1 Introduction

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CONTENTS

ADVANCED ORGANIZER

- Agent–environment transactions represent mutual activities in cognitive systems.
- Design of systems that fails to take into consideration the cognitive–contextual aspects of the user frequently results in errors or mistakes in performance.
- The living laboratory highlights the principle that intentional design must produce effective adaptation to the environment to produce sustainability, resilience, and reliability.

ORIENTATION

I first heard the term *living laboratory* from one of my conversations with an Air Force Research Laboratory (AFRL) division chief in the early 1990s as we discussed ideas about how to study decision making and design decision aids within the command and control domain. Indeed the term has a separate history as a generic term that colors the way it has been considered in our research motivations (see Wikipedia, Living Laboratory, https://en.wikipedia.org/wiki/Living_lab). Having said that, the way this book uses the term *living laboratory framework* (LLF), as applicable within the realm of cognitive systems engineering CSE, has specific meaning and gravitas. The division chief's original quest suggested that research and design must be looked at not just from an ivory tower of theory and lab studies, but from the perspective of a challenging and dynamically changing real world where humans and machines work things out in the midst of ongoing work requirements. The implication being that laboratory research needed to be grounded in the context of work, applicable to designs that enabled humans (embedded within multiple systems) to do *cognitive* work, and reflect the mutual interplay of *agent–environment transactions* wherein power, insights, and effectiveness could be produced. Too frequently, design did not consider the context, the human, the dynamics of change, and what interaction actually meant. In turn what were supposed to be systems that supported *cognition* actually turned out to be outright failures that produced the inability to control and monitor work. Such a state of affairs contributed heavily to what we know as *human error* or the conquests of work that ended up with slips, mistakes, accidents, and even catastrophic failures (Norman, 1988). Although these initial tenets are still true, what we mean and we connote with concepts such as *context*, *agent*, and *cognitive* has changed substantially over the past 25 years, often through the introduction of new technological sophistication.

The initial interpretation of a living laboratory was that poor design often results from limited uses of static guidelines, ancient experimental studies, or traditional wisdom. In contrast, intentional design must dynamically *come alive* based on the mutual transactions of the agent within the environment. In this sense, *come alive* means being able to adapt to circumstances and situations, to sustain operations in balance to maintain veridicality, reliability, and validity, and to be resilient when change happens. Adaptation, sustainability, resilience, and effectiveness are qualities that need to be addressed when practitioners engage in the practice of CSE. As one reads through the various sections and chapters within this book, it is our hope that the LLF unfolds a pathway toward such qualities and opens up new awareness of *what can be*.

MOTIVATION FOR THE BOOK

Historical Imperatives and Flow

The influences spanning across CSE that have led to this book have emerged from many corridors and perspectives, stretched across passages of time (approximately 30 years). This trajectory might be categorized in the following four phases:

1. Early work in *ecological psychology, social science, and design practice.*
2. Formulations in *cognitive science and human–autonomous systems.*
3. Underpinnings in *team cognition and collaborative systems.*
4. Refinements through *sociocognitive simulation and technology development.*

Although I have been involved with many talented and wonderful people and different work groups throughout the years, the evolution of what has come to be our current practice (and indeed the representation of chapters within this volume) has not been straightforward but rather nonlinear, even chaotic at times. I have chosen to label the distinct niche of CSE that we have engaged in—albeit changes and refinements over the years—as the *integrated* LLF. We will explain the concepts and ideas underlying this approach shortly, but first it is insightful to talk about the history and developmental insights of CSE as we have known it and come to practice it in our laboratory, collectively known as the MINDS Group.*

Prelude

Much of the work that has led to this book has emerged from the broad research area of human factors. It has necessarily been coupled with understanding cognition and in turn how cognition could impact the design of machines, interfaces, tools, systems, and/or environments that invariably intersect individual work and team work. My own degrees include titles such as *experimental-cognitive psychology* and *cognitive science*. The HFES† subtechnical group that I am in is titled *cognitive engineering and decision making* (which is the largest technical group of the society). In addition, one of the books I have edited in the past includes the term *cognitive systems engineering* (McNeese & Vidulich, 2002). Indeed, cognition seems to be pervasive and

* **The MINDS** (Multidisciplinary Initiatives in Naturalistic Decision Making) **Group** at The Pennsylvania State University (https://minds.ist.psu.edu/): This represents the collective research group I have directed in toto for the past 17 years. This group has utilized the living laboratory approach for cognitive systems engineering in various instantiations.

† HFES – Human Factors and Ergonomics Society.

holds an esteemed place as a foundational concept in the human factors community of practice. As cognition is a state that is experienced, felt, or noted by the mind, we can say that in fact it is one of the phenomenal bases of human factors (see McNeese, 2016, for a further review on this topic). At the HFES annual meeting each year, we increasingly see evidence of the historical imperative of cognition impacting design through different concepts, constructs, frameworks, models, processes, approaches, and outcomes. For example, terms such as *mental models*, *situation awareness*, *cognitive ergonomics*, *attention processes*, *knowledge/skill acquisition*, *cognitive task analysis*, *transactive memory*, and *macrocognition* are elaborated year-in and year-out within various papers.

As cognition can make note of itself (metacognition), is sensed by *us* and others, and can be thought about as we recall it or change it in midstream (dynamically reconstructed), it is often historically portrayed as an internal, intrinsic, introspective, microscopic, and as inside-the-head phenomenon. However, that is not the full story, as we would like to turn cognition on its head, so to speak. A retrospective look at cognition over the past 50 years reveals a changing landscape of connotative formalisms—Weltanschauungs that mirror positivist, interpretivist, or alternative approaches to frame the place that cognition has in life and work.

As cognition is elaborated by multiple factions with differing goals and cultural lens, flip-over (Whitaker, Selvaraj, Brown, & McNeese, 1995) inevitably occurs creating connotative and interpretive layers of definition, reason, and power. The way *cognitive* is used and employed actively defines what it is and what it means to the user. One of the ways cognition has been used and flipped for use to understand and change people's behavior is through (what has been termed by many) *cognitive engineering* (see Hollnagel & Woods, 1983; Rasmussen, 1986). In this case, one way to conceptualize this book (as a volume on cognitive engineering) is to ask the following questions: (1) Where can cognition make an impact on design? (2) How can a design conform cognition for a particular use or situation—good or bad? (3) How can a complex system be engineered to be integrative with its environment and the people who work with the system in that environment? Cognition flip-over occurs in CSE in that cognition is interpreted to be distributed more externally in the built and social environment—emerging in a dynamical way through the transactions of individuals. Aptly stated by Mace (1977) "Ask not what's inside your head, but what your head is inside of." During the early-to-mid 1970s, this kind of flip-over influenced my own understanding of cognition and what it meant for engineering design was being disrupted and simultaneously transformed through learning. This is exemplified by the following quotes:

> People think in conjunction and partnership with others and with the help of culturally provided tools and implements.—Gavriel Salomon, 1997 (p. xiii).
>
> Cognition observed in everyday practice is—stretched over, not divided—among mind, body, activity, and culturally organized settings.—Jean Lave, 1988 (p. 5).
>
> The emphasis on finding and describing *knowledge structures* that are somewhere *inside* the individual encourages us to overlook the fact that human cognition is always situated in a complex sociocultural world and cannot be unaffected by it.—Ed Hutchins, 1995 (p. xiii).

As an example of alternative landscapes, CSE has typically taken a different view of inside-the-head cognition, and some of the primary schools of thought are heavily influenced by ecological psychology and affordances (Norman, 1988; Rasmussen, 1986; Vicente, 1999). Like many others, I have been influenced by ecological theories as well, but more specifically in terms of situating and representing cognition within specific environmental, contextual, and cultural surrounds, often referred to in the research literature as *situated cognition* (Brown, Collins, & Duguid, 1989) and/or *distributed cognition* (Hutchins, 1995). Therein, a lot of the LLF is predicated on ideas and seed concepts that propagated within these areas.

Early Work in Ecological Settings and Cognitive Design Practice

My first encounter with designed environments,* people's behavior, and how they think or do things came through work on a senior honors synthesis at The University of Dayton, Ohio (McNeese, 1977). This thesis consisted of an ecological study of how groups use space (personal space and orientations at different architectural or situated contexts within the university setting—library, student union, etc.). This way of considering how people act and think about their actions within the context of space was very much coupled with individual/social awareness and how designed environments afford different use and experiences. The study involved qualitative methods and represented research ascribed to environmental psychology (Altman, 1975), ecological settings (Barker, 1968), and human–social cognition (Fiske & Taylor, 1991). Although not specifically representative of the kinds of quantitative cognitive studies I would later be engaged with, this study was important as it (1) represented an initial foray into ecological dynamics within built contexts, (2) explored how social psychological variables interact with the ecology, and (3) studied how systems can be designed to enhance the intended function of an environment (i.e., *use*). Although this was very early work, it laid foundations for the melded, integrative, and interdisciplinary nature of social psychology, collaboration, human-centered design, and ecological settings—components still facile for CSE in our lab. In particular, the emphasis on studying collaboration in context, and how design influences behavior, set the initial seeds for the living laboratory conceptualization.

Much of the formative years in cognitive systems and the ecological foundations came from the philosophical direction and training of my advisor, Dr. John Bransford (while he was at Vanderbilt University, Nashville, Tennessee), in the areas of problem solving—problem-based learning—and information seeking. Much of my formal training was in cognitive psychology and design, but my intent was to do experimental work to better understand phenomenon in terms of ecological connections of a human embodied in a context. The theories associated with distributed cognition (Hutchins, 1995), ecological psychology (Gibson, 1979), and problem

* Note this was my first encounter with a research study involving ecological settings and design work. As mentioned within the preface—my first encounter with human factors and design per se came through work as a designer on a school bus monitoring display system circa 1973 with the Automatic Control Device Corporation, Dayton, Ohio.

solving/learning (Bransford & Stein, 1984) started to permeate how I framed cognitive systems within real-world environments (fields of practice). As such, they were very much in play as forces that helped meld a specific methodological framework for the pursuit of cognitive-engineered systems.

Collaborative and Human–Autonomous Systems

Continuing with this line of thought, as one considers where the current framework came from, one important influence was placement in an early research role (as a USAF [U.S. Air Force] scientist) responsible for the government cognitive science oversight of the USAF Pilot's Associate program in the mid 1980s. This position enabled yet another distinct change in thinking about cognition—basically that it could be mediated among humans, intelligent agents, and interfaces—within the context they were required to perform in. This came about in 1986 while conceptualizing how humans and artificial intelligent systems might unfold within a complex fighter pilot environment (McNeese, 1986). This notion was important for what I termed *mindware inferencing*, and how collaborative-based cognitive systems could develop sensemaking about how their action was relevant in the unfolding context, and in turn how the ecology of interagency drove cognition to be distributed outward. At the time I referred to this as *macrocognition* and *macroawareness* to signal the increasing role of context, how interdependent layers of information are distributed across an environment (the information surround), how human and computational agents represent a new type of teamwork (human–autonomous interaction) within the aviation domain. This provided a lens on which CSE could be shed in a new light—what might be referred to as a *collaborative ecosystem* where domain knowledge became very important for designing intelligent systems that transact, transform, and adapt in context in order to survive and be sustainable. This set up a seed to begin thinking about cognition using a living ecological metaphor, and to enable methods that could bring this to pass. This marked a variation in my own zeitgeist with respect to cognition (cognitivist to ecological–contextualist/social constructivism) as it unveiled the future path I would take in my own research agenda in the next 30 years. Engineering agents to adapt with humans to formulate unique types of teams that can evolve with the changes in the context they live in. In a crude way, this was the primordial beginning of collaborative ecosystems as a *living laboratory.*

The AKADAM Initiative

During the late 1980s into the mid 1990s my group at the Paul M. Fitts Human Engineering Division, AFRL developed a specific initiative and approach for the Pilot's Associate program (which we called *advanced knowledge and design acquisition methods*—AKADAM (see McNeese et al., 1990; Zaff, McNeese, & Snyder, 1993), which modeled some of the first principles and notions of what would eventually become a partial basis for the LLF (McNeese, 1996). The program was predicated on ideas involving *knowledge as design* as articulated by David Perkins (1986). The basis of this approach focused on understanding a *user's experience* in terms of both conceptual and functional knowledge as a foundation to develop designs for specific contexts of use. AKADAM utilized techniques in concept mapping (conceptual knowledge representation) and IDEF (functional knowledge representation) to understand information systems and to inform human-centered design (through the use of picto-literal representations such as design storyboarding).

Theoretically, AKADAM integrated cognitive, computer, and design science as a nexus that would be applied in various domains. Therein, AKADAM really substantiated and tested methods for knowledge elicitation and design storyboarding to reveal cognitive aspects of systems within specified contexts. Continuing with the experience gained with earlier efforts in ecological settings and design, AKADAM maintained a sustained coupling with contextualistic-social constructivist perspectives that framed cognition as a phenomenon that integrated inside-the-head knowledge with distributed, external situations/events. Around the time of our 1995 publication summarizing the AKADAM work—Ed Hutchins came out with his monumental book on *distributed cognition* (Hutchins, 1995) that continued to reinforce how we thought about cognition, but also highlighted the point that CSE would need to aim not only at individual work but collaborative, distributed work that increasingly was supported by information technologies (e.g., computer-supported cooperative work, Schmidt & Bannon, 1992).

In essence, AKADAM was an early CSE approach that produced human-centered designs specifically adapted for human–autonomous interaction (i.e., for the Pilot's Associate) that pointed toward coordination/cooperation. While this approach was applied in human–autonomous interaction initially, it was also adapted and applied in other complex domains as well (see McNeese, Zaff, Citera, Brown, & Whitaker, 1995).

Developing Team Cognition and Collaborative Systems

Simultaneous with creating and applying AKADAM, I was very much absorbed into three related theoretical areas that bridged cognitive science, social psychology, and team cognition to support two distinct areas within the AFRL community: (1) command, control, communications, and intelligence (C^3I) and (2) collaborative design technologies (CDT). As one can see, this is where theory intersected practice and design work, continuing themes of research from the other phases of work I was involved with. When I transferred into the Paul M. Fitts Human Engineering Division*, I was immersed into the C^3I community and part of a group called COPE (C^3 Operator Performance Engineering). Working with the COPE program provided another forerunner of experiences that led to the LLF perspective of CSE. Actually one of the roles I took up in this group was looking at team cognition through the lens of cognitive science, specifically in the form of quantitative research

* My initial work in the U.S. Air Force was as an engineering psychologist (civil servant) working for the Human Factors Branch of the Aeronautical Systems Division, Wright–Patterson AFB, Ohio (1981–1984). This was an excellent opportunity, as part of the work consisted of being a chief human factors engineer for real-world system programs offices (e.g., the KC-10 was one plane wherein I was responsible for all human factors considerations), whereas another aspect was to be a research scientist within their crew station design facility where I was heavily involved in the human–computer interaction designs and assessment for the F-16 aircraft cockpit.

experiments utilizing team-based simulations (TRAP—team resource allocation problem, Brown & Leupp, 1983; Kimble & McNeese, 1987; Wilson, McNeese, & Brown, 1987; CITIES, Wellens & Ergener, 1988; adapted DDD, McNeese, Perusich, & Rentsch, 1999) that investigated sociocognitive science constructs such as team-situation awareness, team mental models, information sharing, and team performance. The CITIES simulation was the initial work that launched our newer simulation—NeoCITIES—a client-server architecture-based simulation in which multiple team cognition research studies have occurred (see McNeese & McNeese, 2016). The emphasis on simulation set forth another key seed for the LLF. In fact, it provided the medium to connect many of the elements of the LLF together that allowed innovative design ideas to be tested before introduced as interventions into fields of practice.

As time marched on, I was also able to forge paths between computer-supported cooperative work (CSCW) and design teams after being appointed as the director of the AFRL Collaborative Design Technology Laboratory. This provided the stimulus to integrate and merge the research from AKADAM and human centered design with team cognition and the development of collaborative systems in unique ways. This initiated the early beginnings of the LLF as an integrated set of methods to explore and build cognitive systems for complex domains that could in turn be tested in scaled world testbeds (simulations) prior to employment.

At Wright–Patterson and/or within the greater Dayton and Columbus Ohio Human Factors community, I have been heavily invested and owe a lot. Although there are both similarities and differences between naturalistic decision making (Zsambok & Klein, 1997) and cognitive engineering research and practice, at times they have had a major cross-pollinating effect. As I was working as an engineering research psychologist at AFRL at WPAFB, I cannot over estimate the contributions and influence made to my own thinking by such luminaries as Dr. Gary Klein (then of Klein Associates, Inc.), Professor John Flach (Wright State University), Dr. A. Rodney Wellens (University of Miami), and Dr. David Woods and Dr. Emily Patterson (The Ohio State University). I did a sabbatical as a visiting professor at Ohio State working with David, who shaped a lot of beliefs and principles about CSE that still hold true today. Likewise my collaborations and friendship with the late Rod Wellens will always be valued and remembered.

A lot of the research I am currently supervising with my PhD students is directly linked to the theoretical ideas and operational measurements of group situation awareness that Rod articulated in the early days (Wellens, 1993). Likewise my government and support contractor colleagues provided great insight and challenged my perspectives. In particular, Dr. Randall Whitaker and Dr. Brian Zaff (then of Logicon Technical Support Services—LTSI) and Professor Clifford Brown (Wittenberg University, Ohio) composed my research group while I was the director of the Collaborative Design Technology Laboratory, and really helped to infuse foundational knowledge within the areas of CSCW and team cognition. My colleagues at the Fitts Human Engineering Division also provided intellectual stimulation and support within the cognitive systems area. In particular, Donald Monk, Dr. Robert Eggleston, Dr. Michael Vidulich, and Gilbert Kuperman were highly instrumental in my development as a professional. They sharpened my knowledge of human factors and cognition within the aviation domain. Special thanks to Dr. Michael Vidulich who was my coeditor for the first book I did on cognitive engineering for the aviation community (McNeese & Vidulich, 2002). Special thanks also to Dr. Kenneth Boff who supported the visions of cognitive systems as our Chief Scientist and as our division chief at AFRL.

Moving Forward with Sociocognitive Simulations and Technology

During the formative years of cognitive engineering (while at Wright–Patterson AFB), the seeds were thrust into motion for establishing an integrative framework to apply to various fields of practice. Although the original framework was first published over 20 years ago, the actual utilization of the LLF has been ever-present while as a Professor at The Pennsylvania State University. I moved from AFRL to Penn State in 2000 (17 years ago) and established what was originally called the user science and engineering (USE) Laboratory. That eventually morphed into the MINDS Group at Penn State. MINDS stands for Multidisciplinary Initiatives in Naturalistic Decision Systems. As director of The MINDS Group, I have overseen a number of LLF efforts and implementations, being strategic for a number of PhD dissertations produced in our group as well as actively applied to different research grants.

Hence, this final phase of development and history—sociocognitive simulations and technology development—put into place a strong emphasis on scaled worlds and innovating new technological designs that could be embedded within a given scaled world for test, evaluation, and refinement. While originally doing fieldwork studies for C^3I, the original CITIES simulation (Wellens) provided an analogical work setting focus—*emergency crisis management*. As years went by we redesigned and structured a newer simulation termed NeoCITIES, which has been an anchor for the research conducted while at The Pennsylvania State University. NeoCITIES has also spawned other spinoff simulations in the area of cybersecurity (see Tyworth, Giacobe, Mancuso, McNeese, & Hall, 2013) to create new opportunities and insights in research.

The MINDS Group as It Has Evolved at The Pennsylvania State University

Although the preceding historical movements laid foundations for the LLF and defined the subsequent methodological perspective, our articulation of a living laboratory necessarily means it (1) *evolves* with changing forces to be relevant, (2) provides *useful outcomes*, and (3) highlights *learning* to move data and information toward solutions. As articulated problems compose the fabric of societal advancement and exist as the fulcrum in the LLF. Identifying, solving, and exploring problem spaces generate information seeking that colors in the tradeoffs that represent viable solutions. The general mantra of the LLF is actually the same as a top value communicated at The Pennsylvania State University—that of *Making Life Better.* The following statement exemplifies this:

> As the knowledge needs of society rapidly change and expand, higher learning has a more important role to play than ever before in advancing the quality of life. Penn State's commitment to students, to outreach, and to progress touches the lives of most Pennsylvanians and improves the quality of life for all (PSU Budget Office Communication).

The MINDS Group as mentioned in the previous section represents an emerging living laboratory within itself, extensible and adapting as a function of the demands put before it. A living laboratory is made of individuals who form a knowledge-based collective that expands interdisciplinary knowledge, promotes mutual learning, and targets problems to make life better for contexts that are addressed. In some ways a living laboratory is akin to a living document in that it is continually updated, changed, adapted, and adjusted to better serve the original purpose for its existence—but also evolves to accomplish new purposes that arise along the way through the collective efforts of those who work together. This highlights the living ecosystem characteristics mentioned earlier. One of the primary reasons for composing this volume was to show the collective output of the MINDS Group as it has grown as an intact living laboratory over the past 17 years—by presenting some of the learning, activities, products, and innovations that have transgressed albeit in many different ways. Many of the chapters that compose this volume represent the distillation of the collective mindset of the MINDS Group. Although many of the contributors have moved forward to new venues and careers, a lot of their worldviews, perspective, awareness, heart, and training have been developed as active participants and change agents in the LLF.

Note that the following students in the MINDS Group have contributed to the collective knowledge of CSE through the LLF, and have produced dissertations under the advisement of Dr. Michael McNeese—Dr. Rashaad Jones, Dr. Edward Glantz, Dr. Mark Pfaff, Dr. Arthur Jones, Dr. Vincent Mancuso, Dr. Chris Dancy (Dr. Frank Ritter and Dr. McNeese—coadvisors), Dr. Tristan Endsley, (Dr. McNeese and Dr. Forster—coadvisors), James Reep, (PhD candidate and current student, Dr. McNeese, advisor). Dr. David Hall provided dissertation advisement to Dr. Ben Heller and Dr. Jeff Rimland. Dr. Hall and/or Dr. McNeese served on the dissertation committee of most of these students either as a member or coadvisor. Dr. Madhu Reddy (formerly of The Pennsylvania State University, College of IST and now at Northwestern University) provided dissertation advisement to Dr. Nathan McNeese, a member of the MINDS Group who has also contributed to this volume. It is our great honor to have all of these MINDS Group members (and former students) produce chapters for this book and therein collectively represent The Pennsylvania State University MINDS Group perspectives on CSE. Furthermore, the work continues with Samantha Weirman (Dr. McNeese and Dr. Forster as coadvisors) who is pursuing her PhD and will be contributing to the body of knowledge.

We also acknowledge the following dissertations that have contributed to both the MINDS Group (as members advised by Dr. McNeese and/or Dr. Hall) and to the collective knowledge of CSE and the LLF: Dr. Ivanna Terrell, Dr. Erik Connors, Dr. Andrew Reiffers, and Dr. Nicholas Giacobe.

In addition, we also point out the contributions made to the LLF through postdoctoral scholars who have been part of the MINDS Group over the years: Dr. Isaac Brewer, Dr. Katherine Hamilton, and Dr. Mike Tyworth. I also want to pay special tribute to MINDS Group members who have been my Research Assistants and/or Teaching Assistants along the way—(Dr. Xun Ge, my first TA and RA at The Pennsylvania State University; Dr. Patrick Craven; Dr. Bimal Balakrishnan; Dr. Tyrone Jefferson; Dr. Lori Ferzandi; Dr. Elena Theodorou; Dr. Priya Bains) who have made indirect contributions within this volume.

Finally The Pennsylvania State University faculty who have served as advisors and mentors to the above researchers have been extremely important to facilitate the kind of active learning environment we have put in place. Their knowledge, devotion, and encouragement have made this book what it is. The late Dr. David Hall, Dr. Susan Mohammed, and Dr. Peter Forster have been valuable components of the MINDS Group and have provided the vision necessary for students to achieve high levels of success. Also special thanks must go to Professor Clifford Brown (one of my longtime colleagues and mentors) who spent his sabbatical from Wittenberg University, Ohio working with the MINDS Group developing scenarios and research studies for the NeoCITIES simulation.

AUDIENCE FOR THE BOOK

This book has been written for cognitive systems engineers, information scientists, and human factors professionals who are typically involved with complex systems that include the necessary integration of information, technology, and people within a given work context. It provides useful theoretical imprints, methodological approaches, and practical findings for professionals involved with cognitive systems research and development. In addition, the book provides a viable product for use in the classroom for faculty and students enrolled in courses that are pertinent to cognitive and information sciences, industrial/cognitive systems engineering, human factors—human-systems integration (HSI), human–computer interaction (HCI), user experience (UX), and usability. The volume also provides relevance for iSchools (Information Schools) wherein the information society is connected to socio-technical systems, context, information seeking, human-centered design, and collaboration as studied through a panoply of philosophies relevant to science and the building of systems.

The type of work presented is typically interdisciplinary, can be observed, interpreted, and analyzed from multiple perspectives, consists of layered-interdependent systems and system of systems, involves ill-definition and uncertainty, yet has routine elements as well, is emergent, temporal, may contain elements of information overloading from multiple sources, requires information fusion across various sources (distributed cognition), is typically predicated on successful individual and team work, is reliant on interdependencies with various technologies, is understood through the application and use of multiple methodologies, and is usually comprehended through data-information-knowledge-based analytics. The philosophy that pervades this book's understanding of complex systems and environments is one that is

- Human centered
- Problem focused
- Team enabled
- Design supported

In summary, the book is designed for professors, graduate students, specialists, and practitioners who are currently engaged in human-centered design or other applied aspects of modeling, simulation, and design that require joint understanding of theory and practice. As the book synthesizes aspects of information science and human factors through the LLF it fills a niche that is rather sparse at the moment. Furthermore, practitioners in given domains/fields of practices utilized within specific chapters may have a focused interest in work relevant to their concerns (e.g., emergency crisis management, cyber security). Faculty teaching specific research methodologies in cognitive systems and/or human factors would utilize the book to show a given genre of research methods of relevance and how they are used in an integrative manner. The book may be used as both reference and as a textbook for college coursework (fourth year undergraduate or graduate student work).

Why the Book Is Necessary

Many books in human factors specialties and professions downplay information and cognitive science, computational foundations, and the information technology aspects of distributed work. In turn the truly interdisciplinary components that are required to competently address complex systems in today's contemporary society are not really dealt with or acknowledged very well. Likewise, many in the information and cognitive science community have given human factors, cognitive engineering, and HSI short shrift especially downplaying teamwork and the emerging context that underlies human-centered design. The consequences—therein—is that research and design requires a broad transformative leading edge approach that supplies integrative understanding for *learning and discovery*. Unfortunately each of these respective areas tends to be polarized from the others and provides isomorphic limited perspectives. Limited perspectives arise mainly in theories, methods, and design practices.

This overall issue is seen in many areas today where computation and cognition and context must exist as an ecology of layered and functional relationships that facilitate dynamic change and adaptivity in order to assuage the emerging complexity that ensues when information, technology, and people have to function and work together in an efficient and effective way. To the extent that the information society that lies before us is human centered—then an effective framework to generate ecological precedence is very much necessary. Therein, we are writing this book to introduce, explain, and provide studies, examples, and cases that demonstrate the use of an integrated LLF in order to establish a cohesive, feasible, and mixed methodological approach for complex interdisciplinary systems.

Topics and Coverage of the Book

As indicated in the previous paragraph, complex systems are omnipresent in everyday life with the introduction and presence of information technology within areas such as social networks, the Internet of Things, online banking, big data, traffic control and transportation, smart cities, logistics, military aviation, military command and control, robotics, big data informatics, distributed learning, augmented reality, emergency crisis management, intelligence, and cyber security, to name just a few prominent industries. Because distributed work almost always involves people in planning, decision making, operations, safety, and financial interests, there is a prime need for (1) human-centered understanding and (2) implementing cognitive-systems level considerations within information science/information technology designs. As these needs require timely integration of interdisciplinary (and often nested) topics the LLF provides a holistic and sustainable approach to leverage researcher and designer activities toward distributed work concepts that are sound, testable, as well as implementable for revision, resilience, and adaptation.

The book chapters cover what an integrated LLF and approach consist of through relevant and current research topics, application of apropos methods, and development of specific cases as studies; and specifically will answer the following questions: Why is the living laboratory important for implementing cognitive systems within a given context? How can I utilize the living laboratory for various fields of practice and work domains? How does human system integration/team system integration emerge within a dynamic, living environment? How is cognition understood in terms of information science and living systems metaphors? How can information, technology, and people be synthesized in a meaningful way using multiple methodological approaches? What is the basis for interdisciplinary research and design where human-centered knowledge and technology development, theory and practice, models and use, scenarios and simulations and are all considered holistically and kept in proper balance to insure that problems are both learned and solved within the constraints of many impinging variables and factors.

A Progression of Human Factors/Cognitive System Terms

As one begins to read the book chapters it will become obvious that the use of terminology and lingo can connote similarities in meaning yet also represent subtle differences in the application of the author's terms to a given research or design topic. Not only is this true for this book, but it is becoming a problem for disciplines in general where authors or researchers even use the same term but dispatch different intentions in the meaning. This book is absolutely focused on the topical content related to cognitive and collaborative systems extant in complex domains, and methods that result in understanding, developing and building, and testing systems *in situ*. But let us calibrate some thresholds to help situate meanings (at least the way we see it). The LLF framework represents a given utilization of CSE methods. As a reader you will discover that similar terms often are incorporated in the human factors communities of practice in government, business, industry, education, and academia.

As a foundation this book utilizes the term *human factors* to represent a wide purview of designing systems for human use incorporating as many perspectives as necessary or allowable. Human factors, hence, is a comprehensive broad term used to cover many areas. Since I have been involved in human factors (now spanning over 44 years) my first exposure to this area was through two sources: (a) the *Industrial Psychology* book (Tiffin & McCormick, 1965) which was used for an initial course in industrial psychology taught by Dr. John Reising in 1973 and (b) the first edition the book *Human Factors in Engineering and Design* (McCormick, 1976) which was used in an independent study course in human factors with Dr. David Biers (University of Dayton). Note both of these books were associated with

Ernest J. McCormick, a monumental superstar of human factors engineering. The first book focused more on psychology while the second book emphasized components of engineering and design. These books set up human factors as a discipline that actually subsumed human factors engineering in breadth although not necessarily in time. I subsequently came across and own the historical original text *Human Engineering* (McCormick, 1957), which I discovered is short for "Human Factors in Engineering" (p. 1).

As cognition started to become the main phenomena for understanding human behavior (what cognitive psychologists study) it also became a basis for designing for human use. The term *cognitive systems* engineering includes this notion as demonstrated by the work of Jens Rasmussen (1986), and Erik Hollnagel and David Woods (1983) but also connotes the idea that cognition is not only inside the head but is in fact distributed across complex systems (what Norman refers to *user-centered systems*, See Norman & Draper, 1986, and referenced by Hutchins, 1995 as distributed cognition*). Our book locks on to this strong notion of cognitive systems rather than just seeing cognition as a smaller subset of systems engineering as connoted CSE.

In 1982 I was exposed to the necessity of human factors being applied to computer systems as this was necessary in my research and work at the Aeronautical Systems Division at Wright–Patterson AFB, OH. The work as communicated earlier in the history section was heavily coupled to cognitive processes, which often were jointly carried out or assisted by computer systems. The work I did entailing specification of the HCI in the F-16 cockpit with Richard Geiselhart, ASD/ENECH and Dr. Richard Shiffler, ASD/ENECH exemplifies a reformulation of how pilots use information within computer systems to enhance their flying abilities. The work we were involved with at the Air Force Research Laboratory in redesigning military command posts (with Donald Monk and Maris Vikmanis) to incorporate the latest digital technologies and to build human-computer interfaces thus extending human capabilities is also representative of HCI. Our work continued in HCI and even expanded into teams supported with collaborative computing technologies (*computer-supported cooperative work*). Although one can look up specific definitions as to how these areas are defined and what they do, I have decided to classify them under the general term *human factors*. I am sure many would argue against this while others might argue for it but for the purpose of this book it is a useful construction.

As one looks at the current zeitgeist within the human factors umbrella, areas of emphasis may fall out according to whether one gravitates toward a certain societal association Human Factors and Ergonomic Society (HFES), Association of Computing Machinery (ACM), or Institute of Electrical and Electronic Engineers (IEEE). Recently, we see the prominence of terms like *human systems engineering* (HSE) or HSI that signify certain emphasis points within the overall gestalt. Even more prominent is the focus on UX and how this is really driving many human

* We also make reference here to the broad notion of activity theory which has been relevant also in social constructions of what we mean by an integrated living laboratory framework, and hence acknowledge the importance of activities and their cultural/historical foundation (see Nardi, 1996).

factors and *human-centered design* practices today especially within industry and software-related companies. All of this can be framed as a positive response as human production, safety, and well being is strengthened.

While each book chapter reifies meaning within the context of the topic, research, and perspective undertaken, these areas together represent a substantial investment on the future of human beings as they interact and transform life in the contemporary digital world. What one does as a human factors/cognitive systems practitioner may tend to focus on one of the above italicized emphasis areas but many of these areas are intrinsically relatable, complementary, and not mutually exclusive. The chapters presented in this volume innately cover CSE through the lens of the integrate LLF.

THE RELEVANCE OF THE LIVING LABORATORY FRAMEWORK

Many of the chapters that compose this volume are in fact emanating from members of the MINDS Group at The Pennsylvania State University. The unique compilation of chapters presented in this volume represents the state of the art as we have uncovered it (1) within our understanding of CSE, (2) produced through the transformative vision of the integrated LLF, and (3) using multiple integrated methodological approaches to complex systems and environments. While other phases and facets of cognitive system engineering have been encountered over the years (as elaborated in the first section of the chapter), this book represents a collective volume on what the LLF is, and how it has been used for specific challenge problems. It has been possible through the inspiration, hard work, and *mindset* of the authors who have brought their ideas, research, and aspirations together by utilizing the LLF. We will now look at some of the specifics underlying the LLF.

Basic Philosophy

Through the passage of time we have outlined the historical foundations that have been responsible for the emergence of CSE and the initiation of the LLF as a means to accomplish methods of CSE. At this point, we will describe the philosophy and basic elements of what the LLF is. The explanation below uses an overlay model to describe planes of development that can be accomplished in building cognitive systems that work.

Ecological in Nature

This book is focused on articulating all aspects of the LLF as applicable to human factors, cognitive systems, and collaborative work. It provides an interdisciplinary formation of human factors from a living ecosystem perspective (hence the name—living laboratory), wherein the environment is very important to understand human intention and activity. The approach affords a flexible and leveraged use of mixed research methodologies to comprehensively address complex systems in a thoughtful—yet useful way. Living systems require dynamic and timely integration of multiple sources of data, information, and knowledge in order to evolve and adapt to the context they exist in while they pursue intentions and desires. Resilience and sustainable operations are high-level values in approaching human factors from a living ecosystem perspective. In turn the living laboratory reflects the values of (1) multiple perspectives and (2) system of systems transformation with the intent to translate knowledge into designs that afford effective use. This requires theoretical knowledge to be integrated with real-world fields of practice and human expertise through the use of various tools, techniques, and processes. HSI is accomplished by utilizing a problem-based learning approach within the LLF. Therein, mixed methods are structured/integrated to leverage understanding and development of problems, issues, and constraints that are revealed in a context.

Experience Matters in Fields of Practice

The foundation of the living laboratory is based on the idea that *experience matters*, but it is not all that matters when one takes an interdisciplinary/transformative view of information, technology, and people. Experience builds on itself through *human–agent interaction*[*] set within a specified context of use. Take, for example, an area within our research labs at Penn State—emergency crisis management. Experience emerges cojointly with complex situations that involve human actors (often a distributed team) using technological artifacts (e.g., analytical social networks) to track changes within the context. In this case, an agent may be another human (human-to-human interaction results in typical formulations of teamwork), or a system, tool, aid, computational agent (a newer form of teamwork), or a combination therein. In addition, the context may be multilayered in that it could include movements in and out of the physical, social, cultural, and cognitive environments that specify changes in the situation as the agent becomes aware of it. Experience requires sensemaking, awareness, and a trajectory of what is coming next (expectations/beliefs/hypothesis formulation). Experience can be informed by the context of action, by cognitive learning within a context, through the culture present in the context, by providing opportunities of exploration via a scaled world of agents where testing what you know is put to use and adapted through many cycles, and through sound designs that create ecological balance in human–agent interaction (cognitive systems engineering/human-centered design).

The living-laboratory approach begins by focusing on experience that is acquired in a context or field of practice when a human addresses a set of problems, situations, or cases—often through the use of technologies that amplify performance, enhance learning/cognition, or overcome limitations/expand capabilities. The LLF researcher's major quest is to identify and define problems in a way that user's experience becomes readily available and is understood to the maximum extent possible. Note this is how we nuance UX within the living world.[†] Of course because real-world

[*] Note here that this directly comes from the historical precedence of *collaborative-and-human autonomous systems* (as described from Section 2.1.2 of this chapter) and has continued as an emphasis in current work. We refer to human and computational agents as broadly defining human–agent interaction (human-to-human agent, human to computational agents, or computer-to-computer agents) within collaborative systems.

[†] As mentioned previously, many of the semantics of like-minded areas (e.g., user experience) can be connoted differently yet often traverse very similar phenomenological paths.

contexts do not often present every detail or nuance of problem complexity, methods must also be available beyond just observation (more on that to come). Users come in many shapes and sizes, with differing levels of cognitive and physical proclivities. Experience is the knowledge obtained (either theoretical or practical) as a result of addressing various problems, issues, or constraints that is spent into the future (i.e., used or accessed again when similar situations or problems emerge—often without being told to do so). Experience is contingent on perception, memory, situation awareness, attention, language, and other cognitive variables that a user can utilize to address problems within a given system in a context of use. Therefore, *knowledge as design* must intersect UX through examination of problems in the context of use.

As inferred above, the researcher's quest is to thoroughly understand use and UX (for individuals and/or collaborative activity) as problem spaces are encountered. Hence, the lynch pins in the LLF entail how intentions *fold out* through the joint influences of experience, problems, interaction, and context. Each of these lynchpins is derived from empirical work in research within cognitive science, cognitive systems, and computer-supported cooperative work. Therein, they are not just plucked from thin air but represent empirical evidence that supports how people learn and solve problems (Bransford, Brown, & Cocking, 2004) in living emergent worlds that are often messy, complex, dynamic, multifaceted, and ill-defined. See Xun Ge, Chapter 2 (this volume), as it unpacks problems within the context of educational settings.

Practice provides patterns as to the way we go about acting on intentions and desires, and the way we go about doing work that includes complex relationships among information, technology, and people. Practice is predicated on learning new paths to explore the environment and can be the way that transforms the ill-defined, unstructured, and uncertain problems into ones that provide the user with a more routinized, safe, and expected rate of return. As many problems are new, they require learning, creativity, and exploration for discovery to occur. Therefore, nonroutine problems can exhibit major challenges for actors in order to be solved or negotiated. Many problems can be wicked, nonlinear, and complex while at the same time require knowledge of multiple contexts and constraints that are operative.

Often we contrast theoretical with practical viewpoints artificially separating them into isolated understandings that provide only limited angles. The living laboratory aspires to integrate perspectives on how experience can be informed through four major elements: (1) observational ethnography, (2) knowledge elicitation of subject matter experts, (3) development of scaled world simulations–scenarios, and (4) generation of new innovation technologies (e.g., interfaces, decision aids, work tools, intelligent agents) through workable prototypes. In the course of exercising these specific elements—*models* and *use* start to be built and reified. Mutual learning is acquired through opportunistic use of the elements in the living laboratory, wherein feedback and feed-forward help to substantiate knowledge as design (Perkins, 1986). Through these methodological pursuits, mature knowledge concepts can begin to formulate and be tested and refined. Designs can be put into practice as interventions that further shape cycles of the overall process. As such, human–agent interaction can begin to solidify on a firm foundation and provide balance/resiliency within a system, or system of systems. Therein, the living laboratory approach results in using dynamics to comprehensively encourage interdisciplinary science resulting in movement that adapts to change, see patterns that emerge, and encourage transformative forces to play out for a given context. To quote Woods (1998), "the experimenter becomes designer while the designer becomes experimenter."

Elements of the Living Laboratory Framework

Living laboratories emphasize the necessity of studying the context where phenomena exists, but our take on this is that information seeking helps to develop theoretical knowledge and practical knowledge jointly and envelops experience and depth on understanding a given phenomena. Approaching phenomena from multiple perspectives/methods can yield a broader comprehension and integrates sources of understanding to facilitate a stronger base for *knowledge as design* (Perkins, 1986).

Figure 1.1 shows the basic-level coupling at the heart of the framework—what we refer to as the *vertical axis* (shown by the vertical arrow). Figure 1.2 shows the first overlay of the framework: the interrelationship among theory-problems-practice from the perspective of the researcher beginning investigations into living-emergent phenomena.

The living laboratory hence starts with problems that are extant in the phenomena under study in order to expand the researcher's experience with the phenomena. Problems are the basis for discovery in real-world contexts and specific fields of practice, but they can also be informed through the use of theoretical knowledge. As problems present situations that invoke information seeking, exploration, and data discovery in order to resolve them—grand challenges can be identified, set up, and defined, and explored in differing ways—prior to—committing to a solution space. Note in Figure 1.2 that in addition to the vertical axis there is also

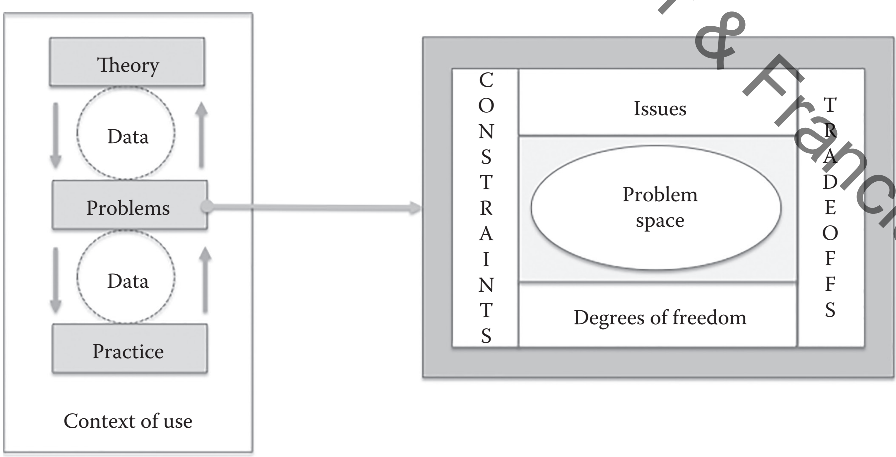

FIGURE 1.1 Basic elements of the living laboratory/Layer I.

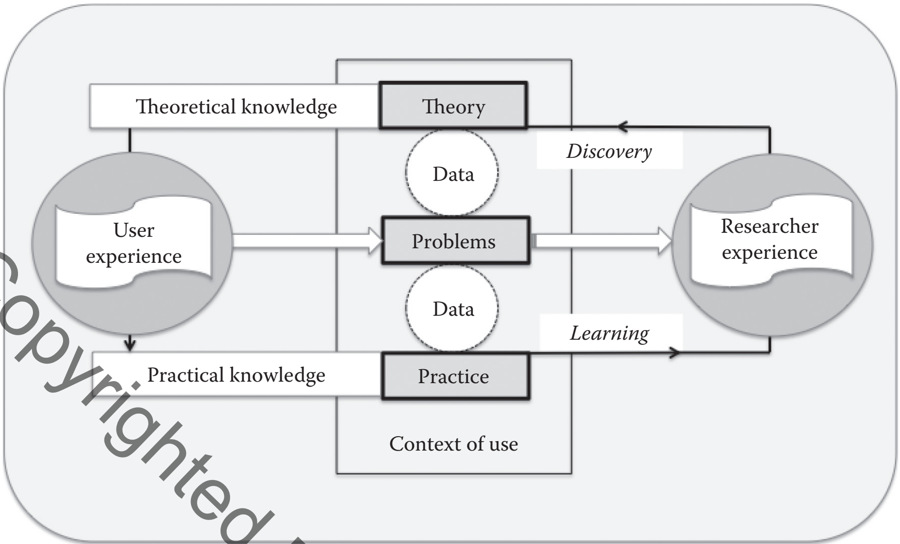

FIGURE 1.2 The living laboratory framework/Layer II.

a *horizontal axis* (shown by a horizontal arrow) within the LLF representing how researchers obtain knowledge about UX in addressing problems to gain researcher experience (RX). Continuing with the layered overlay model of the LLF, Figure 1.3 shows the final development of the integrated living laboratory elements that compose the framework. Although the figure shows an optimal situation wherein all

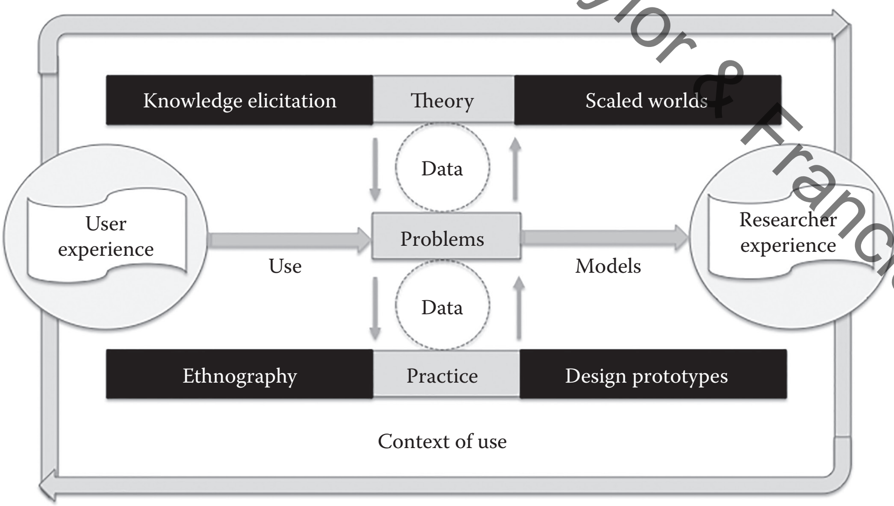

FIGURE 1.3 The living laboratory framework–Layer III.

the elements are utilized in equal proportion to produce UX and RX, the reality of every cognitive engineering project may only utilize a subportion of all the elements that are possible. This is owing to the practical nature of work and the living aspect, wherein demands and constraints make only certain paths possible, as more knowledge is discovered and integrated. For example, a project may only present opportunities for knowledge elicitation, theory, and scaled-world simulation. Figure 1.4 shows the disproportionality of the elements when the LLF is only partially used for this situation. If more sources of knowledge are possible then reliability, validity, and completeness can be elevated, but often real world cognitive system engineering has to be considered within constraints such as time, cost, schedule, availability of experts, and access to environments, as perfect situations do not exist. Also note that in Figure 1.4, the proportionate size of the hexagon varies with the level of effort expended. In this case, the smaller knowledge elicitation element indicates that the availability of experts was limited to 2–3 day period; hence the level of effort is therein proportionate. This particular case shows more of an emphasis on top down research with the major effort being expended through the scaled world, even though the scaled world scenarios and task makeup was informed through theory and knowledge elicitation.

From a top-level view, problems can be approached from different directions: theoretical/quantitative knowledge and practical/qualitative knowledge. The living laboratory utilizes both of these approaches but aims toward integrated solutions. The left side of the Figure 1.3 tends to look at both *what the head is inside of—the context* and *what is inside the head—expertise* (Mace, 1977) from the qualitative methods of ethnography and knowledge elicitation. Alternatively, the right side of the figure tends to represent quantitative/design-based methods, although each of these elements can have quantitative and qualitative analyses present. For example, the development of stories related to UX can lead directly to qualitative design sketches that build up into interactive storyboards, which can then be built as reconfigurable design prototypes that go on to be tested in a scaled world quantitatively. The framework is based on feedback and

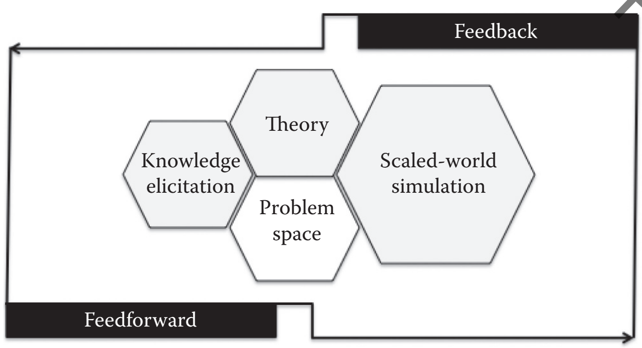

FIGURE 1.4 Example of proportionality of the cognitive systems engineering work.

feed-forward flow to afford integration, holistic understanding, and multiple perspectives of how knowledge influences design within a given field of practice. Therein, prototypes also flow back into practice connecting theory to problems to practice for reiteration and reification.

Knowledge as Design as Living Ecosystem

Living ecosystem's philosophy suggests that cognitive systems are approached in a certain way; wherein they are distributed across cognition and context, embodied in real-world activities, and emergent and situated through successive human–agent interaction necessary for dynamic growth, change that produces adaptation, and therein sustain themselves in order to survive and stay strong in threatening environments.* In the original paper (McNeese, 1996) we refer to this notion as follows:

> The Merriam-Webster dictionary defines ecological as the interrelationship of organisms and their environments; in turn it defines perspective as the capacity to view things with the proper relationships to their value, importance, and basic qualities. Taken together they emphasize the multidisciplinary nature of living systems, their environments, and the reciprocity that has developed between them.

The term *living* connotes an ecological system (ecosystem) wherein human–agent interaction is an emergent set of activities (the give and take) between an agent and an environment, wherein the affordances of the environment are always adjusted in relationship to the capabilities of the agent at a point of time. Interaction emerges in time and space, and is directed through the intentions of the actor–agent, but constrained by what may be available (social, physical, and economic resources), as applied to a given *problem space*. An ecological system is grounded when it is in balance, as the components are greater than the sum of the individual parts (collective induction). When the system is unbalanced, isolated, perturbed, and in conflict, it may not achieve the intentions the agent strives for (i.e., failure or errors are likely imminent). One of the tenets of the living laboratory is to design and secure systems that are adaptive, sustainable, livable, dynamic, and thriving rather than systems that are ad hoc, failing, outdated, and not understood by the human agent. The core principles of the living laboratory are (a) to understand, define, and explore problems from interdisciplinary, multifaceted perspectives; (b) to apply and integrate a multiple methodological lens (different techniques/tools/measurements) to obtain holistic and cohesive knowledge about a problem; and (c) to use this knowledge to design new technologies that enable innovative human–agent interaction that leads to improvements in performance; thereby establishing balance within the ecosystem, enabling transformative effectiveness and efficiency, while increasing resilience in assuaging complexity.

* This perspective is highly consistent with the theoretical work on distributed cognition (Hollan, Hutchins, & Kirsh, 2000); situated cognition (Brown, Collins, & Duguid, 1989), naturalistic decision making (Klein, 2008); embodied interaction (Dourish, 2001).

STRUCTURE OF THE BOOK

This book consists of 19 chapters and has been divided into the following 7 sections to make assimilation of the topic content easy to comprehend:

Section I	Introduction and historical precedence (Chapter 1)
Section II	The living laboratory: Learning in action (Chapters 2–5)
Section III	Theoretical perspectives in cognitive–collaborative systems (Chapters 6–8)
Section IV	Models and measures of cognitive work (Chapters 9–11)
Section V	Scaled-world simulations (Chapters 12–14)
Section VI	Knowledge capture, design, integration, and practice (Chapters 15–18)
Section VII	The future of the living laboratory (Chapter 19)

These sections have been structured to represent the various themes and elements that are present within the LLF. In turn, they provide a comprehensive set of topics that span across the LLF and provide the methodological approach that represents this instantiation of CSE.

Within a given section the papers will present research and topics relevant to the general topical content. Although it is the case that the chapters were stratified by topic, many of the chapters could have been viable for other sections as well, given the scope of information presented.

Academics have been accused of conducting research that is devoid of real-world application. The LLF directly contradicts that perception. The strength of this book is the concrete examples of how the LLF can cross the Rubicon that sometimes separates research from real-world problems. These chapters allow the readers to examine the application of methods and tools to improve their understanding of cognitive engineering systems in expanding foundational knowledge while contributing and maintaining relevance through the provision of solutions to real-world problems. They give substance to the principles of human centered, problem focused, team enabled, and designed-supported research.

The initial chapters examine learning in action, which focuses on the role of the LLF in improving group and individual learning. Dr. Rimland describes the application of a technical solution to support distributed problem-based learning. He specifically focuses on federated opportunities (i.e., note taking and exams), and exemplifies the LLF through its application aimed at enhancing student engagement in introductory computer programming and technology courses in Penn State's College of Information Sciences and Technology. Through the application, physical objection as cognitive artifacts to enhance lasting memories, Dr. Mancuso explains how team cognition and trans-active memory may be used to access outside knowledge and thus improve team performance. In his research, he notes the limitation constrained by the individual's internal knowledge in spite of technological sophistication that has improved the set of cognitive artifacts available. Rather than examining student tasks, Dr. Ge explores the challenges of technology, which simultaneously acts as scaffolding and data collection tools when conducting education research. She concludes that tools may be purposed differently to manage the external influence of stakeholders and other contextual constraints. Dr. McNeese and Reep conclude this section with an examination on the integration of technology with the supply chain to improve efficiencies and sustainability in the natural gas industry. Although deviating slightly from the more pure CSE approaches, this chapter incorporates ethnographic and knowledge-elicitation methods to understand the realities of the industry. It then provides a functional analysis of the presence or absence of collaborative systems and offers a framework for additional research on how technologies might be used to improve efficiencies.

The second section expounds on theoretical perspectives of cognitive–collaborative systems and links the theoretical and applied through the LLF. Drs. Nathan McNeese and Reddy and Demir proposed that collaboration among teams is becoming increasingly important, but collaborative information seeking remains the purview of social and technical research rather than focusing on cognition. Using collaborative information seeking as a framework, They offers perspectives on multiple cognitively-based methods and approaches to better understanding the environment. Drs. Endsley and Forster and Reep used the LLF to assess cognition and teamwork in a crisis situation. Crises create a complex environment that reduces the time in which individuals and teams must respond. Through case studies, the researchers provide a framework for not only understanding crises and cognition, but also examine team-situational awareness and performance in a cross-cultural environment. Stress, particularly in crisis situations, often has been identified as a key factor in operator error; however, research on stress, according to Dr. Pfaff, often portrays it as a *black box*. His chapter addresses the importance of using multiple methodological approaches to understand the nexus of stress, emotion, and cognition. Using the LLF, he substantiates the validity of the multimethodological approach and provides a basis for more reliable interdisciplinary research into the impact of stress.

Measuring and modeling cognition is the concentration of third section. Here, concepts such as information sharing, situation awareness, and team mental models are used to recognize relationships between inputs and outputs in behavior and performance. Drs. Mohammed, Hamilton, Mancuso, Tesler, and McNeese reviewed four studies that explore how various interventions (e.g., storytelling or temporal models) might influence team cognition. Through these methods, the authors expand the literature relevant to the LLF by empirically investigating information, situation awareness, and team mental models in a set of studies; *infusing* time into assessments of the characteristics; exploring the benefits of ad hoc stories and team and individual reflection on performance to improve shared understanding and thus improved performance. In *Modeling Cognition and Collaborative Work*, Dr. Rashaad Jones uses the LLF to create decision-making models using Fuzzy Cognitive Mapping (FCM) and again models the relationships between inputs and outputs to produce concept maps or decision-aids to improve the decision making. In this case of knowledge elicitation, a LLF foundation identifies the decision space and viable decision-aids for a variety of settings. Dr. Dancy's chapter concludes this section by inspecting unified theories of cognition from computational systems (i.e., cognitive architectures) and psycho-physiological measures to study the effects of system design on both predicted performance and changes in cognitive processes.

Often discussed in the introductory chapter, NeoCITIES, a computer-simulated task environment used as the basis for much of the research by MINDS, is the focus of the scaled-world simulation section. In Dr. Hamilton et al.'s chapter, the authors identify both the importance of team cognition across sectors (e.g., defense, medicine, and sports) and the challenges of time and labor that hinder research in this area. They offer that the simulation-based study is a solution to this problem, stressing that NeoCITIES enables the researcher to study multiple forms of team cognition within simulations that are central to the LLF. NeoCITIES is a crisis-management simulation and Dr. Minotra et al. adapt the simulation to study cyber security using a mixed methodological approach, examining the impact of workload and information predictability during crisis events on performance. While demonstrating the value of the LLF, this study resulted in the development of a dual-task attention research testbed, but also recommended adapting scaled worlds to more deeply explore microcognitive tasks. The section concludes with a look at the ubiquitous video game, which, besides providing entertainment, offers a dynamic testbed for research. Dr. Pursel and Stubbs explore how the LLF may be used to study the video phenomenon within the context of Massively Multiplayer Online Games (MMOGs). The authors focus on MMOGs as learning environments assessing behaviors and skills learned in specific games, and the extent to which these skills may be applied to operating in a crisis management environment.

The experimental sections conclude with the *Knowledge Capture, Design, Integration, and Practice* section that further confirms how the LLF is used to enhance performance in addressing real-world problems. In his chapter, Dr. Glantz uses the LLF to investigate cognitive work in high-risk socially distributed problem spaces. Through the application of ethnography and knowledge elicitation with domain experts, the author developed an understanding of the police working environment and then used participatory design to develop a suitable artifact to enhance cognition. In many respects, this chapter represents the living laboratory at its most fundamental level. Dr. Art Jones investigates the intermodal Human–Computer Interaction (HCI) in crises environments in which decision-critical information is only available in analog and subjective formats. The LLF is used to explore the challenge of developing and evaluating interfaces that are able to quickly and accurately collect and display data that have already been interpreted by human users. Using applied experience, Dr. Hellar furthers the theme of applying theory to solve real-world problems. Confronted with the intelligence community's *big data* challenge (e.g., large quantities of data but very strict parameters of the mission), the LLF is applied to define the problem and break it down into its constituent parts allowing the development of agile and innovative solutions. Drs. Craven, Tremoulet and Harkness Regli conclude this section by asserting that improved application is achieved through experimentation in a real-world setting such as an industrial space.

CONCLUDING REMARKS

You are about to begin a journey in an innovative way to think about CSE that elaborates the basis for and examples of the integrated LLF methodological approach to CSE. Each chapter provides topical content in a way that engages current thinking, engages multiple methodologies to uncover knowledge as design, and provides unique insights into contemporary cognition as a living ecosystem that evolves sustained operations according to the need, survival, and environment. The chapters utilize specific learning helps to assist the reader in comprehension of the topic being considered.