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ORIGINAL RESEARCH

Work-focused analysis and design

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Abstract The past decade has seen papers in this journal and other cognitive engineering publications expressing concern about some of our foundational ideas. *Cognition*, a central construct for this journal, is one that some authors would see banished. *Function allocation* is another. These commentaries, if taken seriously, have the potential to transform our discipline but whether for benefit or detriment is questionable. I review those commentaries in this paper and conclude that the issues raised have merit but that the proposed solutions would be counterproductive, having the potential, if widely implemented, to cripple our discipline. I argue that these commentaries appear credible only because they appeal to an objectivist paradigm as engendered by a techno-centric world view and that they fail to accommodate the inescapable subjectivity of a scientific enterprise. I further argue that these commentaries do not take full account of the fundamental basis of our discipline; that it is an analysis and design discipline and that it is first and foremost human centric. Our discipline requires a work-focused perspective. We need to think seriously about what that means, and we need to deploy language and methods that are entirely consistent with a work-focused stance.

Keywords Cognition · Function allocation

1 Introduction

As reflected in its mission statement (www.springer.com/computer/journal/10111), *the focus of this journal*, Cognition, Technology and Work, is on *the practical issues of human interaction with technology within the context of work and, in particular, how human cognition affects, and is affected by, work and working conditions*. The first half of this statement is ambiguous regarding the relationship between the three elements, cognition, technology and work, but that ambiguity is resolved in the second half of the statement. Work is the prime focus. Many factors influence the conduct and effectiveness of work, but this journal is concerned with those practices that are cognitive in nature. Technology would appear to be of interest only in respect of the fact that it is pervasive and that it offers functional support for work.

1.1 Dissension

Dekker and Hollnagel (2004) have argued that cognitive constructs as used in our field are non-observable and lack scientific credibility because they are unmeasurable, they are descriptive rather than explanatory, their claim to causal power is illusory, and they are immune to falsification. They are, in other words, *folk* models. Dekker and Hollnagel conclude that we should not be concerned about cognition but rather about joint system performance. When coupled with a claim by Hollnagel and Woods (2005) that *human cognition is no longer the central issue* and that the *continued use of the term cognition is more than anything else due to terminological hysteresis* (p. 59), it appears that they think of this term much like we think of our appendix; we are stuck with it, but it is unnecessary and sometimes even troublesome. This attitude would seem to encompass a substantive rejection of the mission statement of this journal.

Dekker and Woods (2002) frame a conceptually similar argument around issues of automation. In critiquing a paper

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by Parasuraman et al. (2000), they argue that those who employ cognitive constructs in the service of function allocation are prey to the *substitution myth*, the idea that *new technology can be introduced as a simple substitution of machines for people* (p. 241). Their solution to this problem is to focus on *how to make humans and automation get along together*" and to *abandon the traditional 'who does what' question of function allocation* (p. 243). This exhortation to abandon the question of function allocation is startling in that it defies traditional strategies of design.

1.2 Reflection

These claims regarding cognition and function allocation are provocative. If taken seriously, they would transform our discipline. They warrant independent assessment, because there is room for considerable improvement in the methods and strategies of our discipline, and this sort of radical transformation may be just what is needed. Within my assessment of the *cognition* claim, I will revisit the folk model argument by reviewing the measurability criterion, the description versus explanation criterion, and the falsifiability criterion. Within my assessment of the *function allocation* claim, I will consider the nature of function and will revisit the substitution myth. I will argue that the methodological constraints implied by these claims would cripple our discipline and that they appear credible only within a techno-centric framework. Finally, I outline a work-focused perspective as the basis of an appropriate framework for cognitive systems engineering.

2 Cognition

Work has both cognitive and physical elements, but no work is entirely one or the other and there is a subtle interplay between the cognitive and the physical. Any separation of cognitive versus physical work into sub-disciplines overlooks their interdependence. However, there is also an interplay between work and organizational structures, between organizations and society, between society and political systems, and so on. A research discipline needs to draw boundaries to limit the problem scope to something tractable.

We should seek to draw those boundaries along regions of weak coupling. The region between cognitive and physical elements of work would appear to be one of those. We can, of course, get this wrong, in which case, we should be open to relocating the boundaries. For example, it has been traditional to think of cognition as an activity of the brain. Gibson (1979), for one, took issue with that conceptualization and more recently, many have expanded the boundary of cognitive systems to encompass events in the world.

Dekker and Hollnagel (2004) suggest that reference to joint systems is at least as adequate as reference to joint cognitive systems. However, could we realistically dispense with the adjective, *cognition*? In what respect is a joint system different to a system of systems as commonly discussed in systems engineering? Indeed, a system being a coordinated constellation of elements, how is a joint system (or a system of systems) different to a system? Are we systems engineers rather than cognitive systems engineers even though few of us know much about the general framework of systems engineering?

As an adjective, the term *cognition* distinguishes the subject matter of this journal and distinguishes what we as cognitive systems engineers do from other professional disciplines that also deal with systems. If we were to eliminate *cognition* from the mission statement of this journal, the editorial board could not justifiably reject papers that focused only on physical aspects of work, for example, research on injury avoiding postures for lifting heavy objects. We would need to find another adjective, but that would not solve the folk model problem. It seems we are stuck with the term *cognition* and so how much of a problem is it?

2.1 Folk models

A scientific direction often emerges from an intuition captured in the form of an image or analogy (Dunbar and Fugelsang 2005). From there, the idea will be refined and developed, finally to be replaced by a competitor if it ceases to generate interesting questions or ceases to propose useful solutions (Kuhn 1970).

The issue for advancement of a scientific discipline is not whether the scientific agenda is derived from a folk model but whether the underlying image can serve to initiate a worthwhile advance in scientific understanding. Problematically, folk models often misdirect scientific efforts (Dunbar and Fugelsang 2005). Transfer of training research, for example, has famously relied on simple notions of similarity, physical fidelity, and psychological fidelity to its detriment. It is not that these ideas have no value, but rather that advancement of the scientific basis for training transfer requires a more nuanced appreciation of what must be similar and how similarities might be leveraged to enhance transfer (Lintern 1991). Appropriate images and analogies have considerable value in bootstrapping a scientific agenda, but care must be taken to ensure that superficial readings do not trap researchers in circular argument (Lintern 1991).

So what should we make of the folk model concerns expressed by Dekker and Hollnagel (2004), that the cognitive constructs now used in our field are unmeasurable, they are descriptive rather than explanatory (their claim to causal power is illusory), and they are immune to falsification?

2.2 Measurement

Dekker and Hollnagel (2004) want us to focus on the characteristics of performance (because they are measurable) rather than on inferred and uncertain states of the mind (which are not measurable). Situation awareness is one construct they offer in their critique of Parasuraman et al. (2000) as an example of an inferred and uncertain state of mind.

Situation awareness is often used in a manner that defies measurement but, as noted by Parasuraman et al. (2008), that is not the way this construct is always used. For some, it is measurable construct. To briefly summarize Parasuraman et al. (2008) on this point, Endsley (1988) defines situation awareness in terms of three levels; *the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.* Parasuraman et al. (2008) describe a number of ways in which situation awareness can be measured while Jones and Endsley (2004) have shown how to measure it at each of its three levels.

2.3 Beyond measurement

Furthermore, the demand that all constructs be *directly* measurable is problematic. This sounds like an appeal to objectivism, the philosophical approach that draws much much from the philosophies of Descartes and Kant (Johnson 1987). A scientific endeavor should seek to be objective to the extent it can, but many critics point out that complete objectivity is not possible even in science. For example, properly constituted measurement is objective but the decision about what to measure and how to measure it is not.

Furthermore, and significantly for our discipline, important constructs might not be measurable at this time and might not even be potentially measurable. Should our discipline dispense with unmeasurable constructs in order to conform to as strict an objectivist program as possible or does the nature of our discipline's subject matter demand serious accommodation with the subjective?

To illustrate, the Recognition-Primed Decision Model posits a mental simulation process (Klein 1998/1999). There is, as yet, no objective evidence of such a cognitive process, and it is difficult to see how one might measure mental simulation objectively. Those of us who accept the value of this construct do so on the basis of subjective evidence; subject matter experts report it and those reports correspond to our own subjective experiences of a mental process that we think reasonable to designate as mental simulation. This may sound overly subjective to some, but the alternative is to reject the whole idea of mental simulation and thereby invalidate the experiential authenticity of reports from subject matter experts. Inevitably, that would result in a failure to accommodate mental simulation in the design of technological artifacts developed to support recognition-primed decisions.

2.4 Description versus explanation

The attribution of causality to cognitive concepts is common in our discipline, but at this stage of our knowledge about cognition, and as pointed out by Dekker and Hollnagel (2004), attribution of causality to cognition is problematic. However, situation awareness and mental simulation are constructs that are often used to describe rather than to explain. Poor pilot performance might, for example, be associated with poor situation awareness. In this case, situation awareness is not posed as a causal explanation but rather as a more focused and fine-grained description. If we were to develop a design intervention to improve pilot situation awareness, we would seek to aid it rather than to aid decision making, planning or execution. Furthermore, we might be able to develop an even more focused and fine-grained description by assessing whether a failure of situation awareness resulted from a failure to perceive appropriate information versus a failure to understand information versus a failure to anticipate how events will unfold.

Alternatively, pilots might note that they had difficulty foreseeing the consequences of their own actions. In that case, we would associate poor performance with a failure of mental simulation and would focus our design efforts on strategies to improve or support it. Again, mental simulation is offered as a descriptive rather than causal construct. Much useful design work can proceed in the absence of causal understanding.

Furthermore, it is difficult to ignore cognition in our work. Despite the problem that Dekker and Hollnagel (2004) have with cognitive constructs, Hollnagel (2005), in his description of the extended control model, refer to situation assessment as an active process at two of the four levels of his model. Situation assessment is surely a cognitive construct no more or less measurable or falsifiable than situation awareness or mental workload.

2.5 Falsification

The falsification criterion, established on the belief that a hypothesis must be inherently disprovable before it can be accepted as scientifically valid, originated in the work of Popper (1972), who envisioned science as evolving by the successive rejection of falsified theories. This falsification criterion found widespread support because it was seen to replace logically invalid inductive reasoning with logically valid deductive reasoning. However, the falsification criterion, based as it is on deductive logic, is relevant only to a subset of issues for which outcomes can be explained in causal terms.

Furthermore, if we are to take the falsification criterion seriously, not only should we demand that our constructs be potentially falsifiable but we should also demand that they have been evaluated against this criterion before we use them. At this point in time, I am hard pressed to come up with a single construct within cognitive systems engineering that has been put to and passed a rigorous falsifiability evaluation.

More recently, the falsification criterion has been under attack. Sokal and Bricmont (1998) claim that it cannot distinguish between astrology and astronomy because both make technical predictions that are sometimes incorrect. Sokal and Bricmont argue that scientific theories come to be accepted above all because of their successes. Feyerabend (1975), a science historian who has examined how science progresses, argues more generally that value is more important than method.

Most significantly for this journal, ours is largely (although not entirely) an observational and descriptive discipline with success and value emerging from the effectiveness of our designs. It would be difficult, for example, to establish falsification criteria for the hypothesis that the Aviation Safety Reporting System administered by NASA, to which commercial aviation pilots in the US can submit *incident reports*, has benefited aviation safety. If constructs that contribute to success or value are disallowed by the method, it would seem more sensible to question the method rather than the constructs.

2.6 Interim conclusion #1

In responding to Dekker and Woods (2002) and Dekker and Hollnagel (2004), Parasuraman et al. (2008) have defended their use of cognitive constructs by arguing that, as is evident in a large and diverse body of empirical research, the constructs on which they relied in Parasuraman et al. (2000) are measurable. Furthermore, those constructs are falsifiable *in terms of their usefulness in prediction* (p. 155).

However, this counter claim from Parasuraman et al. (2008) misses the essential point. At first glance, measurability and falsifiability might seem essential for any discipline that wishes to characterize itself as *scientific* but Dekker et al. (2010) observe, at least in respect of the measurability criterion, that data are accumulated within an epistemology legitimated by a paradigm. Some of the possible flaws in a measurement method cannot be identified from within that paradigm's epistemology, for example as I observe above, whether the choice of what to measure and how to measure it is appropriate.

Furthermore, the measurability and falsification criteria are hallmarks of formal systems in which notations have no intrinsic meaning. Applied use of formal notations requires that meaning be attached to symbols via a process external to the formal system. Design disciplines work most efficiently when meaning and its signifier are concordant, as with an affordance (Gibson 1979). Insistence on measures that do not link meaningfully to qualitative properties of the work will severely restrict the sorts of constructs we can consider and will erode the creativity and insight so essential to our discipline. It will force us into a mechanistic straight jacket that will fit well with a techno-centric view of analysis and design but not with a human-centric view.

Beyond the arguments of Dekker et al. (2010), we should remember that the scientific method imposed by adherence to formal criteria (especially, the falsification criterion) results in incremental advancement of knowledge. Ours has been a dynamic, rapidly evolving discipline. We could not possibly maintain relevance to the emerging challenges that accompany rapid changes in technology under the constraints imposed by formal methods.

We do not want to overly constrain the methods of our discipline, nor do we want to sustain an attitude of *anything is acceptable* as might be encouraged by relaxing constraints on measurability and falsifiability in an observational and descriptive discipline. The key to the solution lies in the argument by Sokal and Bricmont (1998) that scientific theories come to be accepted because of their successes. Similarly, cognitive constructs can be judged valid to the extent they are found useful in guiding design. Indeed, I noted above that the criterion of *direct* measurability is problematic. Design success constitutes a form of *indirect* measurement that can suffice as an alternative.

Admittedly, many of our design efforts are guided by diverse ideas and it is rarely possible to attribute success to reliance on any one particular construct. Nevertheless, we can hope that our discipline progresses toward the more effective and useful constructs through our practice of publishing our material in peer-reviewed journals. As observed more generally by Kuhn (1970), scientific theories do not progress through adherence to strict, logically obligatory methods, but rather through (more convoluted and messy) social processes of conceptual growth, negotiation, and compromise. Rather than focus our concern on objective criteria, we should seek to distinguish scientific from folk knowledge by critical reflection and skepticism (Dekker et al. 2010).

3 Function allocation

Dekker and Woods (2002) take Parasuraman et al. (2000) to task for their putative reliance on a paradigm inspired by the Fitts list approach of *Men Are Better At–Machines Are Better At* for allocating functions in design of automation. The Dekker and Woods (2002) paper is troubling, because Parasuraman et al. (2000) do comment on problems associated with reliance on the Fitts list. Either Parasuraman et al. (2000) have failed to appreciate that their approach conforms to a *Men Are Better At—Machines Are Better At* strategy or Dekker and Woods (2002) have failed to understand how it does not.

Dekker and Woods (2002) miss the opportunity to clarify their stance because the bulk of their paper addresses issues of coordination and usability that are not directly relevant to the issue of function allocation. In particular, they imply (Dekker and Woods 2002, p. 241) that Parasuraman et al. (2000) have fallen victim to the *substitution myth*, the idea that *new technology can be introduced as a simple substitution of machines for people*. They make this claim despite the observation by Parasuraman et al. (2000, p. 286) that *automation does not merely supplant but changes human activity and can impose new coordination demands on the human operator*.

Much of the Dekker and Woods (2002) critique is contentious. They state: *we propose that the more pressing question on human—automation coordination is 'How do we make them get along together*?' (p. 240). Is the question of human–automation coordination more pressing than the question of function allocation? Surely, both are important, and which is most important is presumably moot. In their final paragraph, Dekker and Woods clarify their position. They have no use for function allocation; they state that *system developers should abandon the traditional 'who does what' question of function allocation* (p. 243).

Parasuraman et al. (2000) acknowledge that the Fitts list is a simplistic and outdated approach to a complex and challenging problem. From that perspective, their effort to develop a more rigorous strategy of function allocation is well motivated. However, such an effort is not well motivated if function allocation in any guise is of no value, or worse, an impediment to system development, and that appears to be the position forwarded by Dekker and Woods. So, despite the fact that function allocation is currently integral to almost all design strategies, can systems developers really proceed without it?

3.1 What is a function?

Design is the deliberate and thoughtful creation of something to fulfill a specific function. Design is therefore usually focused on the actual purpose and use of the artifact, and every effort is made to ensure that the design objectives are achieved. Hollnagel (2003, p. 12)

Designers approach design problems "systematically," by beginning at a functional level (goals, requirements, constraints, and so on) and then progressively working toward specific solutions, worrying about impasses along the way. Hoffman et al. (2004, p. 91)

Function is a word that can generate misunderstanding. Systems engineers use it to refer to intended activity, usually of a technological artifact. Human factors and cognitive system engineers use it to refer to an intended purpose of a technological artifact or human agent. As is consistent with Vicente (1999), function as used in this latter sense refers to an activity-independent capability, the potential to accomplish something specific if the artifact in question is used in an appropriate manner and if the human worker behaves in the desired manner.

This use of function is allied with the ecological concept of affordance, although function in this context refers to a designed property while an affordance encompasses both natural and designed properties (Gibson 1979). The two quotes I offer above suggest that design is a thoughtful and deliberate process that involves, in part at least, functional specification in this activity-independent sense. A joint (cognitive) system is developed to satisfy a global function. The prevailing strategy is to design sub-systems that provide particular functions and to assemble those sub-systems into a coordinated entity.

3.2 Design of socio-technical systems

Development of socio-technical systems is typically driven by a techno-centric design strategy. The technological functions of the system are conceptualized, designed, fabricated, and fielded, leaving the human operators to adapt as best they can (e.g., Sinha et al. 2001). Presumably, no single individual in human factors or cognitive systems engineering approves of this strategy.

However, even human-centric design strategies consider functions that can be used to satisfy the system purpose and how the required functions might be distributed between technological subsystems. In Web design for example, the commonplace advice is to decide on page content, page style, and text format before thinking about navigation between pages (Warner 2007). In major defense acquisitions, system purpose and system functionality are established early in the acquisition process (MacLeod 2000). While much of that effort is devoted to conceptualizing, designing and implementing technological functionality, human functional assignments may also be considered.

Many different expressions are used to refer to assigning functions to sub-systems. Function allocation is possibly the most popular but functional assignment, role assignment and task allocation also see service, as do several others. I do not wish to debate the relative merits of these terms nor even the relative merits of the design strategies normally associated with each of them. My specific claim here is that systematic design relies on some form of functional or role assignment (also see MacLeod 2000). That could sometimes be implicit acceptance of the current functional assignments as might be desirable when we are called on to improve interfaces or procedures of use for an existing system. At the other extreme, the design of work required for a planned enterprise transformation (Rouse 2005a, b) will demand explicit and systematic consideration of functional restructuring.

The element so far missing from my brief discussion of socio-technical system design is that of coordination. How do we bring structure and process together so that coordination is effective, seamless, and robust? Dekker and Woods (2002) emphasize the significance of this issue as do, for example, Hollnagel and Woods (2005) and Woods and Hollnagel (2006). It would be tempting to think that we could design and build the system before we concern ourselves with the coordination problem. However, the design and fabrication of a socio-technical system imposes a huge number of constraints, many of which will inevitably pose serious challenges to effective coordination if that issue is left until all others are resolved. Somehow, we need to bring the functional requirements and cognitive processes together as a fully coordinated system. Nature does this over an extended time through evolution. How can we do it over a shorter time via explicit processes of design?

3.3 Technology-focused analysis and design

In some circles, the solution to the problem of integrating human cognitive processes with technological functionality into a seamlessly coordinated system is thought to be resolved by reducing human involvement to the extent possible (e.g., Seng et al. 2009). This sort of view has encouraged the dominant techno-centric strategy of automating what can be conveniently automated and leaving the rest to the human supervisor-controller. In this scheme, automation is seen as an over-arching design requirement and also as the ultimate design solution. Indeed, one of the more serious problems with this approach is that a design solution has been invoked prior to any analysis of functional requirements.

The development of automation (and more generally, of human systems interaction) has been plagued by a techno-centric world view as enunciated by Birmingham and Taylor (1954) in their observation that *man is best when doing least*. It is difficult to imagine how this perspective gained currency among designers who, being human themselves, must realize that they do not function well if they are constrained to doing as little as possible. I suggest, in contrast, that we are at our best when we are mindful (Weick and Sutcliffe 2001) and engaged with ongoing work processes in a manner that takes account of both local and global constraints (Lintern 2007).

In seeking to counter this techno-centric focus, Sheridan (1988) offers that people and machines are complementary. Similarly, Christoffersen and Woods (2002) argue that humans and automation should be viewed as team players. While Sheridan, with his discussion of supervisory control, and Christoffersen and Woods, by their discussion of observability (actions of the system and automation clearly displayed) and directability (the human can strategically direct the automation), make it clear that the humans in the system have ultimate responsibility, these two images (complementarity and team play) are evocative and suggest, most powerfully, equal status for human and machine agents. Similarly, the concept of joint (cognitive) systems also suggests equal status for human and machine agents. Such an interpretation of these concepts leaves open to the troubling issue of who should be in charge (Inagaki 2003).

3.4 The substitution myth

One assumption underlying technologically inspired design work is that an automated function can replace a human function with no cost to the work effort, work flow, or work organization. The addition of a cruise control to an automobile, for example, relieves the driver of the need to monitor and control speed. Neglected in this consideration is the need for the driver to manage the cruise control and to fit this new functionality into an overall driving strategy.

The belief that the only impact of automation is to remove from the operator the work assumed by an automated function is characterized as the *substitution myth*. At the very least, the operator (or at least someone) now has to manage the automation. How difficult that will be will depend on the nature of the automated system and of the work. More problematically, the insertion of an automated function may have ramifications for how the work is accomplished. The new function may disrupt the natural work flow or may force incongruent work patterns. Worst-case scenarios emerge when workers have forced on them automation that induces fragile work processes or is otherwise difficult to use (its processes cannot be observed and it cannot be directed).

None of this, however, is about functional substitution in itself. Automation necessarily performs some function and when automation is inserted into the workplace, it is likely to have impacts that go beyond those intended. That is true of any design adjustment and, as with any design adjustment, it is incumbent on the designer to make sure that the modified system works in the intended manner (Hollnagel 2003). The substitution myth reflects on a pervasive and unavoidable challenge for human systems design: any redesign may have repercussions beyond the intended effects.

How might we counter this technological infatuation with automation and what sort of design strategy might enable us to assess both the intended and unintended consequences of our design interventions? An appropriate design approach must identify functional requirements in the analysis stage and then specify how those requirements will be satisfied in the design stage. A thorough and systematic functional analysis, followed by thoughtful allocation of functions, is more likely to limit problems associated with *substitution myth* than it is to proliferate them.

3.5 Interim conclusion #2

The technocentric world view has produced two dominant but contrasting methods of function allocation. One distributes functions between humans and technology based on supposed strengths and weaknesses of humans and technological systems. The other assumes that humans are fundamentally flawed and seeks to design them out of the system. For many reasons, some of which are covered by Dekker and Woods (2002) and by Parasuraman et al. (2000), neither of those approaches work particularly well. However, the design of socio-technical systems requires some strategy of function allocation. So, what sort of design perspective would support an effective strategy of function allocation?

Progress toward an effective design perspective is confounded by our use of images that can be co-opted by a techno-centric world view. Images imply equivalence in terms of objects, properties, and relations (Johnson 1987). The *team player* image is presumably intended to emphasize relations (the interaction between humans and technology), but its most troubling implication is of property equivalence; that technology can be designed to have the same functional capabilities as humans, the unrealized and probably unrealizable dream of artificial intelligence.

We need to remember that simple ideas can evoke powerful imagery. Although images can summarize and reinforce important aspects of a conceptual perspective, they can also generate misconceptions. We need evocative images, but we need to avoid those images that encourage false interpretations. In a design world with a predominantly technological imperative, constructs that suggest equal status for human and machine agents (e.g., complementarity, team play, and joint cognitive systems) might initially seem like progress but for the technologically minded, they will serve to sustain a techno-centric world view. We need images that focus on human work and images that unarguably relegate technology to a functional support role.

Progress toward an effective design perspective is further confounded by the way we allow the argument to be framed around issues of automation. It is bad enough that among all possible forms of cognitive support (such as appropriate displays of information, well-integrated communication tools, and support structures for organizing work flow), we accord automation some sort of exceptional status. Notably, all forms of cognitive support I mention above, with the exception of automation, inevitably facilitate meaningful human engagement with work, while automation can be used to limit human engagement with work. This is presumably why automation has found such favor among those embedded in a techno-centric world view.

However, the major problem with automation is that it is widely treated as a design requirement (e.g., Seng et al. 2009). A basic principle of requirements engineering is that requirements should not be expressed in terms of solutions; they should be developed in response to operational need and should be expressed in solution independent terms. Automation as a design requirement does not comply with this principle.

The techno-centric ideal that we can develop a socio-technical system that will function adequately without human involvement is fantasy and the problems associated with adding the human as an afterthought are legion. Our discipline is about promoting a human-centric approach. To do that effectively, we need to move the debate away from solutions to one that focuses on the work to be accomplished. The concern of our discipline, cognitive systems engineering, is specifically with *cognitive* work.

4 Cognitive work

Work is directed at accomplishing something useful. In other words, it has a purpose. Furthermore, it has associated values and it has criteria. For work-focused analysis and design, we must ascertain purpose, values, and criteria as we also identify work tasks, technological supports, and organization that will accomplish the purpose in accordance with the values and criteria.

Work elements can be either physical or cognitive, where physical work involves force transactions and cognitive work involves information transactions. No work is entirely physical or cognitive, but the emphasis in our discipline is on the type of work in which the cognitive challenges dominate; challenges such as assessing situations, deciding, planning, and executing.

4.1 Ethnographic imagery

Theorizing in behavioral science has traditionally derived formative images from a well-known mechanism. Most recently, the digital computer has played a central role, but appeals to mechanical devices, formal logic, and mathematical relationships have also been influential.

Such technical or formal images can be evocative. Gary Klein, for example, has noted that he entered his early decision research committed to the assumption that he would find evidence of option comparison as required for rational decision making. Only after confrontation with evidence that suggested otherwise could he reject this concept and develop the notion of recognition-primed decision making (Klein 1998/1999).

Klein's work on recognition-primed decisions is now held in high regard and deservedly so, but there is one aspect of it that attracts little comment. There is a radical move embedded in this evolution. Klein rejected decades, possibly even centuries of reliance on technological images in favor of a work-focused image, one drawn from the way that experienced operators conceptualize their work. Quite independently it seems, Rasmussen (1986) had already made this strategic move and researchers in situated cognition (e.g., Lave 1988; Hutchins 1995) were actively working through it.

I have heard it said that cognitive systems engineering is no more than good human factors or good applied cognitive science. I reject that observation and do so primarily because of this move. Human factors and cognitive science are guided predominately by theoretical images derived from technology and logic. In contrast, cognitive systems engineering is work focused not only in practice but also in theory. We no longer derive formative images from mechanism (e.g., the computer) but from ethnographic descriptions or analyses of cognitive work. Situation awareness and mental simulation are both constructs that have been derived from such ethnographic descriptions.

4.2 Cognitive constructs

If we are now gaining traction from ethnographic descriptions, it would seem useful to revisit any conceptual constructs of our discipline that have been derived from an image of mechanism to assess whether they describe work in a useful way. Mental workload is one such construct, having been based on the image of physical structures in which overload results in failure. Is this a good analogy for work? Does mental processing fail under high load (mental or otherwise) or alternatively, might an individual or team under high load shed tasks, take shortcuts, or otherwise reorganize their work flow (Parasuraman and Hancock 2001)?

Mental workload was discussed extensively by the presidential task force on aircraft crew complement (McLucas et al. 1981), which contributed to the decision to reduce crew complements in commercial airline cockpits from three to two crew members. There are many references to mental workload in the commission report, but it was a controversial issue and there is no recorded consensus on whether the proposed reduction in the crew complement would mentally overload the two remaining crew members. Presumably, enough of the influential decision makers were satisfied that it would not.

Commercial aircraft with two-crew cockpits have subsequently been involved in many accidents, some of which have been attributed to poor cockpit design. The loss of American Airlines Flight 965 near Cali, Colombia in December 1994 (Aeronautica Civil of the Republic of Colombia 1995) offers an example. There are many references to workload in the relevant accident report, all of which implicate poor decision making, poor situation awareness, and poor task organization as aided and abetted by clumsy automation and inadequate displays. While many of those references could be said to implicate mental workload, the report explicitly references mental workload only once and then in relation to a peripheral issue. The Aeronautica Civil of the Republic of Colombia (1995) report is detailed and exceptionally informative but, in contrast to the presidential commission on air crew complement, its authors apparently saw no value in the construct of mental workload.

There is one striking difference between these two reports. Over 78 pages of analysis and discussion, McLucas et al. (1981) fail to discuss the work of piloting in anything but the most general terms while Aeronautica Civil of the Republic of Colombia (1995), over a similar number of pages, offers detailed and extensive descriptions of it, specifically pilot's goals, their decisions, their work strategies, their situational understandings, and their coordination with each other and with their technological systems. Aeronautica Civil of the Republic of Colombia (1995) offers a constellation of ideas that could inform a robust and effective approach to design, but that constellation does not include mental workload. Our faith in mental workload as an important design construct could possibly be misplaced, not because it is unmeasurable, unfalsifiable or cognitive, but because it fails to connect our analysis and design activities to the nature of work in any substantive, meaningful or direct way.

A work-focused perspective demands a much deeper analysis of the nature of the work, its purpose, its

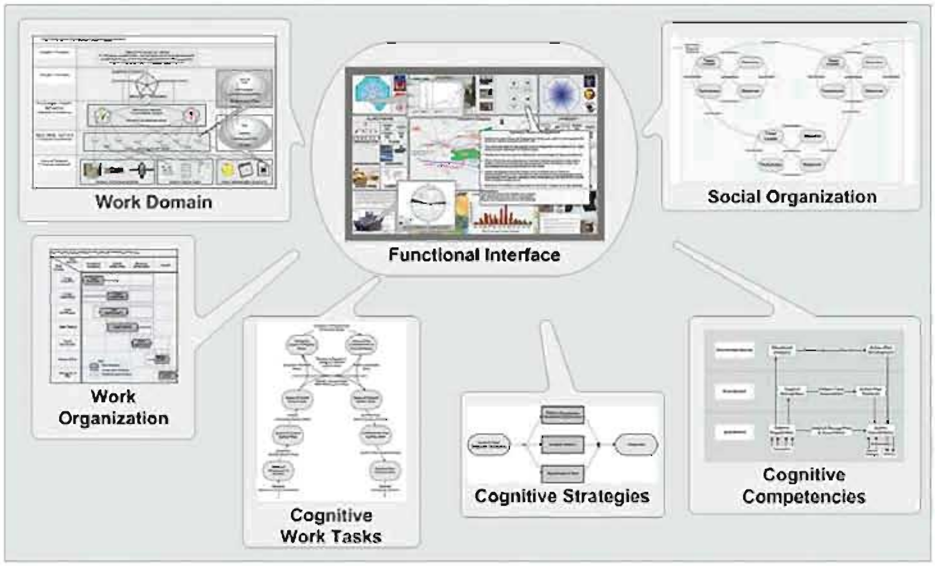

Fig. 1 Cognitive work analysis is a multi-stage analytical framework

organization, and its processes as a prelude to deciding on the functionality of automation or of any other technological support. In short, it demands a systems view of human work. Rather than being concerned with workload, we might be better served by addressing issues associated with work flow; those such as task shedding and spontaneous reorganization of work tasks.

4.3 How might we do this?

To be characterized as work-focused, analysis and design must start by identification of what it is that is to be accomplished, followed by identification of the associated values and criteria. The analysis and design would then focus on how that could be done and finally about how it might be supported and coordinated.

In my own design work, I am mostly concerned with enterprise transformation. I use the framework of cognitive work analysis as outlined by Rasmussen et al. (1994) and Vicente (1999). Cognitive work analysis is a multi-stage analytic framework (Fig. 1) that identifies functional requirements of the work domain at several levels of functional abstraction and decomposition and then identifies the work organization and the social transactions that support human organization and cooperation. Cognitive transformations, strategies, and competencies that might be used in accomplishing the work are also identified. As indicated in Fig. , all of these analytic stages provide information for the design of a collaborative cognitive system.

I prefer the cognitive work analysis framework to others I might consider because it is comprehensive, taking account of functions, individual activities, individual strategies, classes of cognitive processing, worker coordination, and worker collaboration. I also prefer it because the overall strategy of systematic analysis and representation is concordant with the basic strategies of systems engineering.

As both Vicente (1999) and I (Lintern 2009) have laid this out, cognitive work analysis might appear to be not only systematic but also sequential. I doubt that Vicente intended that implication and it is certainly not the way I employ this framework. Design is often described as sequential and systematic but as noted by Hoffman et al. (2004), it is rarely structured rigidly even where descriptions may make it appear so. In my use of cognitive work analysis, I periodically review the separate products of each of the stages and, as those products accumulate, I review their mutual compatibility. I employ diverse scenarios of use to confirm that each of the representational products is internally consistent and then further employ those scenarios of use to confirm that the distinct representational products can be assembled into a well-coordinated system. Workflow modeling can aid these evaluation activities considerably (Lintern 2006). The intent, as I imagine it is for all who undertake design, is to become confident that the system will work as intended before committing to constraints that will be difficult and expensive to adjust at some later time.

I do not want to claim that the framework of cognitive work analysis offers the only (or even the best) strategy to solve the challenge of designing for enterprise transformation. Indeed, I find it lacking in certain respects. It does, however, identify a comprehensive set of attributes that are fundamental to the design of a cognitive system and, when it is used thoughtfully, it will take account of coordination issues.

5 Conclusion

There is a distressing lack of critical reflection within our discipline as we engage with cognitive constructs on our way to design. If the exhortations from Hollnagel and Woods (2005), Dekker and Woods (2002) and Dekker and Hollnagel (2004) could be taken as cautions, their views on these matters would be timely. However, their views were not framed as cautions but rather as prohibitions. Folk models are misleading. Cognition is not a useful construct. We should abandon function allocation. Taken as absolutes, these ideas would inevitably degrade the effectiveness and relevance of our discipline.

Dekker et al. (2010) have offered a radical re-evaluation of measurability, one compatible with the arguments I offer here, although they have failed to reflect on the earlier claims of Hollnagel and Woods (2005), Dekker and Woods (2002) and Dekker and Hollnagel (2004) which are at variance with their new perspective. At the very least, this failure to reflect on those previous ideas will confuse others who encounter these papers for the first time. Additionally, Dekker et al. (2010) failed to deal with the issues of falsifiablity and function allocation. Finally, in consideration of our discipline being concerned with design, Dekker et al. (2010) do not offer a way ahead. My purpose in this paper has been to clarify these issues, and I summarize that clarification below.

Any concern with an uncritical acceptance of folk models has merit but an attempt to banish them would be counterproductive. Ultimately, disciplined extension of folk models will benefit rather than detract from our design efforts. Similarly, it would be counterproductive to banish the term cognition from our lexicon. We need a term that distinguishes what we do from what others do in their efforts to design systems and of all the terms we might use, cognition appears to be the most appropriate.

Any concern expressed about reliance on simplistic and outdated approaches to the complex and challenging problem of function allocation also has merit but the proposed solution, to abandon any interest in function allocation, is unworkable. To abandon function allocation would cripple our efforts to take a systems view and would place us at odds with practically every other design community, thereby accentuating the isolation we already complain about. If we are serious about wanting to engage with engineers and other design communities, we need to help them do a better job of function allocation as we stress the importance of communication and collaboration.

These arguments arise in our discipline because we are not as clear as we should be regarding our fundamental beliefs. Many of our descriptive terms fail to characterize what we do evocatively and unambiguously. The loss of the term cognition would make that worse but problematically, many of the ways we describe our ideas are open to misinterpretation from a superficial reading by those embedded in a techno-centric world view.

If we are to make headway in this heavily techno-centric world, we need to rely on terms that are evocative in their imagery as we describe our human-centric world view. To this end, we need to emphasize terms such as cognition and work explicitly, consistently, and forcefully as we build an approach to work-focused analysis and design, one that commences with an analysis of what is to be accomplished and the associated values and criteria. In our development of cognitive constructs, we would do well to employ critical and skeptical reflection (Dekker et al. 2010) more often than we have in the past. Finally, we need to be assertively adamant in our rejection of design options such as automation posed as design principles and instead focus on the nature of the work and how it might be accomplished as a prelude to thinking about how that work might be supported.

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