (Wickens and McCarley 2008), perception, situation assessment (Vicente et al. 2004), situation awareness (Endsley 1995), decision making and execution, memory (Ericsson and Kintsch 1995), and mental workload (Tsang and Vidulich 2006; Vidulich 2003).

The topic of *human factors* encompasses the "study of those variables that influence the efficiency with which the human performer can interact with the inanimate components of a system to accomplish the system goals" (Proctor and van Zandt 2008, p. 9). Karwowski (2006, p. 4) cites the definition of the

International Ergonomics Association as "ergonomics (human factors) *as the scientific discipline concerned with the understanding of the interaction among humans and other elements of a system and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance*". He further distinguishes between

- **physical** ergonomics, which addresses human anatomical, anthropometric, physiological and biomechanical aspects of work,
- **cognitive** ergonomics, which focuses on mental processes such as perception, memory, information processing, and motor responses, as they affect interactions among humans and other elements of the systems, and
- **organisational** ergonomics or macroergonomics, which addresses the organisation of socio-technical systems, such as the structure, policies and processes (Karwowski 2006, p. 4). It focuses both on organisational and human-machine interface issues (Proctor and van Zandt 2008) in order to seek an integration of humans with advances in manufacturing technology (Nagamachi 2002).

The book's **perspective** is **one of cognitive and organisational ergonomics**. Both can be viewed under the label of "cognition in organizations" (Hodgkinson and Healy 2008). Hodgkinson and Healy (2008) advocate that the complexities of the modern workplace require an increased cooperation across and between organisational and human factors tradition.

The book describes the knowledge and skills required for complex tasks for controlling complex technical systems from a cognitive ergonomics point of view. It then turns to organisational ergonomics, as it proposes training strategies and training regimes for successfully acquiring this knowledge and these skills in "Staged Process Control Readiness Training" (SPCRT). It describes training views on how to impart, develop, and change members' knowledge structures not only to perform immediate day-to-day routine tasks but also to expand their repertoire for managing uncertainties in a wider transfer environment (Hodgkinson and Healy 2008). Training, as well as highly skilled and competent workers, is an essential prerequisite for HROs to function on a high level of reliability, because HROs, as complex and highly coupled systems, require centralisation in order to carefully coordinate resources and concurrently require decentralisation to cope with the unexpected (Perrow 1984; Wickens et al. 2004). Even though Perrow (1984) is not confident that organisations can successfully employ centralisation and decentralisation at the same time, there is consensus regarding the demand for highly skilled and qualified personnel. Decentralised decision making requires continuous learning and training (Weick et al. 1999; Shrivastava et al. 2009), but a comprehensive review of research results and a theoretical overview model of training development and design is still lacking.

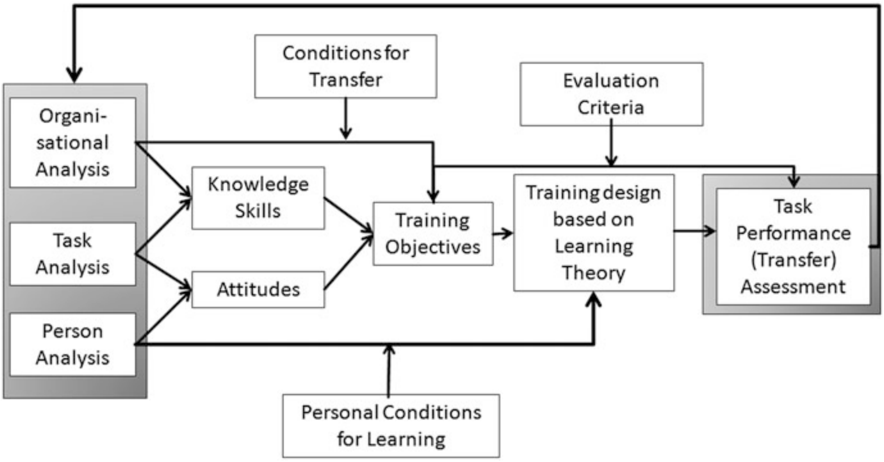


**Fig. 1.1** A general schema of a systematic approach to training (Based on Goldstein and Ford 2002)

## 1.1 The Book's Structure

The structure of the book as regards content is oriented to the "Systematic Approach to Training" model of Goldstein (1993), Goldstein and Ford (2002), Salas et al. (2006) and Coultas et al. (2012), as displayed in Fig. 1.1.

The organisational analysis in the context of this book is important for understanding the jobs and performance conditions under investigation. These jobs have to be performed in organisations in which incorrect actions can have severe consequences for humankind and the environment, as was apparent, for instance, in accidents in the last few years, for example in the refinery in Texas City in 2005 (Fig. 1.2), in the explosion of the Deepwater Horizon in 2010, or in the battle to control the damage following the tsunami disaster in Fukushima in 2011.

To read and learn more about the interplay of organisational factors contributing to theses accidents, such as training issues, process safety, management and leadership issues, accident investigation reports are available, for example, from the Chemical Safety Board in the US (www.csb.gov) or from the IAEA webpage (http://www-pub.iaea.org).

Analyses of blackouts in the electricity power system and investigations of large-scale outages in the North American interconnected electric system in the US and Canada have demonstrated the need to enhance the operators' ability to understand the state of the system and to anticipate possible problems (Greitzer et al. 2009). The scope and complexity of power grid operations continue to grow: "*Widespread electrical outages, such as the one that occurred on August 14, 2003, are rare, but they can happen if multiple reliability safeguards break down. Providing reliable electricity is an enormously complex technical challenge, even on the most routine of days. It involves real-time assessment, control and coordination of electricity production at thousands of generators, moving electricity*

**Fig. 1.2** Texas City, 2005: On March 23rd 2005, 15 people were killed and over 170 injured as the result of a fire and explosion on the isomerization plant (ISOM) at the refinery owned and operated by BP Products North America in Texas City, Texas, USA. http://www.bp.com/liveassets/bp_internet/us/bp_us_english/STAGING/local_assets/downloads/t/final_report.pdf (retrieved September 10th 2012)

*across an interconnected network of transmission lines, and ultimately delivering the electricity to millions of customers by means of a distribution network*" (Greitzer et al. 2009, p. 37). Greitzer et al. (2009) propose that to meet the demands and expectations of this industry, effective training and maintenance of a high level of mastery are required of the system operators and plant personnel.

Organisational and task analysis and the description of the (complex) skills to be performed in the (complex) organisational environment are important steps for deriving the knowledge and skills which are necessary to perform the job of a control room operator in the HRO context. For the purpose of this book, it is important to consider the distinction between routine and non-routine/normal and non-routine/abnormal situations (Kluge et al. 2013) as *conditions for transfer* (referring to the systematic approach to training, Fig. 1.1), because these determine under which conditions, for example under high stress or during night shifts, the trained tasks have to be performed, and to what level they need to be proceduralised, for example when the start-up of a plant only occurs once every five years. Although a great deal could also be said about the technical process and the forms and philosophy of automation which are employed in the process industries, I will limit myself in each case to the consequences of automation, which is relevant for knowledge and skill acquisition.

With regard to needs assessment, this book is not focused on a *person analysis* and the detection of person-related variables required *for the job*. Instead, I only address the group of persons to be trained insofar as this is important in order to design the training under consideration of prior job experiences, e.g. as a field operator, i.e. the *learning biographies*. The group of persons about whom we speak here has (at least in Germany) completed vocational training, e.g. as chemical workers or electronics technicians for industrial plants if they are in a refinery, or as graduates with a Bachelor or Master degree in engineering if they are undergoing initial training as shift personnel in charge of control rooms in NPPs. In many cases, they have already worked in the plant for several years before they switch to the control room as operators, i.e. they already have a long employment history. Frequently, it is also a particular accolade for employees who have proved themselves in production for several years to be permitted to switch to the control room.

From the needs assessment and the derivation of the training objectives, implications emerge for the training design and evaluation criteria. Training design includes the instructional techniques, their sequence (what in which order?), the technical equipment (e.g. full-scope or generic simulator) and the environment (e.g. classroom, immersive environments) in which they are applied. The decision of how to best combine and integrate instructional techniques, sequence, technical equipment and environment is based on learning theories and models addressing the acquisition of knowledge and skill for performing complex tasks (defined in Chap. 2).

When deriving evaluation criteria, the book is less concerned with the theory of evaluation per se. Generally speaking, evaluation means the systematic, scientific, empirical, hypothesis-oriented investigation of effectiveness and efficiency of an intervention, with the aim of using the evaluation results to (re)design and apply the findings in the socio-technical context of training decisions (Goldstein 1993, p. 147; Mittag and Hager 2000, p. 103). The book will address the aspects of how to assess training effectiveness in terms of measuring training results by providing ideas on how to measure learning improvements from a Human Factors perspective as well as successful transfer to the predefined routine, non-routine/normal and non-routine/abnormal situations that can occur. The usefulness will only be described briefly based on verbal statements of various refinery trainers in order to provide an impression of what efficiency of training means in HROs.

In summary, the book aims to

- facilitate the understanding of the task and target job in the context of the organisation (needs assessment) by describing complex technical systems (the process industries), complex tasks and to specify conditions of transfer, meaning conditions under which the later trained knowledge and skills need to be applied in the working context,
- derive the knowledge and skills required to fulfil the task in order to define training objectives,
- develop propositions for how to best acquire the knowledge and skills (defining the learning environment, based on learning theories) and the conditions of transfer by providing theoretical propositions for their acquisition based on the state-of-the-art research on knowledge and skill acquisition for complex taskwork and teamwork tasks, and
- propose the concept of the “Staged Process Control Readiness Training” (SPCRT) as the instructional techniques and within a comprehensive framework on how to best support skill and knowledge acquisition in High Reliability Organisations which can be transferred to routine, non-routine/normal and non-routine/abnormal situations.

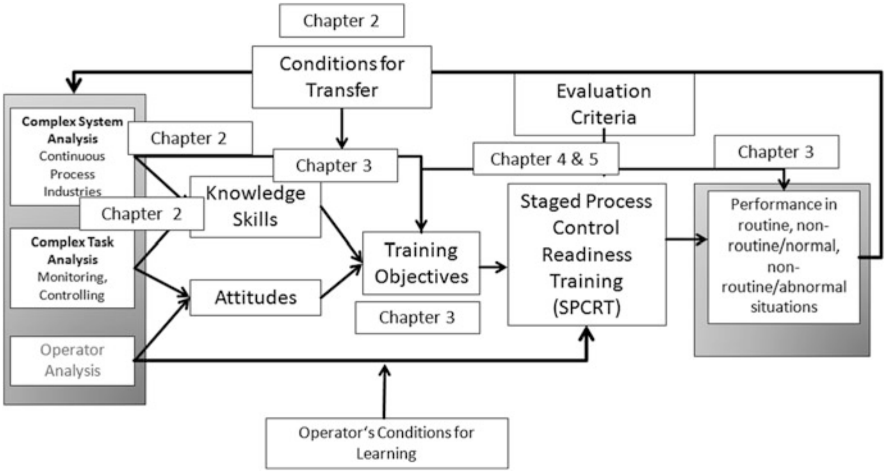


**Fig. 1.3** Systematic approach to training applied to knowledge and skill acquisition for controlling complex technical systems

The structure of the book should therefore facilitate the design of training programs to achieve training objectives based on a generic but solid requirement analysis of process control tasks and familiar jobs. In summary, the structure is oriented to Fig. 1.3, in which the steps of the procedure for training design are categorised into chapters.

This book refers to various theoretical foundations from cognitive psychology, the psychology of learning and skill acquisition, and from industrial and organisational psychology. Knowledge of the foundations is presupposed. The primary concern in this book should be with the application of theories and models in this context of complex tasks to control complex technical systems.

I wish all readers as much enjoyment reading and working with this book as I had writing it. In doing so, I am fulfilling my wish for a book that I would have liked to have had when I was beginning my training research in process industries 13 years ago. Now, it is an interim result of my research and that of my team.

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