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How to characterize a research line for user-system interaction

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Abstract

One of the major challenges in the emerging interdisciplinary field of human-computer interaction (HCI) and user-system interaction (USI) is the specification of a research line that can enable the development of validated design relevant knowledge with a predictive power for the design of interactive systems. Based on the three different elements in the design of interactive systems: (1) human being(s), (2) technical artifact(s), and (3) context of use, different disciplines contribute with different research paradigms to this new field: social sciences with a strong empirical and experimental approach, and engineering disciplines with a strong technical and formal approach. This paper presents and discusses a possible way to integrate the strengths of different research and design paradigms.

Introduction

All over the world, several research and development groups contribute to the growing area of human-computer interaction (HCI) and user-system interaction (USI), based on the context in which each group is established (e.g., computing science, electrical engineering, psychology, etc.). The survival of these groups depends on their capabilities to adapt to their environment, and to which extent the whole community can be established as such. In this paper we try to offer a broad view to continue a discussion about the possible scientific future of HCI and USI. We will begin by describing some aspects of how scientific disciplines can evolve, which the relevant phases are, and what the possible requirements are that have to be fulfilled. In the next step we discuss the relevant paradigms and discuss how the different paradigms could be merged into a necessary new one. In the final part of this paper we present a general framework in which interdisciplinary research for HCI and USI may benefit from a structured approach.

Böhme, Van den Daele, Hohlfeld, Krohn and Schäfer (1983) differentiate three phases of development in scientific disciplines: (1) *Explorative phase*: “Methods are predominantly inductive in character, and research is determined by strategies aimed at classification... The dynamics of the field are characterized more by discovery than explanation. The fine structure of the objects of study remains largely unknown, and is handled in a manner closely paralleling cybernetics’ famous ‘black box’. The scientist knows the relevant input and outputs – but what goes on between remains a mystery”. (2) *Paradigmatic phase*: “The onset of the paradigmatic phase is marked by the emergence of a theoretical approach which is able to organize the field. The introduction and elaboration of this approach represents a theoretical development with a definitive end. ... The theoretical dynamic of the paradigmatic phase is evidently one which can come to a conclusion – that is, can lead to mature theories which contain a fundamental, and in certain respects a conclusive, understanding of the discipline’s research object”. (3) *Post-paradigmatic phase*: “Where the organizing theories of scientific disciplines are clearly formulated and comprehensive, the possibilities of revolutionary changes or spectacular generalizations of their basic principles are commensurably reduced. Instead, the dynamics of theoretical development will be determined by the application of paradigmatic theories for the explanation of complex systems which can be subsumed within them" (Böhme *et al.*, 1983, pp. 6-9).

It seems to be obvious that the actual state of affairs for the interdisciplinary field of HCI and USI is in the explorative phase (Myers, 1998, p. 45), maybe being able to move on to the paradigmatic phase in the near future. This statement does not necessarily exclude the possibility that different research communities contributing to HCI and USI are already in a paradigmatic, or even in a post-paradigmatic phase. The main question so far is: how is it possible to improve the maturity of our discipline? To make an answer possible, we have to discuss the following issues: what is a paradigm, and what are the relevant paradigms for our scope of research?

Design paradigms

All over the world, a number of science disciplines (e.g., human-computer interaction, industrial design, engineering, etc.) are struggling with their foundations, even if they are not fully aware of this. Following Kuhn's (1962) model of scientific development, it can be proposed that the inter and multidisciplinary research arena of HCI and USI may be considered an arena of several distinct 'communities' that coalesce around associated paradigms. 'Paradigm' is defined in the Kuhnian sense of a 'disciplinary matrix' that is composed of those (a) shared beliefs, (b) values, (c) models, and (d) exemplars that guide a 'community' of theorists and practitioners (Kuhn, 1962, 1974). In his thesis, Dorst (1997) introduced and discussed the two most influential paradigms: (a) *positivism* for scientific research and (b) *phenomenology* for design (see Figure 1).

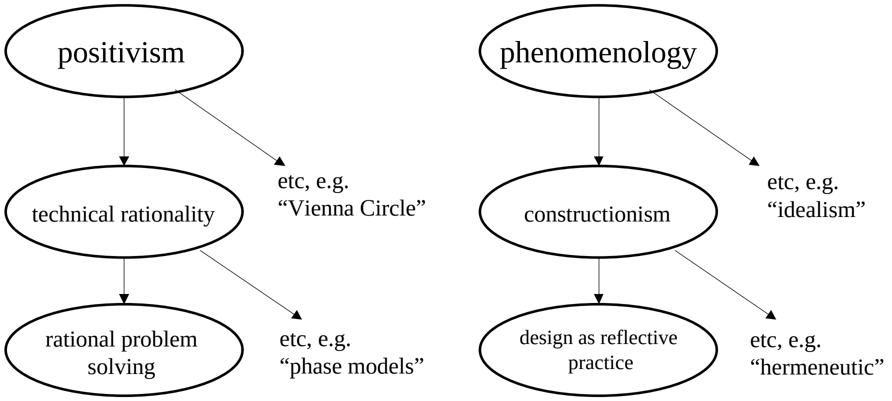

Figure 1: The two different paradigms, 'positivism' for research and 'phenomenology' for design.

Most of the dominant activities in natural and formal sciences can be characterized as a rational problem-solving approach under the 'positivistic paradigm'. This main approach can be described as ... "the search for a solution through a vast maze of possibilities (within the problem space)... Successful problem solving involves searching the maze selectively and reducing it to manageable solutions.” (Simon, 1969). In this paradigm, all knowledge should be described, represented and processed in an ‘objective manner’: independent of an individual and personal knowledge base. Opposite to this position, a personal knowledge base (e.g., ‘craft skill’) is exclusively accessible to the individual him/ herself, even sometimes without the opportunity for conscious reflection about the content (see also Varela, Thompson & Rosch, 1991). In natural sciences most formal descriptions are – sooner or later – validated via empirical observations, experiments or simulation studies (e.g., Monte Carlo method, etc.).

But what can we say about design and engineering activities? To which paradigm do these activities belong? Dorst (1997) characterizes these activities as ‘thrown’ into a design ‘situation’ (‘thrownness’ in German ‘Geworfenheit’, see Heidegger, 1927). Winograd and Flores (1990) illustrate this kind of ‘thrownness’ as follows: “When chairing a meeting, you are in a situation that (I) you cannot avoid acting (doing nothing is also an action); (II) you cannot step back and reflect on your actions; (III) the effects of actions cannot be predicted; (IV) you do not have a stable representation of the situation; (V) every representation you have of the ‘situation’ is an interpretation; (VI) you cannot handle facts neutrally; you are creating the situation you are in” (Winograd & Flores, 1990). The following two main aspects characterize this kind of situation: (1) no opportunity for ‘reflection’ (see (I), (II), and (V)), and (2) no stable and [maybe] predictable reality (see (III), (IV), and (VI)). A design situation based on ‘thrownness’ is a typical context characterized by the latter two main aspects. The designer creates and synthesizes the situation while he/she is acting in. This is our primary motivation for replacing the term ‘phenomenology’ by the term ‘constructivistic’ paradigm from now on, to focus on the constructivistic and synthetic aspects of this paradigm.

Nowadays, the positivistic paradigm seems to be the ultimate characterization for a ‘scientific’ research line. But how can we incorporate ‘design’ as a scientific activity? The first aspect ‘no reflection’ could be overcome by approaches like ‘reflective practise’ as introduced by Schön (1983). Following Schön (1983, p. 129), a “practitioner approaches a practice problem as a unique case. He does not act as though he had no relevant prior experiences; on the contrary. But he attends to the peculiarities of the situation at hand.” The practitioner confronted with a concrete design problem “seeks to discover the particular features of his problematic situation, and from their gradual discovery, designs an intervention” or action (Schön, 1983, p. 129). Schön’s concept of ‘reflection-in-action’ can be applied to a broad range of research activities, in which the scientist is looking for a particular solution for a given set of constraints (e.g., design of an experimental set-up, a formal proof, a research plan, a technical artifact, etc.; see also Reymen, 2001). The implicit nature of all these activities is the synthetic approach, to come up with something concrete as part of reality (‘concrescence’, see Figure 2). The two aspects of scientific activity ‘abstraction’ and ‘concrescence’ are both necessary and also complementary (Guillen, 1995). If this is an appropriate description, why then does science in the positivistic paradigm primarily focus on and praise their ‘abstraction’?

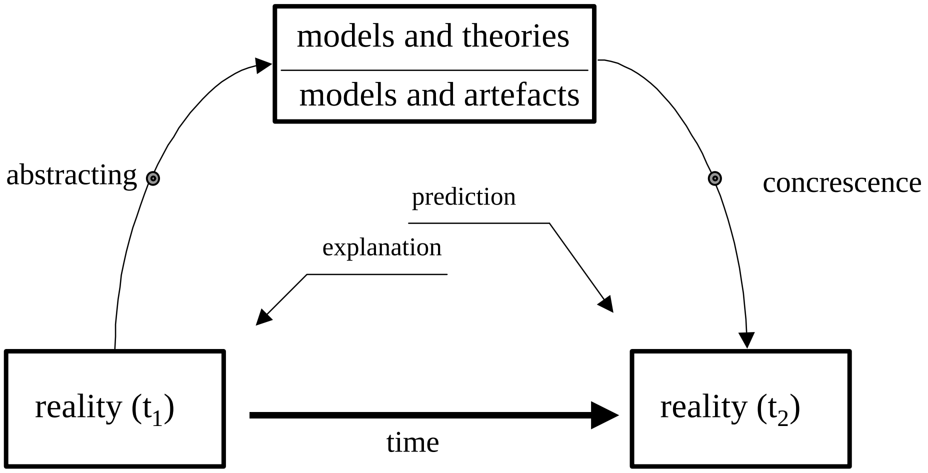

Figure 2: A general schema for the process of ‘scientific’ knowledge development.

Given a reality at time t_1, science in the positivistic paradigm observes and analyses particular phenomena in this reality, makes proper abstractions, and tries to predict similar phenomena for reality at time t_2 (see Figure 2). To preserve a stable reality [reality (t_1) = reality (t_2)], science in the positivistic paradigm has to operate under the following assumption, and this assumption seems to be essential: [{model, theory} $\notin$ reality]. Whatever a theory about, e.g., the phenomenon ‘gravity’, explains and predicts, this theory does not influence or change the phenomenon ‘gravity’ at all. In this sense, models and theories of science in a positivistic paradigm are not part of the investigated and described reality; they are *apart* from this reality. We will use the term ‘reality’ further on to make this distinction clear compared to the broader meaning of the term reality.

The underlying mechanism to guarantee the fulfilment of the assumption is ‘reductionism via abstraction’. Any differences in empirical measurements between t_1 and t_2 are interpreted as just accidental factors (‘noise’), which do not contradict the theory. Only with knowledge, based on theories developed under the positivistic paradigm, the design of a concrete artifact is impossible, because the knowledge in these theories is purified from the changing contextual factors between reality at t_1 and at t_2. This lack of specific knowledge for any concrescence (e.g., ‘craft skills’) gives design and engineering disciplines their right to exist. Dreyfus (1992) and Dreyfus and Dreyfus (1986) stimulated a very important discussion about the importance of ‘intuitive expertise’, complementary to artificial ‘expert systems’ which ‘just’ follow rules.

Activities under the constructivistic paradigm claim to influence the reality and therefore to change this reality via the developed artifacts [reality (t_1) $\neq$ reality (t_2)], and in fact they do. The design and engineering disciplines develop knowledge to make the ‘concretisation’ successfully possible. This knowledge realized in the form of ‘models’ and ‘artifacts’ can be interpreted as part of the reality, and not apart from it [{model, artifact} $\in$ reality]. But how can design and engineering disciplines guarantee a ‘stable reality’? If models and artifacts are seen as part of the reality, i.e., as a subset of the reality under consideration, then any action, which changes this subset, changes the whole set (reality) as well. So, engineering disciplines cannot guarantee a stable reality, and they do not want to (Klemm, 1970).

Up to now, the main conclusion is that knowledge developed in the positivistic paradigm and knowledge developed in the constructivistic paradigm is different. If the schema in Figure 2 describes the whole process to develop knowledge, independent of a given paradigm, then the positivistic and the constructivistic knowledge can be seen as two subsets of a superset of knowledge: [{model, theory} ∪ {model, artifact} ≡ {model, theory, artifact}]. In this sense we can describe them as *complementary* (Pylyshyn, 1991; see also the discussion of Greif, 1991, pp. 212-214).

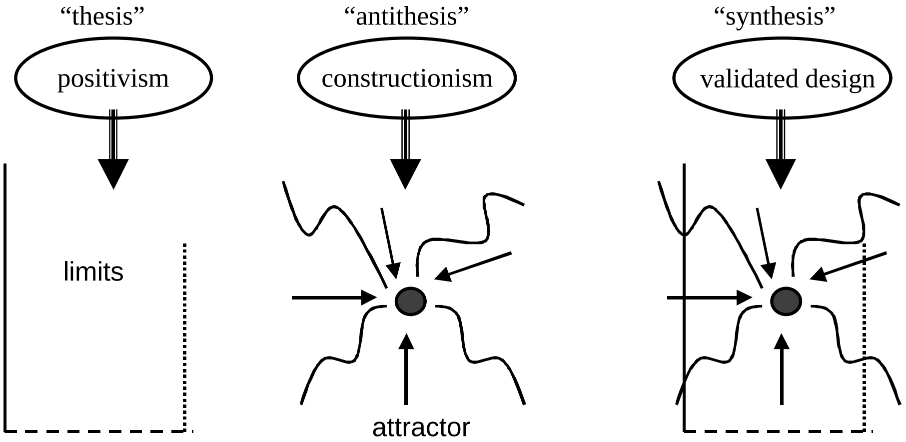

Figure 3: The two different kinds of design relevant knowledge provided by the positivistic ('thesis') and the constructivistic ('antithesis') paradigm, and the possible integration ('synthesis').

The most practical value of the 'positivistic' knowledge is the specification of limits and boundaries under which the 'constructivistic' knowledge has to operate (see left part "thesis" of Figure 3). For example, the actual state-of-the-art theory in thermodynamic explains and predicts that the design of a 'perpetuum mobile' is not feasible; therefore any attempt to design such a kind of system is unrealistic (Guillen, 1995). The challenge in combining both kinds of knowledge is creating artifacts ('attractors' as singularities, see middle part "antithesis" of Figure 3), which fall *inside* the constrained design space (see right part "synthesis" of Figure 3), provided by 'positivistic' knowledge. This kind of 'validated design' is quite challenging, because the designer has to take all relevant constraints and limits into account. This consequence usually is the main reason for designers to reject this position. But still, how can a scientifically sound *research* line be characterized that includes design-related activities? Let us have a closer look at already existing 'design-related' activities inside different scientific disciplines.

First, we will shortly describe and characterize the most well-established disciplines (following Sarris, 1990; see Table 1). Disciplines such as physics, chemistry, etc. present themselves as 'natural sciences'. Theory development takes place in a strictly formal manner with a rigorous experimental validation practice. Truth is based on the conformity of empirical observations with the 'reality'. The most important basis for conclusions is 'inductive logic'. Scientific disciplines like mathematics present themselves as 'formal sciences'. Truth is based on logical consistency. The most important basis for conclusions is 'deductive logic'. On the other hand, humane disciplines can be classified as 'ideal sciences'. Truth is based on 'belief':

hermeneutic evidence grounded in intuition! The most important basis for conclusions is a 'value system' based on an individual knowl-edge base.

Table 1: Overview of different disciplines in relation to 'abstraction' and 'concrescence' components.

	abstraction	**concrescence**	**examples**
Natural science	Strong, explicit	Moderate, implicit	Physics, chemistry
Formal science	Strong, explicit	Strong, implicit	Mathematics
Ideal science	Strong, explicit	Moderate, implicit	Philosophy
Applied science	Moderate, implicit	Strong, explicit	[industrial] design

How is it possible that sciences based on a positivistic paradigm claim and present themselves as 'true' scientific disciplines (compared to the rest), even if they include (and need) constructivistic and synthetic components as well? One possible explanation is the important asymmetry between both kinds of knowledge: 'positivistic' knowledge claims a more fundamental status than 'constructivistic' knowledge. 'Positivistic' knowledge has a stable predictive and explanatory power over time (see Figure 2; based on the underlying idea of 'absolute truth'), because it is particularly designed for this purpose. But this approach pays the price of not being able to reach reality: to explain and predict, but not to touch and change 'reality'. In the rest of this paper, we will develop an outline for research in the field of USI, which tries to take the considerations of this section into account.

What is USI about?

Different fields contribute to user-system interaction (USI): HCI, man-machine interaction (MMI), human factors (HF), cognitive sciences (CS), and cognitive ergonomics (CE). Most of the relevant aspects discussed in this paper are important for USI, MMI and HCI. USI claims the broadest range of research activities including MMI and HCI. In the context of this paper we define the field of USI as follows: USI is a discipline concerned with the design, evaluation and implementation of interactive systems for human use and with the study of major phenomena surrounding them. Furthermore, we define an interactive system as a work system {WS} := [{U}, {S} with ICT[1] component(s), other components]. Following Dowell and Long (1989) we distinguish between a work system {WS} and a [work] domain {WD}, and the relation between these two components (see Figure 4). The major goal for USI to become an engineering discipline is "the design of behaviours constituting a work system" {WS} "whose actual performance (PA) conforms with some desired performance (PD)" (Dowell & Long, 1989, p. 1522).

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[1] ICT = Information and Communication Technology.

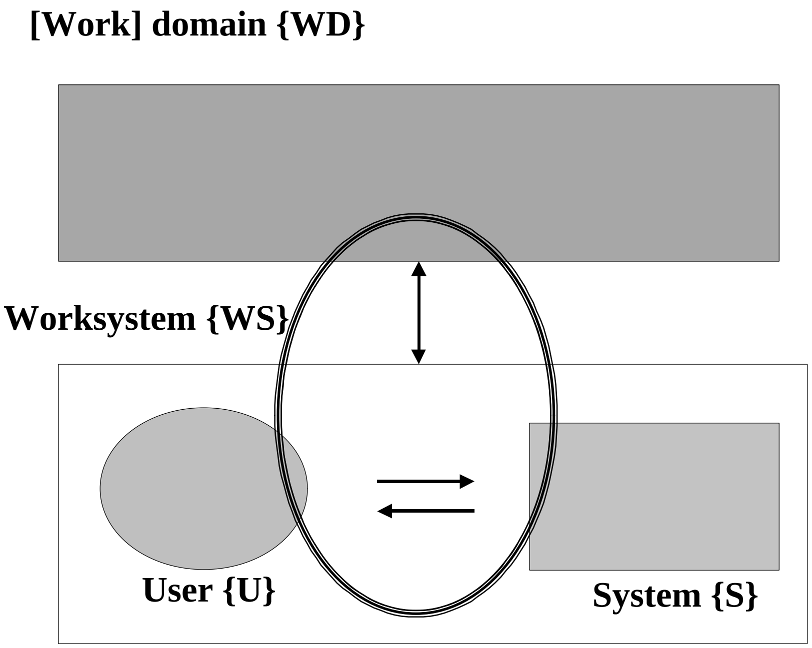

Figure 4: The distinction between the interactive work system {WS} and the work domain {WD}.

The relationship between the work system and the [work] domain has to be investigated in the context of task and domain analysis related activities (e.g., Ehn, 1988; Waern, 1989; Lim & Long, 1994; Paternò, 1999). One of the main issues in the relation {WS}↔{WD} is the man-machine function allocation problem (Kantowitz & Sorkin, 1987). A system {S} for a real-world application domain {WD} can only be developed taking {WS}↔{WD} into account: {S}│{WS}↔{WD} (see also Bannon & Bødker, 1991).

Developing a work system without taking a [work] domain into account is risky, because later there is no guarantee that the designed work system can contribute to achieve the desired performance of the whole system. On the other hand, without technology push, the technical option space for solving real world interactive problems would be seriously constrained (e.g., the visionary device of Vennevar Bush called MEMEX, see Bush, 1945; Baecker & Buxton, 1987, pp. 41-42).

So far, the main conclusion is the need to investigate the relationship between 'push -based' developed technology and the requirements coming from existing or planned work domains. Which type of interaction technique is appropriate for which type of task and work domain? However, how can we develop interaction techniques without having a possible interactive task in mind? One possible answer is the development of 'generic' interaction techniques, which should be applicable to 'any' task type ('generic' in the sense of 'work-domain independent'). Is the 'mouse' for example really a generic interaction technique (see the empirical results in Rauterberg, Mauch & Stebler, 1996). On a more general level, what kind of research line has to be established to gain valid answers to this kind of research questions.

Work system

The two major sub-elements of the work system are of a completely different nature: (1) the human being can be described in terms of perceptual, cognitive, acting, and emotional capabilities and limitations (user {U}); (2) the system (a technical artifact) has to be described in processing power, system architecture, input/output relations, functionality, material properties, etc. (system {S}; see Figure 5). Green, Davies and Gilmore (1996) differentiate between three different views: (1) psychological view, (2) systems view (focus on artifact), and (3) interactive view. We follow this classification: (1) design knowledge related to the *user* {U}, (2) design knowledge related to the *system* {S}, and (3) design knowledge related to the *interaction space* {IS} (Barnard & Harrison, 1992; see Figure 5).

Attempts to integrate the two ‘worlds’ of the user and of the system have a long tradition and it still is the most important challenge (see Green *et al.*, 1996; Nickerson & Landauer, 1997). If we conceptualize the field USI as an engineering discipline, we have to translate research results from social and cognitive sciences into technical dimensions that can be directly applied for solving design issues for interactive systems (e.g., Rauterberg, 1995; Janssen, 1999; De Haan, 2000; etc.). This kind of ‘translation’ could be a valuable but challenging goal for the whole USI research field.

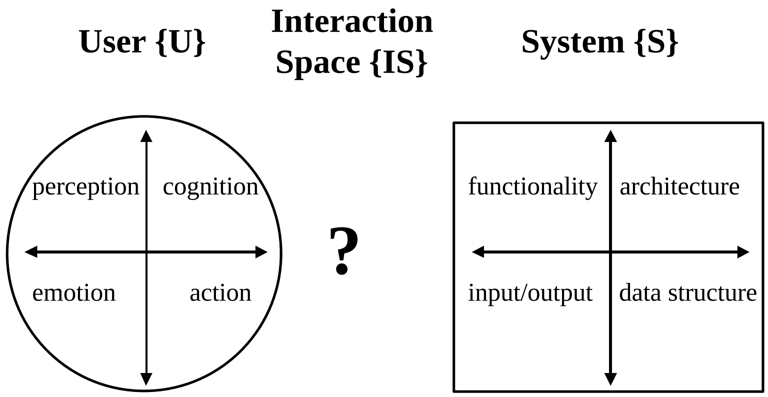

Figure 5: The different natures to be investigated and described {U}, {S} and {IS}.

Even today, one of the dominant USI research lines has focussed on the design of the interface of the interactive system, but as a matter of fact, ‘interface designers’ design the ‘interaction space’ {IS} between the user and the system (see Figure 5). This view has a strong impact on the theoretical foundations of USI in the future: describing user-system interaction as a dynamic relation $\{IS\} := f[\{U\}\leftrightarrow\{S\}]_t$ taking the relation $\{WS\}\leftrightarrow\{WD\}$ into account. The ‘interaction framework’ of Bernard and Harrison (1992) is a first attempt in this direction. Any kind of ‘inter-action’ has at least one essential component: the *synthetic* part, to end in something concrete (‘concrescence’, see Figure 2).

Two different approaches to investigate the user can be distinguished: (approach-1) to treat a user as a human being (e.g., the view of biology, psychophysics, experimental psychology, etc.), and (approach-2) to treat a user in a particular context of use (e.g., design, marketing, manufacturer, etc.). Approach-1 looks at a user without taking the relation $\{WS\}\leftrightarrow\{WD\}$ into account; but this description is not completely correct. The human being is investigated in his/her ‘natural’ environment, which can be described in physical terms. So, one could interpret {WD} as the whole world, specified and described beyond any cultural, political, economical, and social constraints (the pure physical view to nature). Approach-2 tries to incorporate the relationship {WS}↔{WD} in a more specific manner: {WD} as a concrete (inter)action space with all related semantics regarding cultural, political, economical, and/or social dimensions (see Neisser, 1976; Suchman, 1987; Dowell & Long, 1989). To connect approach-2 with approach-1, we are looking for a theoretical foundation of human activities that can take explicitly contextual boundaries into account (e.g., 'activity theory', see Hacker, 1985; Greif, 1991; Kuutti, 1996).

Green *et al.* (1996) discuss in detail the pros and cons of trying to connect these two approaches. They describe three lines of possible development: "Two of these lines are ventures in developing representations of interactive situations which apply equally to both partners, the person and the system. The third line is even less theoretically ambitious, seeking only to crystallize and expose concepts which many users (even if not HCI workers) already recognize, but which have not yet been presented in an organized way" (Green *et al.*, 1996, p. 109).

Work domain

For all design projects, which have to develop a fully-fledged product for a particular market segment, we cannot avoid seriously investigating the domain in which the product has to survive. The domain can cover a broad range of social activities. Following Dowell and Long (1989, p. 1524) "a domain of application can be conceptualized as: 'a class of affordance of a class of objects'. Accordingly, an object may be associated with a number of domains of application ('domains')".

Following Nardi (1996) three main approaches to investigate a user in a task context can be distinguished: (1) situated actions (Suchman, 1987; Lave, 1988), (2) distributed cognition (Flor & Hutchins, 1991), and (3) activity theory (Leont'ev, 1974). Nardi (1996, p. 96) concludes: "Activity theory seems to be the richest framework for studies of context in its comprehensiveness and engagement with difficult issues of consciousness, intentionality, and history". With a concerted effort by scientists contributing to the USI field to develop a systematic conceptual framework (the work domain as a well specified context for human activities), much progress could be made.

Last, but not least, a very practical argument has to be discussed: the argument that a 'task context' cannot be excluded from a research line to acquire design knowledge for interactive systems. Any kind of a human action can be described and interpreted as a task and/or problem-solving activity (Kuutti, 1996). If for example in a laboratory setting, as an example for a very artificial context, we investigate human (re)actions to a controlled environment, then – whatever this test subject is doing – his or her (re)actions cannot be interpreted without taking the concrete 'task' context into account (the intended part of the design of the experimental setting: the independent variables/factors). The main critique against experimental settings is the unclear relation between an artificial experimental setting and natural task contexts (the 'ecological validity' discussion; see Neisser, 1976; Lave, 1988). But nevertheless, if we follow a research line in which we try to exclude a work domain (in the sense of Dowell & Long, 1989), we will not be able to exclude a 'task context' in this very general sense. In the following section 'the user's validation cycle' we will come back to this issue.

How to get a scientific language?

Kuhn (1959) differentiated between two phases in the development of a scientific discipline: before and after reaching consensus. Reaching a consensus phase can take a long time (e.g., between decades up to centuries). The consensus phase is, e.g., characterized by a common content in different textbooks providing successful exemplars from which students can learn. Green *et al*. (1996, p. 99) stated very clearly that the aim of establishing a common research line for USI “is only feasible if a ‘common language’ can be developed, in which relevant aspects of both the person and the system can be expressed”.

What is a scientific language?

A coherent and powerful technical language based on consensus is a necessary pre-condition for any progress in USI (Kuhn, 1959). Up until now, the HCI community has had no well-established corpus of descriptors. For example, the important concept ‘interaction style’ introduced by Shneiderman (1987) is translated into ‘dialogue style’ by Mayhew (1992) and into ‘dialogue technique’ by Cakir and Dzida (1997), referring to ISO 9241. Neither term ‘interaction style’ and ‘dialogue style’ can be found in the keyword index of Fox (1990) or Helander, Landauer and Prabhu (1997). Baecker and Buxton (1987, p. 427) distinguish between nine major categories of ‘interactive style’: (1) command line, (2) programming language, (3) natural language, (4) menu, (5) form filling, (6) iconic, (7) window, (8) direct manipulation, and (9) graphical interaction. They conclude that “more effort needs to be expended on developing a taxonomy of the content of human-computer interaction” (Baecker & Buxton, 1987, p. 434).

De Vet and De Ruyter (1996) developed a “concept of interaction styles” that decomposes an interaction style in three components: (1) conceptual operations, (2) interaction structure, and (3) interaction techniques. “An *interaction style* is thus defined as the execution of a conceptual operation within an interaction structure using an interaction technique” (De Vet & De Ruyter, 1996, p. 8). Rauterberg and Szabo (1995) made a small constructive attempt to conceptualize and compare different perceptual effects (e.g., visual and auditory modality on the human side) with different technical options to produce particular perceptual impressions. To be able to compare the published empirical results with the strength and weakness of different technologies, a special notation language was developed (Rauterberg & Szabo, 1995). Only with such a kind of notation language, the results of published experiments can be compared and discussed to achieve valuable conclusions for further improvements.

How to get consensus

Habermans (1981) differentiates four types of speech acts: (1) ‘communicativa’ imply the freedom for an expressed opinion itself and the freedom to express one’s own opinion (everyone is allowed to take part in a communication); (2) ‘representativa’ imply the semantics of the expressed statement and the possible subjective bias in it; (3) ‘constitutiva’ cover the objective truth in the statement; and (4) ‘regulativa’ enable the expression of normative aspects. Agreement, according to Habermas, can be reached via truthful expressions in a power-free communication (in German ‘machtfreier Diskurs’). A ‘truthful’ expression in a speech act is characterized by all involved parties to be able to give a potential agreement, based on their rational reason. ‘Rational reason’ is defined as knowledge about a possible way to justify the ‘truth’ in an objective manner, during the speech act itself ('veracity') and beyond in daily practice ('credibility'). To achieve consensus, it seems to be important that all involved parties share and accept a similar way to *describe* and to *justify* the 'truth'. At a minimum this means having consensus about a *validation* methodology. In the following sections several cycles for establishing validation into a USI research line (on different levels) are described and discussed.

Coherent research line

This section discusses most relevant aspects of a possible research line for USI on a high conceptual level. Inspired by the maturity model of Humphrey (1990), we try to introduce a similar view to start with. The major steps a new discipline might go through successfully to become mature are (1) initial phase, (2) repeatable design processes, (3) defined research line, (4) managed research activities, and (5) optimized theory development (for an extended discussion see Popper, 1963; Lakatos, 1978). At the top level (5) a cyclic structure for self-optimizing theory development should be established at least.

To combine the analytical strength of empirical validation methods (e.g., observation, experiment, inquiry, etc.) with the synthetic strength of system design, we suggest the triangle structure presented in Figure 6. This triangle structure conceptualizes the three most important components of USI research: (1) the collection of 'design relevant knowledge', (2) the 'interactive system' {S}$\vert${WS}↔{WD} in different possible representation forms, and (3) the several possibilities to represent a 'user' {U} for [empirical] validation. This triangle structure (Figure 6) is similar to the circular model of Henderson (1991) in which the following steps are differentiated: (1) design ("creating improvements in the activity"); (2) implementation ("bringing the designs to life"); (3) use ("people's work that is to be improved"); (4) observation ("encountering and capturing the activity"); and (5) analysis ("understanding the regularities in the activity") (Henderson, 1991, p. 262).

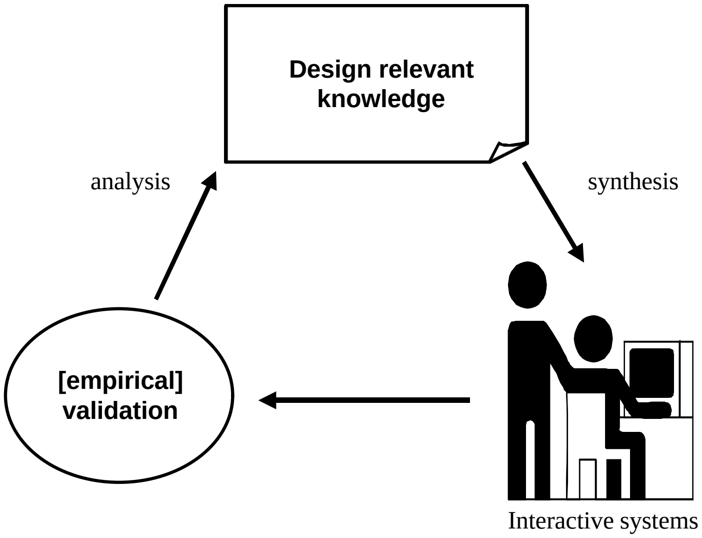

Figure 6: Triangle structure for a research approach with a rigorous validation component.

The development and collection of 'design relevant knowledge' is the primary goal for the whole research line. This validated knowledge with high predictive power should be formulated in design theories based on high-level design principles (e.g., Gram & Cockton, 1996), medium-level guidelines (e.g., Mayhew, 1992), and low-level implementation techniques (e.g., 'design pattern' according to Gamma, Helm, Johnson & Vlissides, 1995). The predictive power enables the design expert to apply this knowledge to a concrete system design with guaranteed outcome of the interactive nature in line with the requirements. In the most powerful form this design relevant knowledge enables the designer to 'calculate' the intended system characteristics in advance (Klemm, 1970). All design relevant knowledge can be given away in the form of design theories, written down in books and articles, shown in videos, taught in education and training, etc., and sometimes demonstrated in the form of concrete artifacts as well (Carroll & Kellogg, 1989). To be able to validate this knowledge with *empirical* research methods, the abstract design principle for a particular type of 'design class' has to be instantiated via concrete artifacts $\{S\}_1\{S\}_n$. We will briefly discuss two success stories for concrete artifacts.

Example-1: One of the most influential inventions for modern user interface concepts of computer systems is the 'mouse' device (Smith, Irby, Kimball & Verplank, 1982). The inventor Engelbart and his colleagues validated this 'new' interaction device in an empirical manner (English, Engelbart & Berman, 1967; Card, English & Burr, 1978). Up until now, the mouse seems to be the fastest interaction device in human-computer interaction (Rauterberg, Mauch & Stebler, 1996).

Example-2: Barnard (1991) and Landauer (1991) describe and discuss another good example of this kind of empirically validated success stories, the Superbook project at Bellcore's cognitive science group. In the domain of textual information access, the Superbook project could be successfully finalized, showing that the developed text retrieval and browsing system was able to outperform ordinary paper and print books (Landauer, 1991, pp. 69-71). This success could be achieved by integrating theoretical work, empirical investigations, applying principles and methods, building prototypes, and finally the system. Landauer (1991, pp. 69-70) believes "that the two essential ingredients for success were (1) a good analysis of what people needed to achieve their goals that prior technology did not provide well enough (rich indexing with good disambiguation, good contextual and organization support for orientation and navigation), and (2) iterative formative evaluation of designs to remove the flaws and improve the flows (better interaction protocol, controls, dialogue, screen design, code.) Received cognitive theory found only a very minor role". This statement does not necessarily imply that cognitive science cannot contribute to good design, but so far, cognitive science has not shown this promising potential. The influential book of Card, Moran and Newell (1983) was a first attempt to relate results of cognitive psychology to system design.

Applying 'design relevant knowledge' to conceptualize, to develop, and to build concrete interactive systems {S}, several 'structured methods' can be used (e.g., Lim & Long, 1994; Paternò, 1999). Doing the 'synthesis' in a purely ad hoc manner increases the development costs and decreases the chance for necessary improvements. Nevertheless, the synthetic step is mainly based on implicit and tacit knowledge ('intuition', 'craft skill', etc.; see Berry & Dienes, 1993; Underwood, 1996). This kind of knowledge has to be developed in the context of a phenomenological and constructivistic paradigm via intensive training and practical exercises (Merleau-Ponty, 1945). One major consequence for the aim of this paper is the incorporation of synthetic activities (‘concrescence’ in Figure 2; ‘synthesis’ in Figure 6) in the whole research line, as equally important as ‘abstracting’ and ‘analysis’ (see Figure 2 and Figure 6).

A serious, but frequent mistake, is the confusion between ‘creativity based on need ideas’ and ‘creative problem solving’. A solution, based on creative problem solving, has to fulfil the following two criteria: (1) it has to be a *new* solution compared to the state-of-the-art, and (2) it has to be a solution for a specified problem (see Weisberg, 1986; for further discussion see Rothenberg, 1979). Without a clear problem specification beforehand, a candidate for a possible ‘improvement’ seems to be very hard to evaluate and, therefore, progress in design-oriented scientific research can probably be neither guaranteed nor achieved.

Industrial relationship

Up to now, the whole research field of USI has primarily been industry driven. “The human-computer interface is critical to the success of products in the market place...” (Myers, Hollan & Cruz *et al.*, 1996, p. 794). ICT companies have a growing need for ICT professionals with an increasing expertise in USI. What industry is looking for are highly skilled ‘interaction designers’ who can contribute to commercial success. It is a plausible, but still unproven assumption, that ‘usability’ immediately contributes to commercial success (see Figure 7). Bias and Meyhew (1994) present and discuss several projects in which a cost-justifying usability approach was successfully applied. They collected and discussed a couple of ‘cost-justifying’ arguments to convince project managers in indus-try to invest in usability engineering activities.

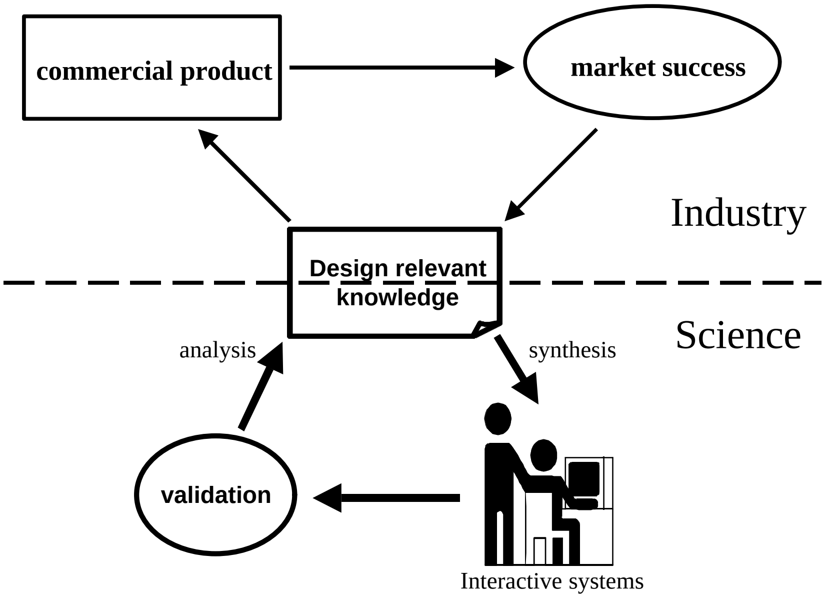

Figure 7: Relation between the scientific validation cycle and the commercial validation cycle.

Given the high pressure and urgent demands from industry, the whole USI field offers and delivers primarily ‘usability engineering methods’, instead of validated design relevant knowledge via highly skilled ‘interaction design’ experts. ‘Discount usability’ and ‘usability testing’ seems to be an outsourcing strategy for selling scientific validation methodology, instead of developing and delivering the desired design-relevant knowledge. This statement is clearly over-critical, but it points to the core of the problem. So far, books contain a lot of relevant, design-related hints and tips (e.g., Tognazzini, 1992), sometimes called guidelines (e.g., Mayhew, 1992) or even design principles (e.g., Gram & Cockton, 1996). But, what still is missing is a basis for a coherent design theory that contains sufficient empirically validated knowledge (Winograd, 1996). As Gaines (1999, p. 19) points out, "I will conclude that we are still at a very early stage in the development of HCI, that the major impact of the technology on society is yet to come, and that to understand the design issues involved we will need much greater overt understanding...".

'System' validation cycle
One of the open questions is the appropriate substitute of a 'real system' with 'something' else that is much faster to create, but still keeps the most relevant features for further validation. Hix and Hartson (1993) emphasize a two-step approach: (1) conceptual design and (2) [initial] scenario design. "*Conceptual design* is higher level and has to do with synthesizing objects and operations. *Detailed design* has to do with activities such as determining the wording of messages, labels, and menu choices, as well as the appearance of objects on the screen, navigation among screens, and much more" (Hix & Hartson, 1993, p. 132). A scenario design can be worked out in the form of a set of screens, story boards, or even video clips (Carroll, Kellogg & Rosson, 1991).

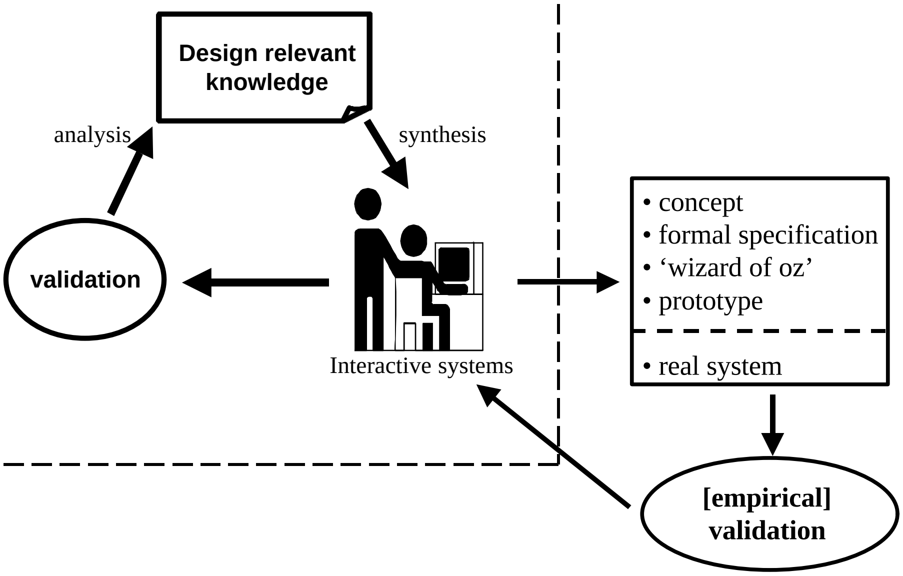

Figure 8: System validation cycle with different possibilities to substitute a 'real' system {S} with a 'cheaper' replacement.

Particular research questions can only be investigated if a complete interactive system is available. Fortunately, a lot of relevant questions can be answered with 'lighter' substitutes than the real system (e.g., prototype, 'Wizard of Oz' simulation, formal specification, concept; see Figure 8). However, these substitutes can only replace the real system if they are – in general – fully validated beforehand, and all their methodological constraints are well investigated and known. If we have to rely on 'cheap' replacements or 'light' substitutes, then we have to make sure that the results gathered with these substitutes are not biased, at least not *uncontrolled* biased with the chance for proper corrections afterwards. Very little has been done so far, to validate these substitutes compared to real systems (e.g., Boehm, Gray & Seewaldt, 1981). This issue seems to be a very important, but highly underestimated, research contribution (see Long, 1997; Middlemass, Stork & Long, 1999). This research contribution will lead to a properly validated design methodology (e.g., Lim & Long, 1994).

'User' validation cycle

Up until now, the USI research arena has demonstrated a strong eclecticism in its approach to methodology. Methods from psychology and social sciences have been adopted to solve some of the immediate problems without taking into account the ontological consequences. Books and articles about a particular 'USI methodology' give an introduction and overview about possible methodological adaptations (Sackman, 1970; Monk, 1984; Kirakowski & Corbett, 1990; Landauer, 1997).

The preference for empirical validation methods (compared to formal validation methods) is based on the fact that user's behaviour, confronted with a new {S}, is very difficult to predict. If a 'user' substitute (e.g., user model, user simulation, etc.; see Figure 9) instead of a representative set of real end users is used for validation, these substitutes have to be validated beforehand as well. These validated 'user' dummies could be delivered by the following research disciplines: cognitive modelling (Taatgen & Aasman, 2000), human factors (Turner, Szwillus, Czerwinski & Paternò, 2000), artificial intelligence (Levesque, 2001) and robotics (Kamejima, 2000). Research in this direction led to tools like HOMER (Davies, 1998), or IMPRINT (Allender, Salvi & Promisel, 1998).

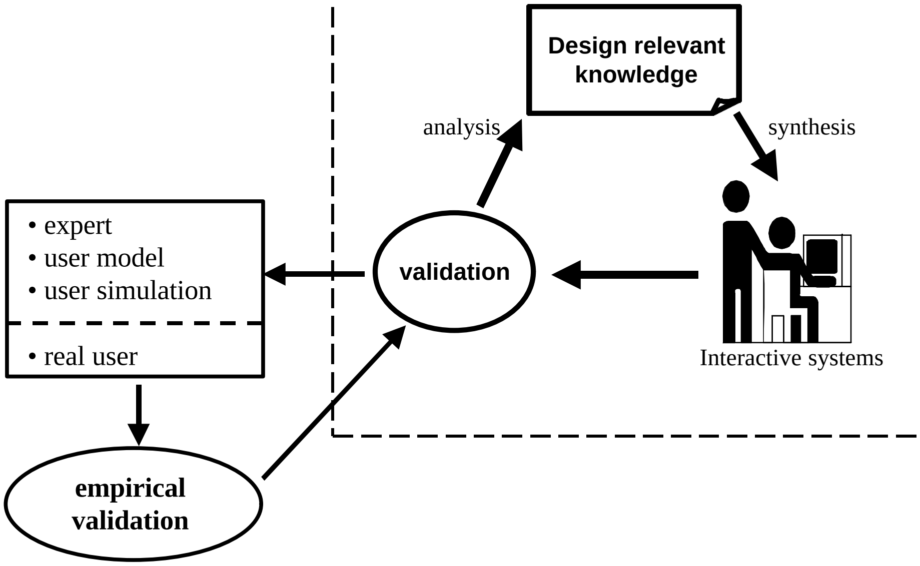

Figure 9: Empirical validation cycle for different possibilities to substitute real users with 'user' dummies.

We entirely agree with Landauer (1997, p. 204) that the professional use "of good research methods is a pressing and immediate practical concern, not just a step toward a firmer scientific base." Monk (1987) differentiates between the following four polarities: (1) 'naturalistic observation' versus 'rigorous experiments', (2) 'field' versus 'laboratory research', (3) 'scientist as participants' versus 'scientist as observer', and (4) 'few' versus 'many test subjects'. One important point he makes, is "the importance of developing *predictive models and theories* which can suggest and explain empirical results" (Monk 1987, p. 136). Only with a rigorous validation methodology will the development of design relevant knowledge lead to stable theories with sufficient predictive power for the design of new interactive systems. These theories will enable interaction designers to 'calculate' the intended system characteristics beforehand.

Conclusions

Evaluating the role of theory in USI (and taking design seriously) means evaluating the usefulness and usability of applying a theory to artifact design. "A deeper understanding of how representations are created and how they contribute to the solution of problems will become an essential component in the future theory of design" (Simon, 1969, p. 78). Today, what does USI really need to have a serious chance of becoming an established engineering discipline? In addition to Long (1999), here are some very basic answers:

- A new theoretical focus to investigate the interaction space {IS} based on specified problems (see Figure 5):
  The interaction space between a human and a technical artifact is difficult to conceptualize, and it is difficult to find the proper set of parameters. On the one hand, we have to deal with the human being, primarily described and specified in qualitative dimensions, and on the other, we have to design a technical artifact, described and specified with quantitative parameters.
- A coherent taxonomy with a powerful corpus of descriptors and technical terminology:
  To develop a coherent taxonomy includes the development of a coherent theory as well. A scientific terminology without a theoretical context is neither possible nor desirable.
- A rigorous validation method to prove the design relevant knowledge to achieve progress (see Figure 6):
  If the scientific community of USI could agree upon an objective and rigorous manner of validation, the 'wild' growth of not validated statements could converge to a couple of stable theoretical nuclei. One necessary pre-condition seems to be the specification of 'relevant' problems in relation with the state of the art (documented via publications, but for technical artifacts mainly via patents).

The needs of USI are growing as the power and complexity of interactive systems continue to grow, and "we will be unwise to neglect any approach to meeting them" (Lewis, 1991, p. 160). If the USI research area wants to survive as a scientific discipline in the future, at least three conditions have to be fulfilled (to move from the *explorative* to the *paradigmatic phase*):

- The specification of all relevant elements ('research objects'; including 'problem definitions').
- The development of a coherent scientific language (for achieving

'consensus').

- Founding a research line to develop design relevant knowledge in a validated manner with predictive power.

"A number of dramatic human-computer interaction design successes, ..., have already occurred as a direct result of systematic research – as contrasted with intelligent creativity alone" (Landauer, 1997, p. 224). On the one hand 'systematic research' and on the other 'intelligent creativity alone' seems to be *contradictory*, but we have argued that they are *complementary*. Historically speaking, USI research and development has been 'spectacularly' successful, and has indeed fundamentally changed interactive computing (Myers, Hollan & Cruz *et al.*, 1996). It is important to appreciate that decades of research are involved in creating and making interactive technologies ready for widespread use. Using methods researched and validated in other scientific fields allows USI to move quickly to robust, valid results that are applicable to the more applied area of design. Let us summarize the two major messages of this paper: (1) from art to science, and (2) from evaluation to calculation.

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