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Developing human factors/ergonomics as a design discipline

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ABSTRACT

This paper deals with internal challenges that the human factors/ergonomics (HFE) research faces when wishing to strengthen its contribution to development of work systems. Three established characteristics of high-quality HFE, i.e., HFE takes a systems approach, HFE is design-driven, and HFE focuses on two closely related outcomes, performance and well-being, are taken as a starting point of a methodological discussion, in which conceptual innovations, e.g. adopting the technology-in-use perspective, are proposed to support development of HFE towards the high-quality aims. The feasibility of the proposed conceptual choices is demonstrated by introducing a naturalistic HFE analysis approach including four HFE functions. The gained experience of the use of this approach in a number of complex work domains allows the conclusion that becoming design-driven appears as that most difficult quality target for HFE to reach. Creating an own design discipline identity in a multi-voiced collaboration is the key internal challenge for human factors/ergonomics.

1. Introduction

This paper deals with methodological challenges that the human factors/ergonomics (HFE) research faces when it attempts to increase its contribution to design of complex work systems. I shall discuss the topic on the basis of own experience of HFE research at the Technical Research Centre of Finland, a multi-disciplinary national research institute that is positioned between the academia and the Finnish industry and interacts with both. The research at VTT is motivated by its input to development of technologies and work systems. Also HFE is considered potentially to contribute to technology development, in particularly in the meeting the safety objectives of organisations and in responding to the developing demands on personnel competencies. So far HFE has mainly been applied in improving the operations of the plants and organisations. A need to involve HFE in the design of tools and technologies, or in the planning of future operations, has been identified only relatively recently.

Beyond safety, further objectives, like usability of tools and services and experience concerning their use, have also been identified at VTT as significant motivators for exploitation of HFE. Reaching the usability-driven objectives is considered to have an influence on the performance of the systems. This potential is demonstrated by the interest that the concept of "User Experience" (UX) has raised among some leading companies of the Finnish and international metal industry, resulting in the launch of a large public–private-partnership type of research programme (UXUS, 2010). The emergence of the UX construct characterises the so-called third wave usability research, and it has, in particular, been connected to new business possibilities that the human-centred design could provide (Roto et al., 2011). Usability and UX research originate in the Human–Computer Interaction tradition that has the advantage of having an intimate connection to design activity (Savioja and Norros, 2012).

In spite of some positive signs of change towards acknowledging the role of HFE for the design and development of industrial organisations, we still face the situation both in the safety-critical and business-critical domains that HFE is interpreted as a secondary means in accomplishing the targets of the organisations. Hence, on the basis of my own experience, it is easy to agree with the conclusions of the recent article concerning the strategy of HFE (Dul et al., 2012) that the potential of HFE is underexploited. This applies in particular the stakeholders in the design and management of organisations who typically focus on performance outcome. Several reasons hinder the exploitation of the potential of HFE, such as insufficient awareness of the value of HFE, lack of high-quality HF or too limited scope of the input of HFE, the relatively small size of the discipline, and vagueness of its identity in cross-disciplinary connections.

The present paper continues this discussion, but, compared to the cited article, I will focus more on the HFE internal reasons for still incomplete exploitation of HFE in design. I believe (applying

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the idea of Bannon, 2002) that even though industry and engineering research probably share the human-oriented *values* with HFE, and even understand the potential benefits of applying HFE in design, this is not enough. There is a pressing need for *conceptual* innovations for tackling the HFE problems. Such innovations are needed to concretise the three characteristics of a *high-quality HFE* as defined by Dul et al. (2012), drawing on the definition of the International Ergonomics Association: HFE takes a systems approach, HFE is design-driven, and HFE focuses on two closely related outcomes, performance and well-being.

My intention is to propose concepts that would bring depth and concreteness to these three characteristics and, and via these improvements promote the goals of high-quality HFE. In particular I am interested in how to facilitate HFE as a design discipline. The examples from our own research aim to elaborate how we at VTT have attempted to move towards a more design-oriented HFE approach.

2. High-quality HFE – need for change of paradigm

The starting point of my discussion is that the three characteristics of a high-quality human factors/engineering mentioned above are presently taken too much as pre-given ahistorical characteristics of HFE, and the problem of HFE practice is seen as an incapability of realising these features fully, due to external reasons. As an example, the qualification of systemic approach reduces very often to an extended *listing of factors* that are considered in analyses, or as moving the focus of design *from* technology-driven *to* human-driven, of which tendencies even the Dul et al. (2012) paper tends to suffer. What would be needed is focussing on principles of *interaction* and *co-functioning* between elements of a *whole*. I assume that interpreting the three qualifications of HFE rather as goals towards which HFE is currently moving due to the pressures from the working life and modern society, would draw attention more on the needed changes in the basic definitions and content of HFE itself.

The quality attribute systems approach is most intimately related to the pressures of current working life and living environments that increase the complexity of these systems, induce dynamic changes and load the systems with unexpected phenomena. These changes are deeply rooted in the characteristics of the information and communication technology (ICT). While ICT has opened new sources of information, improved storing and transmitting information, and it has enabled new forms of communication, and new ways of organising activities in time and space, people's lives have become completely intertwined with and dependent on this technology. It has become a universally utilised medium in the modern society. Management of the changes in people's work and daily activities, and gaining control of the new medium is still on-going and the transition is mastered insufficiently. In this situation also HFE faces new challenges.

It has even been argued that due to the difficulties in tackling problems emerging from the above sketched broad transformations in work and daily life, HFE faces a pressure for change of paradigm (Hollnagel and Woods, 2005). The cited authors see that the traditional "natural" distinction between human and technology as two separate elements draws the interest to identifying the internal processes of human brain, and technical devices, and the computational connection with the elements in terms of their interaction. As a consequence, difficulties arise to see the wider connection in which the human and machine are situated, and the constraints the environment puts. The authors write further that because traditional ergonomics never questioned the validity of human-machine distinction, it has run to difficulties in reaching the systems view even though claims for such have been expressed widely.

Another example from a paradigm shift that especially HFE experts who work in safety-critical domains have identified regards the concept of safety. The prevailing basic assumption in systems engineering and also in the cognitive engineering is the assumption of a "perfect system" that ideally is reachable when appropriate principles of "defence in depth" are followed in design, and complied with during operations. Due to experience of a number of large accidents much self-reflection is currently going on in safety-related HFE to revise understanding of a safe system. The concept of "resilience" has been brought up as a key concept that would enable a more realistic understanding of safety of systems (Hollnagel et al., 2006, 2011). Central in the proposed new safety paradigm is acceptance of the variability and unexpected events in the system as inherent features of the system that cannot be fully eliminated. Finding concepts to characterise the variability and unexpected events have been proposed (Weick and Roberts, 1993; Weick and Sutcliffe, 2007; Furniss et al., 2011; Pidgeon, 2012) and appropriate means to respond to, and be prepared for them are currently sought intensively in the HFE community.

Pressure for paradigm change is characterised not only by overt difficulties in tackling existing problems, but also by the emergence of optional approaches that are capable of articulating new and more relevant problems. In the issue of identifying the overt problems that HFE faces in solving problems currently I rely on the analysis of Dul et al. (2012). As a complement to that, I shall focus on the optional concepts that are currently emerging within the HFE. Hence, in the forthcoming sections I shall discuss three methodical perspectives that I believe could support development of high-quality HFE. These perspectives are technology-in-use, extended conception of outcome of design, and adopting design thinking in HFE.

3. Technology-in-use

Common to new approaches in HFE is to conceive *human–technology–environment* a unity, and adopt this as the new object of analysis. These approaches offer articulated conceptions to what a systemic HFE could be.

Having first defined the object of design as the human–technology–environment united system, the critical point is to identify concepts and methods that are capable of tackling the functioning of this system in some details. One way is to consider technology from the point of view of its usage, *i.e. technology-in-use.* From this perspective the technological and human elements become automatically inseparable, and their mutual determination becomes evident (Orlikowski, 2000; Hollnagel and Woods, 2005). Several attempts to re-define the object of design of HFE from the technology-in-use perspective are currently under discussion in the international research community. A good example of this line of research is Wanda J. Orlikowski via her analyses of practices and the role technology in the formation of structural properties of social systems (2000). Orlikowski elaborates, e.g., the theories of Giddens (1979) or Bourdieu (1977), and provides a good insight of the ways how technology shapes the rules and resources of organisations.

My own approach to technology-in-use draws on philosophical and psychological theories concerning the human-environment relationship. This background provides several ways to approach technology-in-use. I shall name three which have emerged in our human factors research in different industrial domains. Arguments for these three views may also be found from the distinctions that John Ihde (1990), drawing on the philosopher Martin Heidegger, made regarding how human–technology–environment relationships may be experienced (embodied technology, hermeneutic technology, and technology as the other).

3.1. Technology as tool

The first way of dealing technology-in-use is to comprehend technology as a *tool* that people take advantage of in their various activities, especially in work activity. This way of thinking is self-evident in everyday sense. Should this idea also be adopted in a scientific discourse assumed of HFE, it would become necessary to define a concept that elaborates the role of tools in human behaviour. This concept is "*activity*". Surprising as it may seem, the concept of activity is not very generally used in HFE, except that it has a central position in the Francophone ergonomics research, as explained, e.g., by Daniellou and Rabardel (2005).

The tradition in which the concept of activity is central is the Cultural-Historical Theory Activity Theory (CHAT) (Leont'ev, 1978). This theory has become known also within the human factors/ergonomics community via its implementation in the so-called developmental work research by Engeström and his collaborators (Sannino et al., 2009). Via this concept it is possible to analyse the role of technology in the behaviour of individuals and teams in organisations within one united system. The concept has been given a visual form of a triangle that in an illustrative way demonstrates the systemic nature of activity (Fig. 1). According to this model, three basic elements can be identified first: *actor*, *community* and the *object of activity* (Engeström, 1987).

The relationships between the three first elements are mediated by further three elements: *Tools and concepts* that are needed to maintain relationships between the actor and the object of activity. The further mediating elements are *rules and norms* that enable individual actors to interact within the communities in which they belong. *Division of labour* is the third mediating element that takes the role of organising the community to act upon the object of work.

The feature that supports the integration of the elements of the activity into a whole is that the object of activity takes a primary role in shaping the characteristics of the other relationships within the entire activity system. This is due to the potential of an object to motivate acting and to suggest purposes for acting. Furthermore, the object of activity is always loaded with particular constraints that need to be taken into account in the actual process, via which the object is transformed into the outcomes of activity (Leont'ev, 1978). This transformation process is represented in the model by the horizontal arrow from the object to the outcome. This arrow is a double one indicating the structuring effect of the intended outcome and the pressures on both the outcome and the object from the environment. In detailing the constraints of the object of activity, a functional analysis of the domain, e.g., the abstraction hierarchy and part-whole analysis approach proposed by Rasmussen may be used (Rasmussen, 1986; Vicente, 1999; Norros, 2004).

A further step in considering technology as a tool is to elaborate in more detail the mediating role of a tool in the psychological structure of activity. Drawing from Vygotsky (1978) we have

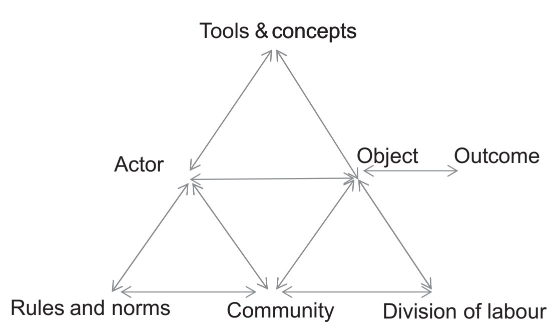

Fig. 1. Activity as a system of interacting elements. Interaction with the environment is considered in this basic model to take place via the outcome (Engeström, 1987).

proposed to distinguish three functions of a tool, the *instrumental, the psychological and the communicative functions* (Savioja and Norros, 2008, 2012). Via its instrumental function technology has a capability to influence the environment according to the actors' intentions. For example, one of the most widely used tools of today, a mobile phone with the wireless network providing the infrastructure for this tool, acts in an instrumental function as it enables mobile connectedness among people. The psychological function is the external control of human behaviour that the tool enables, once the human has developed schemes to use the tool. Without such schemes the tool is not integrated into the action of the user, and is actually not a tool at all (Rabardel and Beguin, 2005). The way of using the mobile phone first imitated that of using a traditional phone, but when the appliance spread especially among young users its capabilities started to realise and the tool was appropriated more fully, launching further development of the tool itself.

Beyond the instrumental and psychological functions of the tool, we distinguish a third one. Here we draw on the reasoning of Georg Rückriem, an expert of CHAT who has studied the connections between the CHAT and media theories (Rückriem, 2004, 2009). The communicative function emphasises the role of the tool to develop collaborative social activity and shared meaning. The mobile phone functions as a communicative tool because many people have appropriated the use, they know who uses it, what to expect when using it, or what is the correct etiquette of use. In archaeology past cultures are typically identified by the usage of a particular tool or artefact. Using the mobile phone conveys the message that we belong to the same community of "mobile phone users". By distinguishing the psychological and communicative functions of artefacts, and thereby elaborating the mere instrumental role of technology in human activity, our analysis corresponds to the ideas of Orlikowski, in which she elaborates how technologies become part of behavioural structures to deal with the environment (Orlikowski, 2000, 2002).

One expression of the need to re-conceptualise the object of design, and to look at technology from the point of view of its usage, is the increasing application of the notion of *"Concept of Operations" (ConOps)*. This concept was originally developed in the 1980s in the design of software for complex and safety-critical domains (Fairley and Thayer, 1997). Concept of operations provides a vision of the future system in use. It is a description of the problem domain and the future operational environment of the new system (e.g. we used it to analyse a future manufacturing system) from the perspective of use and users. Domain specific non-technical language is used to describe how work is going to be accomplished when using the projected system. A concept of operations document is prepared for the design of the new system that provides an integrated view of the system and its operational characteristics. This document serves communication between different parties involved in the design. Hence the ConOps document is clearly a "boundary object", delivering understanding of a joint object across disciplinary borders (Star and Griesemer, 1989).

The notion of concept of operations has been adopted without much theorising in e.g. nuclear power plant control room design and modernisation (EPRI, 2004, pp. 2–10), and it is also used in other large scale technology development projects (Jpdo, 2007). The use of this concept also by the proponents of the CHAT for describing the processes and ways of working in an organisation, demonstrates its compatibility with the concept of activity (Virkkunen, 2012).

Also the *Joint Cognitive System* concept proposed by Hollnagel and Woods (Hollnagel and Woods, 2005; Woods and Hollnagel, 2006) advocates the idea of technology-in-use. By exploiting this perspective, attention is drawn on the joint capability of the human-machine system. As the unit of analysis changes to the Joint

Cognitive System (JCS), the interest is shifted away from the internal processes of the two elements, i.e. human and technology, to the external functions of co-agency of the JCS. Different from CHAT, the authors focus on the two elements of human and technology (actor and tool), while the environment providing the object of activity is not included. This solution has been criticised of a difficulty to argue why a particular joint function emerges and what is the reference for its appropriate operations (Norros and Salo, 2009). These authors claim that the environment, due to the possibilities it offers and the constraints it puts on activity, needs to be included in the analysis in order to understand the content and behavioural patterns of the joint system.

3.2. Technology as medium

The communicative function of tool explained above links to the second option to interpret technology-in-use, i.e. analysing *technology as a medium.* Technology as a medium emphasises the role of any used artefacts to mediate messages that are incorporated in the technology itself.

As the concept of tool, also the concept of medium refers to something that is between two elements, and they both also denote to transcending beyond a border, or over distance. But unlike a tool, a medium is *not defined by serving a deliberate purpose*. Rather a medium, e.g. photography or augmented reality (AR), is a generic mode of influencing people and involving people into action. A medium is effective through being coupled with human senses, and it extends the power of the natural senses. In this way, the medium is directly incorporated in sense making. When doing so, the medium tells something of itself. Its dominant message is how it affects the human actors' acting, not the content that it typically also carries. For example AR is a medium because of the new dimension in perception it enables, which gradually will be expected of the environment, and only secondarily via the content that it provides, e.g. showing assembly instructions directly on the object under maintenance. This medium role of technology for human activity was analysed 50 years ago by Marshal McLuhan, who crystallised the idea by the famous slogan "Medium is the message!" (McLuhan, 1964). McLuhan also pointed out that the effect of a medium typically remains unnoticed by people, which may result in experiences of uncertainty and loss of control when media are transformed (McLuhan and McLuhan, 1988). Internet and the technological enablers called "ubiquitous computing", function as media, and when adopted in use these enablers will shape peoples' ways of acting. Rückriem (2009) writes that the digital information technology, having become a universal form of technology, has made the connections between perception, language and experience more complex, and it has created completely new social and economic structures. Due to the insights of media theory concerning the changes in the generic ways and experience of control, HFE needs to establish a relationship with media theory to tackle deeply the technology's role in shaping our consciousness and culture. It should collaborate with engineering and industrial design with the aim to discover the medium characteristics of particular technologies.

3.3. Technology as object of care

The third technology-in-use perspective brings forward the idea that *technology needs to be taken care of.* When thinking of technology from this perspective we apply the idea of Martin Heidegger who emphasised that when human beings shape the environment via technology, the environment becomes resource of people's activity (Heidegger, 2007/1962). Examples of such resources are, e.g., roads, railways, electrical grid, or the Internet, but we may think that the relationship applies all technologies. It is evident that when becoming a resource the environment affords new possibilities for action. Less evident is that by creating a resource people become responsible of taking care of it. Technology does not exist autonomously, but assumes more or less frequent maintenance and great effort from people in order to deliver the possibilities that it basically opens.

In a case study in a large telecommunication network operator we asked network operations experts what would happen to the network without human intervention to it. We found that about half of the respondents emphasised the robustness of the network, and human actors as a source of failure of the network functioning. This is true but it reflects a traditional point of view to human–technology relationship in which the possible negative influence of human behaviour on the system is emphasised. The other half of the respondents considered the network to require constant care, due to the system being prone to failure, and due to its continuous change and development. The latter epistemic attitude emphasises the human responsibility of the network resource and the human operators capability to contribute to the stability and development of the system (Norros et al., 2012). In practice, activity systems, i.e. maintenance activities, have emerged, to which care taking has been delegated, but, clearly, the operational practices and culture also count. The quality of both activities, i.e., operations and maintenance, reveals how aware people are of the fundamental responsibility for the technology. For example everyday traffic culture, or safety culture in safety-critical production organisations, have a major impact on the capability of these resources to enable human activity.

The idea of technology as an object of care raises even a more fundamental issue of what are the limits of acceptable intruding into nature, and transforming nature into resource. This is one of the deepest ethical problems of the modern man. The advice of the late Finnish philosopher Georg Henrik von Wright in this issue was the following (Von Wright, 1998): The epistemic attitude called the "scientific rational attitude" of modern people acknowledges the power of science to understand nature, and it also includes understanding that it is impossible to control nature. Therefore, people need to adjust their wills according to nature. Von Wright continues by saying that this is still not enough. Instead, people should develop a "practical rational attitude" that would bring forward prudence and moderateness in our acting, and consideration of wider connections and longer perspectives. In other words, it would not be rational to do everything that science and technology enables, but instead to withdraw from some projects in the name of the sustainability of the environment and human life.

Interest in value-informed design, with which the above concerns can be linked, appears to be increasing today, as is indicated e.g. Guy Boy in a new book in which the author advocate a humanistic view to technology (2013, p. vi). Also Wright and McCarthy in their experience-centred design convey a strong message of humanistic aims in design (Wright and McCarthy, 2010). The trend of emphasising values in design is demonstrated also the by emergence of networks connecting students, researchers and universities to develop approaches to value-oriented design in different domains. Examples of such networks are. e.g., the Values-in-Design (ViD) network in the USA (ViD, 2012), and international design research networks operating in Europe, e.g. Design Act and IDEA League (Designact, 2012; Idea, 2012).

4. Extended conception of outcome of design

The second methodological issue I consider relevant for developing HFE concerns the conception of the *outcome* of design in which HFE intends to participate. The design-relevant outcome of

HFE is brought up in the above-cited definition of HFE (Dul et al., 2012) which states that performance and well-being are integrated in the outcome of HFE research. It will be argued here that the expressed aim to support both performance and well-being related outcomes (Dul et al., 2012) should be supported, but that maybe there is more to understand the nature of these outcomes that would improve reaching them: My argument is that the well-being related outcomes that HFE typically promotes are defined by criteria that are not very different from performance-related ones, and that the usual well-being related criteria do not reveal the potential that the actors possess to develop the work system. I refer then to criteria like, e.g., absenteeism, occupational accidents, near misses, job satisfaction and motivation, etc., which typically offer an external and non-contextual perspective to work. As such these measures are useful for building an overview of the present state of well-being in an organisation. But these measures do not really capture what is valued as good work and as worthy outcomes to strive towards. These outcomes would be important for understanding the creative potential of the actors and their willingness to participate in design.

I shall clarify my point by referring to the distinctions made in the cultural-historical theory of activity with regard to the outcome of activity. The theory proposes that the outcome activity has two intertwined aspects. The first one is the evident *materialised product*, e.g. a well-equipped automobile. Also in the modern knowledge-intensive work the materialised product appears to be in the focus, typically because the product is relatively easy to identify and measure. Even in activities like university education, the material product deserves the main interests as attention is focused on spent money and number of degrees or publications, etc.

The outcome of activity also has a second aspect which relates to the *potential for action and development* that it is able to create. In the case of an automobile, the created capability of production workers to develop even better vehicles to support mobility in a sustainable way would offer a more holistic perspective to consider automobile production. In the case of the university education the potential aspect would be the capabilities of students to identify emerging problems in their natural and social environment and invent new ways of tackling them with the aid of the means their studies have made available for them. In high-reliability organisations a sign of created potential would be the personnel's intrinsic readiness to act in situations that were not anticipated and trained, i.e., a qualification of a safety-critical system that is currently discussed as resilience (Hollnagel et al., 2006).

The above distinction between the two aspects of outcome applies when HFE experts evaluate human behaviour: Good outcome is typically measured as success in *performing* pre-defined actions, errors, time, level of mental load, etc. Even the more cognitive measures like situation awareness convey the idea of fulfilling externally defined criteria of good performance. We have proposed that the performance perspective corresponds to what has been defined as *external good of practice* by Alasdar McIntyre (MacIntyre, 1984; Norros, 2004). Without doubt, it is important to measure the outcome as the resulting performance effect. Yet, in our studies with experts in safety-critical domains (Klemola and Norros, 2001; Norros and Nuutinen, 2005; Savioja and Norros, 2012) we have, found that all experts typically reach a high performance outcome level, but that there still exist relevant differences among experts, which experts themselves or some of the instructors may identify. These are the differences in ways of acting that can be interpreted as optional approaches to professional agency adopted by the actors. These differences relate to variations in the *potential for acting.* The *effects* of such potential become overt in situations that are especially demanding or unexpected, but their *existence* may also be identified in normal situations. The latter assumes focussing on generalised patterns of behaviour expressing the sense of acting. We have termed such patterns habits of action (practice) (Norros, 2004). By analysing habits of action it is possible to identify what MacIntyre labels *internal good of practice.* This qualification of practice complements the material external good of practice, and denotes ways of working that the professional community of practice holds as worthy and valuable. Traditional expressions, like "good seamanship", capture the idea of internal good of practice. We have developed methods for identifying habits of action on the basis of observed performance, and identify habits of action with the aid of the pragmatist notion of habit (Peirce, 1998a,b; Norros, 2004). The interest in the exploitation of different types of Schema Theories in HFE research conveys the same intention of deepening understanding the dynamics of acting in real life environments (Plant and Stanton, 2013).

The point I try to make with above reasoning is that as long as HFE dominantly focuses of the performance outcome in its material sense, the input of HFE with regard to solving problems in work tends to remain reactive. If we are also able to find complementing outcome criteria that reveal the capabilities of people to bring their creative potential to work, HFE will bring added value to the design processes.

5. Adopting design thinking in HFE

The final methodological point to be made relates to the role of HFE in *design.* As is expressed in the definition of HFE, the discipline is expected to be design-driven (Dul et al., 2012, pp. 4–5). The claim to be defended here is that in order to realise these expectations, HFE needs to adopt an epistemology of a design discipline, i.e. HFE should learn design thinking.

Design activity is not the same as research activity, and the epistemology, i.e., the concepts of the nature of knowledge and justifications, relevant in design and research are not the same. Drawing on Findeli (2001), Kuutti (2009) maintains that the conception of design as an "applied science" is invalid. According to this notion knowledge is first created outside design itself, typically in research, and it is later simply used in design. A more appropriate view is that new knowledge is created within the design activity. It should also be understood that when design solutions emerge the entire system changes, including the designer and the customer. Consequently, design should be labelled as "involved science".

According to Kuutti and Findeli, design thinking is parallel and holistic and resembles visual comprehension of objects. Therefore, the notion of "visual intelligence" is used to characterise the cognitive efforts required in design (Findeli, 2001). Kuutti (2009) lists issues that should be taken into account when developing the epistemology of design to meet the target of "visual intelligence". The first point is that design knowledge is created in all the activities in which an artefact is involved, i.e. in design, use, or production of the artefact and also when training the use of the artefact. The second issue relates to the type of knowledge in design. Typical for artefacts is that they have a meaning related to the purpose of their use. Hence, different from science that aims at general, global and timeless knowledge, design creates knowledge and utilises knowledge that is local, particular and timely because the artefact should work in the near future fulfilling the identified needs of the users. Finally, the availability of knowledge in the sense of its level of explicitness distinguishes design knowledge from ideal scientific knowledge. Design knowledge concerning artefacts is only partially explicit, i.e. in the form of specifications, programmes, description of modelling methods, etc. A large part of knowledge is embedded in ways of designing, hence not explicit and taken for granted.

If HFE should qualify as a design discipline the above described characteristics of design knowledge and thinking should be accepted also to HFE. It is evident that the traditional division of basic and applied science is dominant in HFE. HFE is considered as an applied discipline. Due to this identity, basic science with its standardised and well- controlled forms of creating knowledge, including focused and specialised topics, is held as an ideal for knowledge that is exploited within HFE. Should, instead, the identity of an "involved science" be adopted, HFE should actively develop formative, i.e., developmental methods in analysis. These methods should enable quality control of holistic and context dependent knowledge that emerges in less controlled ways, and in interaction with the actors in realistic work settings. Methods are needed to make involvedness an advantage of knowledge creation, instead of considering it as a threat to objectiveness. Statistical generalisation should be complemented by well-argued interpretation of particular instances. Case-based reasoning is one possible approach that could improve the control of reasoning in HFE studies.

Even though user-centred approaches are generally recommended and case studies have become usual also in HFE, the above listed methodical problems are not sufficiently solved. Modelling methods, simulations or virtual techniques could be developed, to experiment together with the users on systems and to anticipate functioning of technology, to make implicit knowledge explicit, and to create dialogue among disciplines and perspectives. Need for integrated design methodologies that would incorporate the contribution of HFE in engineering have recently been expressed in the context of design of large process plants (Papin, 2004; MMOTION, 2011).

Table 1 summarise the arguments of Sections 3–5. In the table three high-quality HFE attributes identified by Dul et al. (2012) are cross-tabulated with the three theoretical perspectives that were proposed to provide support to reaching these quality attributes.

6. Towards design-oriented analysis of activity

Like most HFE studies also ours have originally focused on analysis of work. The results of these analyses have served evaluation purposes. We have, however, identified the need to transform the approach and methods towards innovative use of HFE in design. The main characteristics of the current analytically-oriented research approach have been summarised in an earlier work (Norros, 2004). The transformation of the approach to meet better the emerging design needs started some years ago in a national research project (Kaasinen and Norros, 2007). Overall, in our methodology we draw on philosophical backgrounds that make an attempt to overcome the Cartesian dualisms. Hence Marxist praxis notion and also phenomenological ideas of lifeworld provide lines of thinking that support our methodological work. The philosophical school that also has appeared appealing to our HFE methodology is philosophical naturalism, and its adaptations in American pragmatist tradition, especially Charles Sanders Peirce and John Dewey (Peirce, 1998a,b; Dewey, 2002). Due to these foundations our approach could be labelled "naturalistic". We view human activity, experience and consciousness as a result of an evolutionary development of human beings with their natural environment. We emphasise the real world as the object of knowledge. We study human behaviour in practical and particular contexts, but we also look for how people urge for generalisation that provides continuity to behaviour and enables sense making.

Drawing on the above sketched methodological grounds we may characterise our input to design by defining an application space of HFE, which idea was proposed already in an earlier study (Norros and Salo, 2009). In that previous version the scope was broader and slightly different epistemic dimensions were used to describe the space. In the present conception of the application space we use two epistemic dimensions. The first is the type of knowledge central in the HFE work. The dimension ranges from knowledge of particular objects to generic knowledge that could be useful in further cases, also. The second dimension is about the type of reasoning we use. It would range from analytic thinking in which control and compartmentalising would be important, to formative thinking which would be developmentally-oriented and synthetic (see Fig. 2). In Fig. 2 four different *functions of HFE* are depicted which emerge in the fields defined by the two dimensions. The figure also illustrates the idea that HFE efforts expand from understanding the present towards projecting the future work and tools. Important is that both in dealing with the present and the future both types of knowledge and ways of reasoning are relevant. Consequently the different functions of HFE may all be useful. It

Table 1
Theoretical perspectives and concepts proposed in Sections 3–5 to support the high-quality HFE characteristics.

Perspectives to support realisation of high-quality HFE. Identified features of High-quality HFE (Dul et al., 2012)	Technology-in-use - Technology as tool - Technology as medium - Technology as object of care	Outcome of design - Product - Potential	Design thinking - Involved science - Visual intelligence
Systemic approach	Concepts and approaches that focus on interactions and relationships: - Activity - Technology-in-practice - Joint cognitive system - Concept of operations - Technology as a generic medium	Analysis considers - Object and objectives of activity because they shape the structure of the entire activity system - Resilience of the system and the adaptive mechanisms to achieve it	Analysis considers that - Technology is shaped in all life-cycle activities
Oriented to both performance and well-being	Concepts that make explicit the role of technology and draw attention to development in work - Psychological function of tool - Communicative function of tool - Understanding media as extensions of human capabilities	Concluded is that - Performance point of view describes actual and specific behaviour - Activity theory, Scheme theories and Practice approaches enable understanding the generic potential in behaviour	Analysis considers - The collaborative and dialogical nature of creative behaviour
Design-driven	Design focus extends to: - Concept of operations - Humanistic point of view to design, e.g. Values in design	In complex system design - Experience may reveal the potential for development connected to technology that is not yet realised	Analysis that supports design adopts: - Developmental, formative approaches - Exploitation of conceptual models and simulations

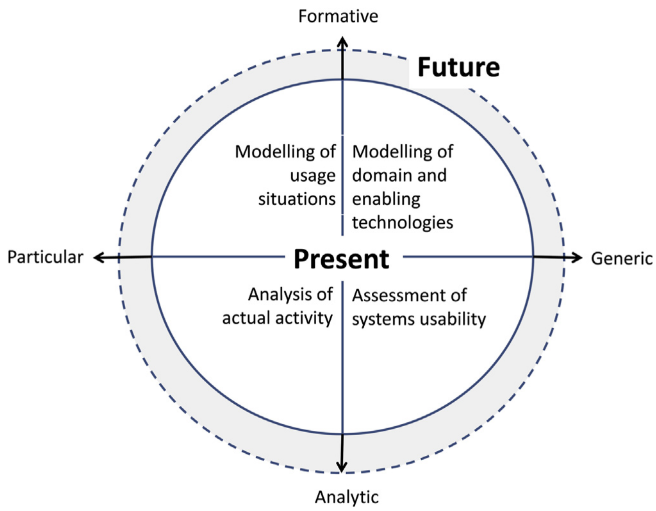

Fig. 2. The functions of HFE in a design-oriented study.

may be quite usual that HFE experts start with an analytically-oriented work that focuses on understanding of particular work activities and tools as they presently are. In the analysis of particular work, models may be used to describe the contexts and constraints in which work takes place. These contexts and constraints may, however be considered as instances of some more generic features of the environment and domain which also may be modelled. These generic features may be used in design of particular work and technological solutions, and, when the design proceeds, evaluative analyses have their role. Assessment is particularly pronounced if the product requires formal licensing due to the safety criticality of the context of its use.

The four functions of HFE are not thought to appear in a certain sequential order. They may also have to be repeated several times during the study. In the next, I shall bring examples to demonstrate the four functions but, because no single study provides a best example of all of them, it is necessary to refer to different studies that have been accomplished in different industrial domains.

6.1. Modelling of the domain and enabling technologies: examples from maritime and telecommunication domains

Drawing on Activity Theory and Developmental work research (see Fig. 1), we consider work organisations as historically developing activity systems that typically contain diverse tensions between and within their elements, and also between the present system and the future emerging system. By modelling the work as an activity system, it is possible to identify the global tendencies of the development of work, and to specify the demands that optional, and often contradictory objectives put on the organisation and its processes, and on the practices of the personnel. This is the first function of HFE we apply.

An example of analysing the developmental pressures of work with the aid of the activity-system model is the study we accomplished in accident investigation concerning maritime accidents in pilotage situations in Finland (Nuutinen and Norros, 2009). This was an exceptional accident investigation that focused on 10 accidents at the same time. It was accomplished because the Accident Investigation Board of Finland became worried of the high frequency of maritime accidents while ships were in piloting situations. The board wanted to create a more holistic view of the problems in the pilotage activity. Drawing general conclusions is not the primary objective of accident investigations, and the investigation methods are typically tuned to provide explanations for the particular courses of action. In the example study, data concerning the course of events in each studied case was collected first according to standard investigation methods. Then the analysis continued by an attempt to identify more generic habitual patterns of behaviour on the bridge that could be responsible for the events in each particular case. For example we found, that when the control demands became more difficult, collaboration between the pilot and the master tended to get reduced. We then made an attempt to find reasons for the identified patterns. In order to do this we conducted an activity-system analysis of the piloting work based on all material we had collected of the accidents, from various documents, including historical sources, and on literature of pilotage in comparable conditions. As a result of this analysis, nine major tensions were identified. As an example we found a reduction of safety margins of sailing, which is caused by the fact that ever larger ships enter to the traditional narrow routes of the Finnish coastal waters. It was reasoned further, that this tendency could be coped with by introduction of technological tools, like autopilots with predictive characteristics, and piloting practices that demonstrate readiness to apply the advanced tools, or good communication among the bridge personnel and the pilot. The empirical results from the investigation demonstrated, however, that the required change in practices had not taken place. Instead both the pilots and the bridge personnel considered that a good piloting practice is characterised by an individually-oriented skill-based tacit adaptability. Collaboration or use of technology was not inherent in this implicit competence model. The described accident investigation demonstrates a case where we started from analysis of singular courses of action but proceeded towards a system-oriented modelling of constrains of the domain in order to find generic explanations of the observed practices.

In a second example I shall demonstrate how an activity-system analysis of a domain may be developed further towards modelling of intrinsic demands of controlling the system, and towards inferring psychological core-task demands that tackling the system by people require.

The illustrative modelling tool that we use is depicted in Fig. 3. Drawing on literature regarding complex work domains we consider three generic control demands, i.e. dynamicity, complexity and uncertainty (Norros, 2004). In tackling the control demands people may exploit basic functional resources of activity, i.e. pragmatic resources, i.e. skills; epistemic resources, i.e., knowledge; and heuristic resources, i.e. self-reflection and collaboration to strengthen the control (Arguments for these three categories may be found e.g. in Rabardel and Duvenci-Langa, 2002; Norros, 2004). When connecting each control demand with each these resources nine types of work demands emerge. We call these core-task demands. Fig. 3 illustrates the interaction between the control demands and the psychological resources (indicated by dots in Fig. 3), out of which core-task demands emerge (in italics). Own empirical material and literature findings are used to identify and to elaborate the control demands and the psychological resources in the particular domain under study. The emerging psychological core-task demands are later used as contextual reference in the analysis of actual actions.

Fig. 3 demonstrates the use of the above described modelling approach in the analysis of human operators work in the on-line management of telecommunication networks (adapted from Norros et al., 2012). On the bases of comprehensive interview data, control demands were characterised, and 9 generic core-task demands could be identified (in italics). The emerging core-task demands were named (see Fig. 3) and concrete examples of ways of acting were identified that concretised each core-task demand. The examples of ways of acting were typically features of good practice

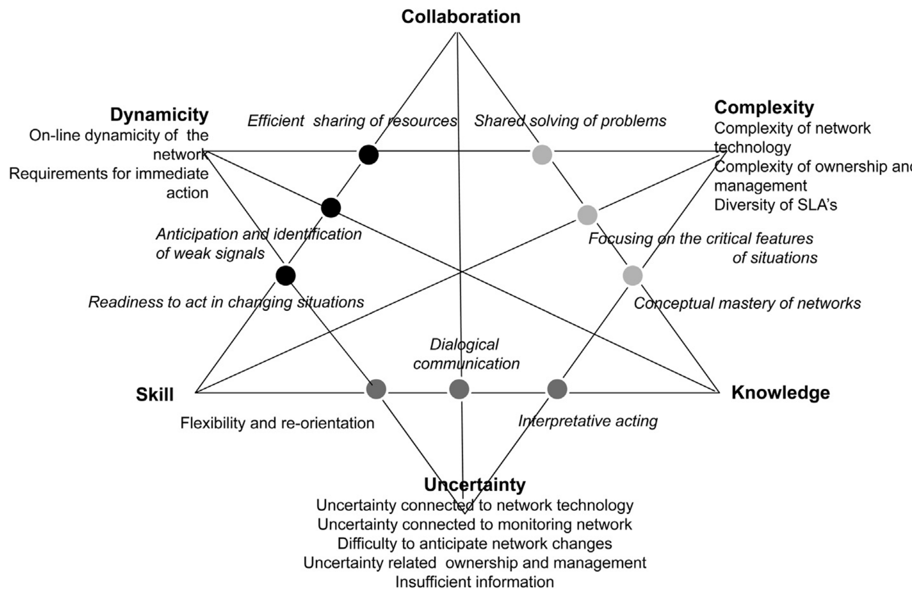

Fig. 3. Core-task demands of on-line management of telecommunication network. The core-task demands (in italics) emerge when resources of skill, knowledge and collaboration are mobilised to tackle (indicated by dots in the figure) dynamicity, uncertainty or complexity demands of the domain (adapted from Norros et al., 2012).

that the communication network operators identified in our interviews (these details are not indicated in Fig. 3).

6.2. Modelling of usage situations: example from nuclear power plant domain

The generic control demands and core-task demands are not sufficient for understanding the particular characteristics of the situations that people actually face in their work. In order to comprehend how these generic demands portray in the concrete situations under study, we developed a modelling technique called Functional Situation Modelling (FSM) (Savioja et al., 2012). Using these is the second function of HFE that we apply. Via FMS we concretise the control and core-task demands and describe how these become evident in the operative situations (scenarios). The models require a great deal of understanding of the context and are always developed together with domain experts. In some studies situations are defined and simulated by high-fidelity research or training simulators. In other cases, when analyses are accomplished in real situations models are created post-hoc.

The models represent the temporal and functional structure of a control task. The generic template of creating the FMS is depicted in Fig. 4 (Savioja et al., 2012). The temporal structure includes main phases of an activity in particular control task (vertical axis in Fig. 4). The horizontal axis portrays the main objectives of the activity. In describing the tasks needed to reach the objectives we exploit a functional abstraction hierarchy approach (Rasmussen, 1986). First we identify the critical functions that need to be maintained to reach the objectives when particular process events have actualised. The functions are broken down into technical and other means and operator actions that could be used to tackle them.

The model does not define a sequence of correct actions, but provides a reference to which the actual observed course of events can be compared in order to understand the meaning of acting. The modelling technique makes evident the connection of the actual constraints and possibilities in the situation with the upper level control functions and objectives of the activity. The eventual analysis exploits the model and focuses on identifying the actors' attention and prioritisations in the situation. Observations and post-action interviews are accomplished, on the basis of which we analyse on which of the possibilities and constraints of the situation the actors focused during their task performance. All this information is used to gain understanding of the logic according to which the actors acted, and what was the meaning of acting.

The modelling tool is explained in more detail in a study, in which a model of a nuclear power plant process control situations is presented. (Savioja et al., 2012).

6.3. Analysis of actual activity: example from medical domain

The analysis of activity is the third function of HFE we apply. It is based on comprehensive empirical data from the field or from simulated real-like situations. Interviews, observations of performance (video recorded), and process tracing interviews (the actors post-hoc accounts of their performance) are collected. All data is used in an analysis that covers two levels: We first reach an understanding of what was each actor's or team's performance sequence and performance outcome. Earlier achieved, or post-hoc defined modelling results, are exploited as reference against which we try to make sense of the data. Then we abstract practices, i.e. meaningful patterns of behaviour in certain situations (Norros, 2004), on the basis of these descriptions. The reason for including the analysis of practices is that such an analysis results in a deeper understanding of the potential, or capability, inherent in peoples' situational acting.

As an analytical tool in abstracting practices we use the semiotic model of habit proposed by Charles Sanders Peirce (Peirce, 1958; Norros, 2004). Using this triadic structure we analyse the environmental cues, or *signs*, in selected episodes, find out what behavioural reactions, i.e. *interpretants*, were released to interpret the meaning of these cues while connecting them with certain *objects* or objectives. In our analyses we have identified, as may be expected on the basis of the Peircean theory, that same cues may be part of semiotic connections of different level of interpretative power, i.e. there may be interpretative, confirmative or reactive responses. These qualifications are drawn from Ch. S. Peirce's ideas of epistemic attitudes that people may take to the environment when facing a state of doubt (Peirce, 1998a,b; Norros, 2004) and they reflect the depth of involving oneself with making sense of the particular situation. Which one of these attributes fits can be

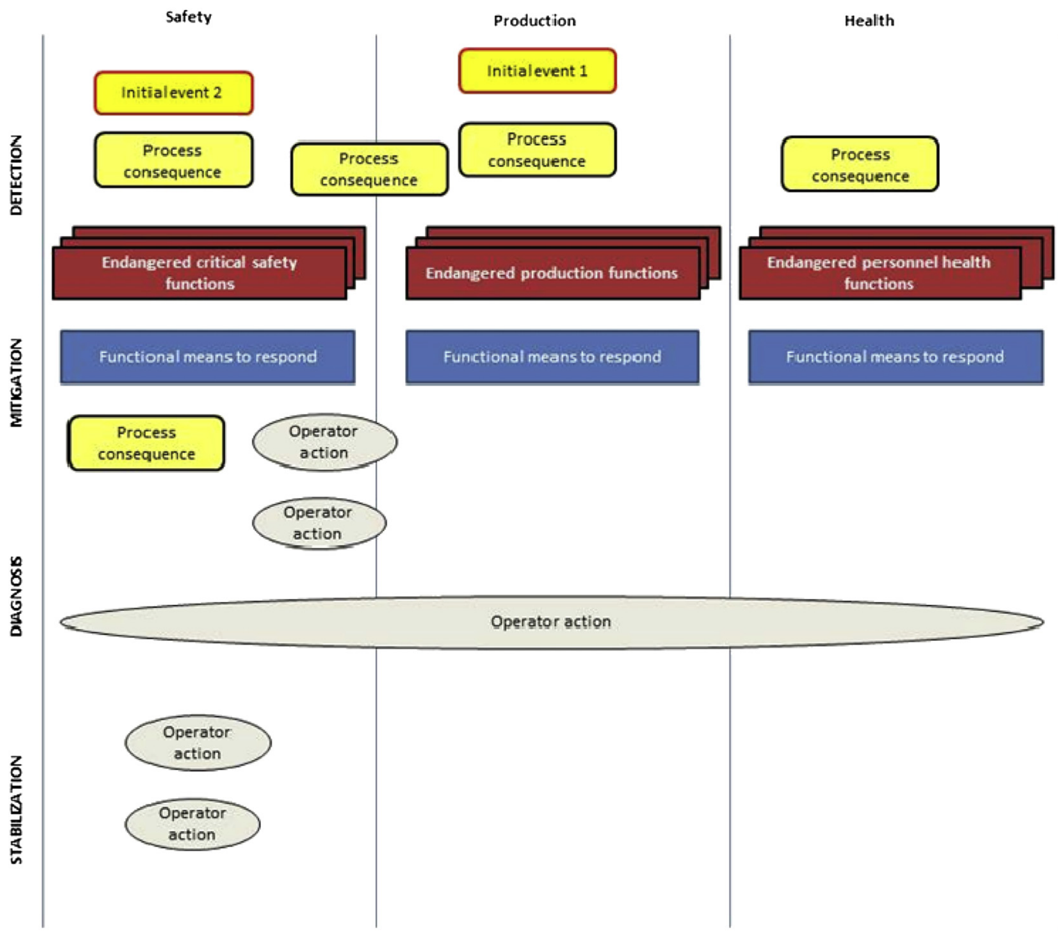

Fig. 4. The basic structure of a Functional Situation Models constructed to serve as reference to understand the meaning of actual actions in real situations. The model combines a temporal structure (vertical) and functional structure (horizontal) of an activity in a situation (Savioja et al., 2012).

identified on the basis of what objectives appeared as operative and which interpretative acts were connected to these objectives.

A first attempt to analysis of practices based on the semiotic model was our study on expert anaesthetists' practices (Klemola, 1998; Norros, 2005). The semiotic habit structure – including the environmental sign, the object it refers to, and the interpretant expressing the connection to an object – is repeated continuously in on-going perception-action cycle between the doctor and the patient in the operating theatre during the anaesthesia process forming and shaping habits. Episodes to be analysed were selected on the basis of our previous modelling of the anaesthesia core-task demands and the generic sequential structure of the anaesthesia process. In the analysis we first developed behavioural markers that would characterise habits portraying different degrees of interpretative attempt with regard to the signs of the patients' states. After formulating the criteria for different habits the entire material was analysed with this tool (more details see Klemola and Norros, 2001; Norros, 2004).

Recently we have accomplished an analysis of nuclear power plant operator crews' practices in a highly proceduralised emergency handling situation. The study was accomplished in a full scope training simulator (Savioja et al., 2013). The approach has also been used to analyse on-line construction of common operational picture among a multi-agent emergency response team (Norros et al., 2009), and in an analysis of the development of a shared understanding of the situation among the metro traffic control team in metro accident exercise (Wahlström et al., 2013).

6.4. Assessment of systems usability: example from nuclear power plant domain

The final function of HFE in our analysis methodology is the assessment of systems usability. The assessment is based on the analysis of the role of technologies in practice. As we have indicated earlier (Section 3) we consider tools to serve three main functions in activity, the instrumental, psychological and communicative function. We have proposed to use these different roles as a basis to define the overall system-oriented quality attribute of a tool (Savioja and Norros, 2012). The assessment of a tool's capability to serve in these functions is measured by behavioural criteria. We use three types of behavioural criteria: First, we apply performance outcome measures, e.g. errors, response time, interruptions, etc. In addition to these measures, we use measures to indicate more generic patterns of behaviour, i.e., habits or practices that tools facilitate. Patterns are identified on the basis of empirical material and are different depending on the context. The basic assumption is that practices reflect responses to core-task demands, examples of which in telecommunication network control was given in Fig. 3. Finally we also apply user experience measures. These are aimed at informing of how promising with regard to the needs and values of the users the tool is experienced to be, e.g. self-confidence, embodiment with the tools, sense of control of the system. A 3 by 3 matrix is formed out of the tool function and behavioural dimensions and 9 different types of evaluation measures for the comprehensive quality of systems usability emerge. Using the criteria we may evaluate which tool functions are fulfilled best, whether the tool supports the pre-defined performance outcome, and whether it also has capabilities in the sense that it would facilitate good practices, and is experienced to provide added value for work in the future.

The exploitation of the systems usability metrics in a comprehensive empirical evaluation of a nuclear power plant control room was recently finalised (Savioja and Norros, 2012). In the study we observed that performance-based criteria were useful to deliver information of the tool's instrumental capabilities. Practice-based and user experience-based measures were particularly valuable in informing of the tools capabilities what regards the psychological and communicative functions. For example we could draw attention to the users' difficulties to exploit the features of the new digital medium, or we discovered clear differences in the exploitation of process information among the teams, etc. The results of the psychological and communicative functions supported judgements concerning the tool's more generic capabilities to be applied by the crew in different situations and, hence, facilitated judgements of resilience in the crews' acting.

The value of systems usability evaluations is that features of actors' behaviour can be connected to features of the used tools. This is an advantage compared to performance-based methods currently used: Specific usability evaluations that make the connection to features of tools are not practicable in the analysis of complex tools in realistic contexts, whereas the comprehensive integrated system validation measures, used typically for final evaluations of complex technological systems, have difficulties to trace the performance outcomes back to specific features of tools.

The advantage of the above described analysis framework is that it enables a coherent systemic analysis of work activity. We are capable of analysing actors' behaviour and use of tools within the generic constraints of the domain and in particular situations. Through the metrics used the methodology aims at predictive results that should be useful for design purposes.

7. Discussion and conclusions

In the beginning of this paper I quoted the HFE strategy paper (Dul et al., 2012) that introduces the high-quality human factors/ergonomics and its qualifications: systems approach, design-driven, and focus on performance and well-being. Drawing on our own experience, it seems that of the three aims the most difficult one to reach in practice is to become design-driven. When approaching this goal the other two goals will have to be tackled, too.

The challenge of developing a design-driven approach is the dilemma of maintaining a scientific orientation in a developmental study, in which specific problems are solved and particular solutions created. It is clear that practical HFE consultancy is required by the industries for evaluation of products or environments, or fixing problems with regard to them. In many cases the services of the consultants are well-focused and they are considered sufficient by the industry. The role of HFE research would be to step in when practical problems are evident but difficult to frame, and for which solutions are not available off the shelf. When offered the possibility to solve difficult problems in operations or design the analytical and methodical strengths of HFE come to use. Systemic approach and concepts would facilitate understanding the domain and identification of the problems, which are typically many-faceted and require diversity of views. The capability to comprehend the problems assumes sensitivity to the particularities of the context, and readiness to acquire knowledge from the domain experts. It is helpful if previous experience of the domain exists but often, in difficult or rare problems, the added value comes from the possibility to transfer experience from other domains.

The second major challenge for HFE to become design-driven is to be future-oriented. Requests to exploit HFE expertise with regard to forward-looking targets and innovative solutions are challenging. A longer perspective assumes that HFE critically reflects how the outcome of design activity should be understood. As we discussed in Section 3 the outcome is not only the product (including performance outcome) but also the new potential for acting and living that is created via design. It is important that the HFE analyses are capable in identifying what are the generic features of the domain, organisations and practices that would provide potential and capability to sustain in variable situations, and develop further. As I have indicated the concepts of resilience, practice and also concept of operations express the intention to identify potential and capability for development.

Required are also methods with which to identify what kind of changes in the present work and technologies people would consider promising for their own and others' future life. It appears that people's experiences, user experience (UX), would need to be emphasised more in the evaluation of not only consumer goods but also complex work systems. The reason is that experience reveals both the potential usefulness and value of technology in an integrated way. Work is still needed to comprehend deeper how experience should be understood as a psychological category to be taken into account in activity analyses.

A further challenge for HFE is its integration in large scale design projects and processes. HFE should be able to define basic control demands of work systems during the early phases of design that will significantly influence the work of future operators of production processes or other work. One example of such a critical control demand may be complexity. Early design decisions, e.g. such that define production technology, or automation solutions, have a major effect on the characteristics of the final operative tasks. If the sources of complexity of operative tasks cannot be defined, problems must be solved via e.g., interface solutions that sometimes still increase the complexity of the whole system.

Beyond the need to provide a special input to the design process HFE could also be helpful in managing the design process. One of the most challenging issues is to support the creative characteristics of the design processes. This process, even if it is iterative in structure, is not a linear process of planning and execution of plans, but rather it is characterised by innovative leaps. And yet, it is important to exercise control where it is reasonable, as for example an appropriate management of design requirements would be. Understanding and management of the design process calls for longitudinal approaches in HFE analyses.

Issues listed above all denote that it would be important for HFE research to collaborate more closely with the design research community that has considerable tradition in conceptualising design activity. More understanding should be gained of design activity and of its inherent characteristics. Attention should also be directed to larger networked technology and to research projects that currently shape the physical, technological, and informational and social structures of the society. Understanding technology as a culture-shaping medium would invite HFE to enter into a dialogue with media research.

In conclusion, I see that human factors/engineering has great potential to act in an active role in the shaping the future living and working environments. To act in this role requires capability for cross-disciplinary work, which should basically be natural for HFE: With psychology as the core discipline, HFE is ontologically diverse. HFE has connections to physiology, neurosciences, social sciences, and technology. HFE already has a long tradition of interplay with these sciences and their practices, and new partners for collaboration can be named, e.g. media research or design research. Creating an own design discipline identity in a multi-voiced collaboration is the key internal challenge for human factors/ergonomics.

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