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SPECIAL ISSUE ON END OF COGNITION?

Phil Turner, Guest Editor

Pertti Saariluoma. Editor-in-Chief

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From the Editor in Chief

DESIGNS, SYSTEMS, SCAPEGOATS, AND BUSINESS CULTURES

Pertti Saariluoma
Cognitive Science, Department of Computer Science and Information Systems
University of Jyväskylä, Finland

In November 2007, an event happened in Nokia that threatened the health of thousands of people. Now the Nokia in this story is not the world-known telecommunications corporation, but rather the little city that shares its name: a city in southwestern Finland from which a large rubber company operating there named itself. A century later, that company made a strategic shift in its product focus, and expanded its operations beyond the little city and even outside of Finland. To my knowledge, the Nokia company no longer has factories or offices in the city of Nokia, but this story about the city of Nokia remains an important lesson in human-technology interaction.

The municipal water system in the city of Nokia is designed in such a way that a valve separates the waste water lines from the pure drinking water lines. The purpose of the valve is to allow occasional flushing of the waste water lines (Wikipedia, 2008). The water department employees do not have much use for this valve, which remains undisturbed for years on end. Nevertheless, in November 2007, the unthinkable happened when an employee opened the valve to flush the lines but, because of some glitch, allowed semi-treated waste effluent into the drinking water supply ("Nokia Water Crisis Eases," 2007). Perhaps a thousand residents were sickened by the bacteria- and virus-contaminated water ("A thousand Nokia residents sickened," 2007) and a handful of deaths were investigated ("Investigation underway," 2007; YLE News, 2008).

What is strange about this water system is that the valve was not clearly marked, nor was it locked. When the water system was designed, the world knew considerably less about human-technology interaction. But the events of that November day, and all the problems that followed, offer several perspectives on the human and technology designs and systems. The question is, then, what caused the incident: the employee, the structure and/or usage of the valve, the designer of the water system, or the builder of the water system?

I will acknowledge that I cannot draw conclusions on the event because the official investigation is not yet complete (YLE News, 2008). However, a basic understanding of the events provides a good opportunity to look at the usability of the system from a philosophical point of view. Just as when a competent surgeon may leave a needle within the patient because

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he/she is rushed, fatigued from a long surgery, or did not sleep well the night before, the Nokia water crisis comes down to the question about usability in critical work: Where do you place the blame for a failure in the usability of a safety-critical work system?

Let’s start the philosophical scapegoating with the agent, the user who opened the valve. One could hold that the worker should be able to perform the task assigned, and thus is responsible for completing that task well and without a poor outcome. Yet, what if the hypothetical work had several facets, and one of them was to dance on a tightrope once a year, but the other requirements of the job precluded the worker from being able to practice this task? Now the assumption that the worker is fully responsible for his/her tasks is no longer so clear. Of course, one could say that the individual should not have taken the job if he/she did not know how to dance or to manage on a tightrope. Sometimes workers are not fully aware of or competent in every single element of a job, although he/she can manage most of the tasks quite well, particularly the ones performed regularly. In the case of the municipal water company employee, he was responsible for a task that had not been performed by any other water employee within the previous decade: The valve had not been opened and, when it was in that previous time, it was under different conditions. So, one could blame the employee, but that does not necessarily mean the discovery of the real reason for the disastrous outcome.

So, let us turn our attention to the valve and its safety structure. The valve was not secured against unforced errors. Just as in the Chernobyl nuclear accident in 1986 (World Nuclear Organization, 2008), where the technology itself was deemed substandard, the Nokia water system was created as a system that could easily facilitate a dangerous outcome if workers did not properly use it under ideal conditions. Just one sudden change in the ideal conditions could jeopardize the entire process. But is the technology itself to blame?

What were the design intentions? The designer envisioned the valve to perform an important role in the operation of the system: to flush out the waste system on a periodic basis. But did the designer think through the conditions in which the intended use could be overcome by poor conditions during use, such as low water pressure in the clean water lines? Did the designer assume that the use of the valve, both technically and in practice, would always be performed under the best conditions, and thus neglected a backup system in the event of less-than-ideal conditions? Is the culprit the designer?

And what about the builder? Perhaps the builder viewed his/her role as simply fulfilling the design specifications, irrespective of the need for safety in application. Should the builder have questioned the technology of the design, even if it was fairly typical of the era? Should the builder have seen a need for some locking device or clear signage for safety reasons? As an example, is the manufacturer of a ship responsible for the effects of various future pressures and effects on the keel of the boat when the metal keel is being formed in the factory? Is the builder of any tangible item responsible for thinking through the particular materials and uses of a product being created, when it was designed and commissioned by someone else? Could the blame fall here?

As this short philosophical look at a human-technology failure clearly indicates, no simple answers are possible. While one could logically place the blame on any of these four areas, it would be more of scapegoating than truly understanding the causes and the outcomes. Placing blame surely closes the case, and most people are happy with a resolution—any resolution—even if it does not resolve the true nature of the failure, simply because it allows the ability to move on.

The reality is that poor outcomes in human-technology interaction take place for a variety of reasons. And even though the usability design community has addressed many of the potential and actual problems over the years, more still exist in critical work processes. In some ways, it is a matter of looking at the usability design process in a different way. Technologies, and particularly technological systems, are never guaranteed to be bug free, particularly at the beginning, and users are always an unpredictable element of any system. Designers and manufacturers of technologies, particularly safety-critical work technologies, need to consider not just the current need being met and the successful application of the technology, but also potential future failures and the use of the technology in less-than-ideal situations by less-than-perfect users. Such an outlook on the design of usable systems decreases the likelihood of underdeveloped usability design of the technology side of the human-technology interaction, and improves the favorable outcome of usability by the human side of the equation.

Finally, while establishing blame for any one or combination of factors in a technological system is how business and legal practices traditionally address the fallout of a poor system outcome, that blaming does nothing to proactively address other current and future disasters of similar type. Newsworthy events such as the Nokia water crisis, Chernobyl, airplane crashes, equipment malfunctions, structural failures, and a host of other past, present, and future crises resulting from the mismatch of humans and technologies call attention to what current standards have to say about risks, norms, ideals, and good practices. Sadly, they say too little, and often say it too late. This reality must change, and soon. Therefore, human technology standards and criteria for critical interaction processes are definitely required, and quickly.

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All correspondence should be addressed to:
Pertti Saariluoma
University of Jyväskylä
Cognitive Science, Department of Computer Science and Information Systems
P.O. Box 35
FIN-40014 University of Jyväskylä, FINLAND
pertti.saariluoma@jyu.fi

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Guest Editor's Introduction

THE END OF COGNITION?

Phil Turner
Centre for Interaction Design,
School of Computing,
Edinburgh Napier University,
Edinburgh, UK

The papers that make up this special issue of *Human Technology* have been elicited as a response to the growing interest in user experience and second-wave HCI (human–computer interaction), also known as post-cognitivist HCI. User experience, in particular, has shifted the focus of research interest away from cognition per se to, for example, affect (e.g., Norman, 2004); fun (e.g., Blythe, Monk, Overbeeke, & Wright, 2003), pleasure (e.g., Jordan, 2000), and aesthetics (e.g., Tractinsky & Lavie, 2004), thus begging the question, where does this leave cognition? To judge from the submissions to this special issue, cognition in HCI is alive, well, and positively thriving. Indeed cognition is proving to be a remarkably robust theoretical framework that is expanding and adapting to a growing understanding of how people use, interact with, and think about interactive technology.

CLASSICAL COGNITION

At the heart of all classical cognitive accounts is some form of representation. While it is difficult to be precise about the origins of cognitive psychology, Tolman (1948), some 60 years ago, was one of the first to argue for a map-like representation in the brains of rats that enabled them to find their way around a submerged maze. The presence of this representation raised problems for the then-dominant behaviorist account, which argued that we could only be certain about stimulus (input) and response (output), and what lay between was effectively a "black box." However, it was not until Chomsky's (1959) damning review of Skinner's (1957) *Verbal Behavior* that behaviorism was consigned to the history books and cognition became a dominant paradigm in psychology.

Norman and his colleagues went on to create a human information processing account of human cognition that bore an uncanny, but unsurprising, resemblance to the operation of digital computers (Lindsay & Norman, 1967). Other significant landmarks included the appearance of Simon's (1969) *The Sciences of the Artificial* and the journal *Cognitive Psychology* in 1970.

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The influence of all of these developments can be clearly seen in Card, Moran, and Newell's (1983) psychological model of the user: the model human processor (MHP) that comprised perceptual, cognitive, and motor systems, and was used to develop a set of predictive models known as GOMS (goals, operations, methods and selection). GOMS models behavior in terms of a changing "goal stack" and a set of rules for adding and removing goals from this stack—a cognitive model couched in the language of digital computation. Norman's (1988) execution–evaluation cycle similarly envisages the user formulating a plan of action (a cognitive representation) that is then executed by way of the system's user interface. As this plan is executed, the user observes its results, which then form the basis of the user's next plan. This cycle continues until the goal has been achieved.

In addition to these models, the centrality of cognition to the practical design of interactive technology was recognized with the appearance of Gardiner and Christie's (1987) *Applying Cognitive Psychology to User-Interface Design*. However, it is also worth remembering that probably the most defining characteristic of HCI is *usability*. Usability, according to Nielsen (1993), is defined in terms of five dimensions, namely, learnability, memorability, the treatment of errors, efficiency, and satisfaction. Excepting the final dimension of satisfaction, the others are based on cognition, though satisfaction by no means excludes a role for cognition. Although noncognitive forms of evaluation are being developed and applied, it cannot be denied that usability and its foundations in cognition remain the sine qua non of all interactive technology and media.

Since the introduction of these applications of classical cognition to the problems of designing and evaluating interactive technology, a number of practical extensions have been created, taking cognition beyond its original formulation. One strongly theoretic use of cognition can be found in Vicente's *Cognitive Work Analysis* (CWA; Vicente, 1999). CWA has its origins in the work of Rasmussen and draws on the theoretical foundations of cognitive engineering. The method is primarily targeted at those domains with complex, dynamic environmental constraints; typical examples involve nuclear plants and operating theatres. The approach includes five complementary analyses: the *functional structure* of the work domain; *control tasks,* which must be undertaken to achieve work goals; *strategies* to cope with task demands; *social organization and cooperation* (broadly, allocation of responsibilities for tasks and communication between roles); and *worker competencies*. Together the analyses provide a very full description of the work domain under study, having addressed many of the shortcomings of classical cognition.

In parallel to these developments, the whole bases of cognition in HCI have been challenged, firstly and most significantly, by Suchman's (1987) *Plans and Situated Actions,* and then by other researchers, such as Bannon (1991) with his "From Human Factors to Human Actors." These works, for many people, marked the end of the dominance of cognition in HCI and the beginning of the "turn of the social." Suchman highlighted the importance of contextual or situated factors in using technology, concluding that a plan is better thought of as a resource that could be drawn upon rather than a program to be executed, while Bannon criticized the laboratory-based study of technology use and the accepted practice of treating people as mere "users."

RESURGENT COGNITION

In many respects, the frequent citations of Suchman and Bannon's criticisms of cognition may be a little unfair, since they only really address classical cognition, that is, the cognition of symbol manipulation and rules; a cognition unconcerned by context, culture, or the social world; and a cognition that is rarely, if ever, found in human–computer interaction today.

Cognition has successfully extended and reformulated itself in the last 20 years. For example, Hutchins (1995) is one of the originators of the concept of distributed cognition. Distributed cognition incorporates social and organizational perspectives, the premise being that cognitive processes and the representation of knowledge may be distributed among both multiple human actors and artifacts. It is also distinguished by its emphasis on the role of external representations (cf. Rogers & Ellis, 1994). The elements of the cognitive system include human beings and artifacts, representations of information that may be both internal and external to the human actors, and the relationships between these elements as they work to achieve the system's goal. In the real world, tasks involve the coordination of representational states, both internal and external, whereby multiple representations are combined, compared, derived from each other, or made to correspond (e.g., Hutchins & Klausen, 1996). A distributed cognition approach thus offers a means of understanding how socially shared activity achieves its goals. In addition to distributed cognition, Clark (2005, p. 1) has proposed an "extended mind hypothesis," which is the view that ''the material vehicles of cognition can be spread out across brain, body and certain aspects of the physical environment itself.'' Meanwhile, Edmondson and Beale (2007) have written of projected cognition, which adds intentionality to these accounts.

Predating these innovations is, of course, activity theory. Activity theory is not a cognitive account of the use of interactive technology but has, nonetheless, strong social cognitive and distributed cognitive dimensions. Central to activity theory is the argument that all purposive human activity can be characterized by a triadic interaction between a subject (one or more people) and the group's object (usually loosely translated as its purpose) mediated by artifacts or tools (e.g., Blackler, 1993, 1995; Bødker, 1991; Engeström, 1987, 1990, 1995; Holt & Morris, 1993; Kuutti, 1991, 1996; Nardi, 1996). In activity theory terms, the subject is the individual or individuals carrying out the activity, the artifact is any tool or representation (the internalization of external action, as discussed by Zinchenko, 1996) used in that activity, whether external or cognitive; and the object encompasses both the purpose of the activity and its product or output. Developments of activity theory by Engeström and others have added more elements to the original formulation and these are: community (all other groups with a stake in the activity), the division of labor (the horizontal and vertical divisions of responsibilities and power within the activity), and praxis (the formal and informal rules and norms governing the relations between the subjects and the wider community for the activity). These relationships are popularly represented by an activity triangle. Given this description, it is perhaps unsurprising that Cole and Engeström (1993) have argued that activity theory in itself is an account of distributed cognition.

Cognition is also recognized as being embodied, that is, cognitive processes are not confined to the brain but are deeply rooted in the body's interactions with the world (e.g., Lakoff & Johnson, 1999). These ideas echo the words of philosophers such as Whitehead and Merleau-Ponty. Whitehead (1997), for example, observed that, "We have to admit that the body is the organism whose states regulate our cognition of the world. The unity of the perceptual field therefore must be a unity of bodily experience" (p. 91). However it is Merleau-Ponty's work that has witnessed a renaissance in recent years (e.g., Dourish, 2001). Merleau-Ponty (1945/1962) has argued that it is only through our lived bodies that we have access to what he describes as the "primary world." The world and the lived body together form an intentional arc that binds the body to the world. The intentional arc is the knowledge of how to act in a way that coheres with one's environment, bringing body and world together. "The life of consciousness—cognitive life, the life of desire or perceptual life—is subtended by an 'intentional arc' which projects round about us our past, our future, our human setting, our physical, ideological and moral situation" (Merleau-Ponty, 1945/1962, p. 136). For Merleau-Ponty, the intentional arc embodies the interconnection of skillful action and perception. More recently, Wilson (2002), in a critique of the embodied cognition hypothesis, noted that she has been able to distinguish a number of different claims for it. These include that it is situated; that it functions in real-time; that we off-load cognitive work onto the environment; and that off-line cognition is bodily based. While distributed, situated, and embodied cognition are yet to be fully, practically realized, we can be confident that cognition itself is alive and well and continuing to underpin most of the current research in HCI.

This issue addresses a number of current and overlapping research themes identified above while adding particular new perspectives and interpretations. The first two papers consider embodied cognition.

Hurtienne begins by discussing image schemata. Image schemata are described as "abstract representations of recurring sensorimotor patterns of experience." They are formed by and directly structure our experience with the world and, as such, present an important means of exploring the embodied nature of cognition. Hurtienne shows how these image schemata can be used directly drawn in the design of interactive technology.

Preferring the term embodied embedded cognition (EEC), van Dijk writes that EEC is characterized by both its phenomenological roots and action-centeredness. The phenomenological character of EEC is an explicit link to user experience research by relating the ultimate goal of good design in HCI to the quality of the (user) experience of using it and the recognizing that usability is still best understood within a cognitive framework. Moreover, van Dijk argues for a renewed focus on improving usability based on this EEC perspective. He concludes with a tentative sketch for an embodied embedded usability, while retaining the original goal of making interactive technology easy to use.

Next, van den Hoven and Eggen consider the role of external cognition in everyday lives and environments. They introduce the concept of *autotopography*, which refers to the study of personal collections of physical artifacts that serve as a memory landscape to the owner. These artifacts, such as photos, souvenirs, furniture, or jewelry, physically shape an autobiography because they link to memories that are important to the owner. Since those memories are important, the artifacts that link to them are also important, although this link is often invisible and unknown to other people. The collection of artifacts, and their disposition and location, represents a part of the owner's memory, history, and thus identity (cf. Turner, 2008). These artifacts also might represent desire, identification, and social relations, establishing a form of self-representation. In their paper, van den Hoven and Eggen consider the range of memory cues in the environment by comparing the effect of cue modality (odor, physical artifact, photo, sound, and video) on the number of memory details people related from a unique one-day real-life event. They argue that the HCI specialist or interaction designer cannot just focus on the interaction at hand but must adopt a wider remit and address an individual's broader environment.

Hall, Woods, and Hall introduce and use theory of mind (ToM) methods to investigate children's interpretations of the social and emotional states of synthetic pedagogical characters. Their work focuses on children's cognitive and affective empathic responses to virtual characters in bullying scenarios and their social awareness and understanding of the characters' situations. Although cognitive approaches typically do not consider user social awareness and emotional understanding and their roles in interaction, these are critical for our research, with a focus on empathic engagement. In their paper, Hall et al. present an approach focusing on story and character comprehension using concepts from ToM methods. This approach seeks to understand children's interpretations of the characters within virtual role play scenarios, which were then compared with an adult perspective. Their results imply that ToM methods offer the potential for determining user social awareness and emotional understanding, with the key results suggesting that adults and children have different perspectives on how victims and bullies are feeling. Despite the differences in how the adults and children responded to the characters in the bullying situations, Hall et al.'s study demonstrates that children can exhibit ToM and are able to respond to synthetic characters in virtual learning scenarios.

The concluding paper by Turner and Sobolewska revisits a classic study of mental models but from the perspective of individual differences. They argue that people are able to exhibit different cognitive styles, either a tendency to systematize or to empathize with interactive technology. Systemizing is associated with the creation of mental models, while empathizers tend to treat technology as though it were a friend. Following Payne's (1991) study of how people thought automatic teller machines worked and using Baron-Cohen's work on cognitive styles, they examined the relationship between the cognitive styles and how people think about their mobile phones. Turner and Sobolewska report evidence that lends support for this relationship of cognitive styles, but concluded that the situational factors are important too.

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Author's Note

I would like to thank the contributors for all of their hard work in creating this special issue.

All correspondence should be addressed to:
Phil Turner
School of Computing
Edinburgh Napier University
Edinburgh, UK
EH 10 5DT
p.turner@napier.ac.uk

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COGNITION IN HCI: AN ONGOING STORY

Jörn Hurtienne
Chair of Human Machine Systems
Technische Universität, Berlin, Germany

Abstract*: The field of human computer interaction (HCI) is deeply rooted in cognitive science. But can cognitive science still contribute to the newest developments? This article introduces the recent trends towards "embodied cognition." Then research on image schemas and their metaphorical extensions is reviewed as an example of how understanding a special branch of embodied cognition can be useful to HCI. Special emphasis is placed on the validity of the theory and its practicability in different phases of the user interface design cycle. It is concluded that cognition can still contribute to current HCI and that the dialogue between the different schools of thought is beneficial to the field.*

Keywords: *user-centered design, image schemas, embodied cognition.*

INTRODUCTION

New challenges require new solutions. Computers are becoming smaller, more powerful, and ubiquitous. They are no longer used exclusively for solving work tasks. They support communication and cooperation; they help with exercise and wayfinding; they entertain and educate. New design themes like user experience, emotion, and artistic expression emerge. The emphasis is shifting towards the analysis of context, embodiment, and values. New interaction paradigms, such as ubiquitous computing, tangible interaction, and ambient interfaces, have appeared that require new approaches to design well beyond those used for traditional graphical user interfaces. Design inspirations are drawn from phenomenological philosophy, ethnography, and industrial design. These new approaches to designing human–computer interaction (HCI) have been called third-wave HCI (Bödker, 2006), or the third paradigm (Harrison, Tatar, & Sengers, 2007) in the sense of Kuhn (1970).

Traditional HCI is rooted in cognitive science as well as in ergonomics and human factors engineering. From cognitive science it has inherited its focus on theory-based research, on experimental methods conducted in the laboratory (e.g., usability tests), and on information processing by humans and computers. From ergonomics and human factors engineering, it has inherited its focus on design for the workplace, emphasizing effectiveness

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and efficiency as design objectives. Traditional HCI, it is felt, cannot address the new developments adequately, hence the call for a paradigm shift.

Do these new developments mean that cognition and the scientific method are not needed anymore? Looking from the cognitive science perspective towards third-wave HCI, however, these approaches seem to be eclectic collections of fairly vague design philosophies; the insights generated by research are highly context dependant and lack generalizability; and subjective interpretation prevails, which does not contribute much to finding "objective truth."

Who is right and who is wrong? Is there really a paradigm shift going on? Does one approach have to dominate another? According to Kuhn (1970), a generally accepted set of theory, associated methods, and domains of applications characterize a scientific paradigm. A new paradigm can only exist after it has overthrown the old one by being better able to explain new and old phenomena. A paradigm shift only occurs by a process of scientific revolution.

Is this what is currently happening to HCI? I would say no. Grudin (2006) pointed out that several approaches to HCI are currently coexisting. There is not a sole paradigm; there is a multitude. It seems that, rather, we are in what Kuhn (1970) describes as the preparadigm phase, in which different schools of thought advocate different theories, approaches, and applications. In this phase there is no consensus on any particular theory, although the research being carried out can be considered scientific in nature. Current HCI then should be seen as a dialogue among members of different schools.

In this article I view cognition as one school of thought rather than a paradigm in the Kuhnian sense, and I will show what this school of thought has to contribute to the scientific dialogue in today's HCI.

TRADITIONAL AND EMBODIED COGNITION

The advent of computers influenced cognitive science and cognitive science influenced how computers were built. The computer brought a powerful idea to psychology: understanding the mind as an information processing device. Massaro and Cowan (1993) describe the defining properties of the information processing approach as follows: (a) The environment and cognition can be described in terms of input, process, and output; (b) Stages of processing can be broken down into substages; (c) Information is transmitted forward in time and all inputs necessary to complete one operation are available from the outputs that flow into it; (d) Each stage or operation takes some time; and (e) Information processing occurs in a physical system; representations are information embedded in states of the system, and processes are operations used to transform the representations. This idea of information processing means that one can trace the progression of information through the system from stimulus to response.

A high-level schematic of this approach is shown in Figure 1. The mind is seen as an information processing device consisting of independent modules for perception, cognition, and action. Often connected with the information processing view of cognition is the view of intelligence being explained by processes of symbol manipulation (Newell & Simon, 1976). Because symbols are abstract and amodal (i.e., not tied to perceptual representation), their processing can be implemented without difference in hardware, in software, in a brain, or in a

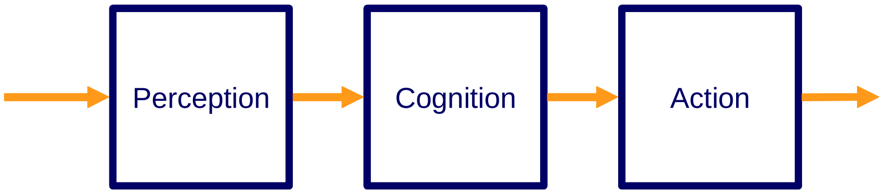

Figure 1. The traditional view of the mind, in which cognition forms a module separate from perception and action.

brain in a vat. Knowledge is equated with symbols, and thinking is equated with the application of algorithms. Theories of cognition are interchangeable with algorithmic programs. Indeed, a large part of the field of artificial intelligence was occupied with testing theories of human cognition that were formulated as computer programs.

Card, Moran, and Newell (1983) introduced this traditional view of cognition to HCI in their influential book, *The Psychology of Human Computer Interaction*. For an audience of computer scientists, they described the human mind as an information-processing system with memories, processors, cycle times, and specific laws of operation. They described it as *the model human processor* and proposed it as a general-purpose thinking device. This view of cognition and the model human processor was very successful in HCI. Card et al. summarized many principles, like the power law of practice, Fitts' law, and Hick's law, that enabled engineers to predict—within limits—human performance when interacting with computers. The GOMS (goals, operators, methods, and selection rules) analysis and the keystroke level model were powerful tools for modeling human–computer interaction. The model human processor concept influenced many milestone textbooks in HCI, among them Deborah Mayhew's (1992) *Principles and Guidelines in Software User Interface Design*. Cognitive modeling (or cognitive engineering) is the subfield in HCI that tries to replicate users' cognitive processes within the computer in order to better predict user behavior (Byrne, 2003; Norman, 1986). Different stages of information processing can still be found in today's human factors or usability engineering textbooks (Rosson & Carroll, 2002; Wickens & Hollands, 2000).

The metaphor of the mind as an information-processing device soon attracted criticism. Winograd and Flores as well as Dreyfus, Dreyfus, and Athanasiou (both in 1986) maintained that the traditional cognitive view on the mind is flawed and that artificial intelligence will not go far, based on this model. They backed their arguments with philosophical theories by Heidegger and Merleau-Ponty that bring in the ideas that thinking is dependant on perception, action, and experience; that having a human body thoroughly influences and constrains human cognition; and that human experience must be studied using a phenomenological approach. The mind cannot be viewed as a device operating on bits of information according to formal rules. Much of human intelligent behavior and expertise relies on intuition and subconscious processes, rather than conscious symbolic manipulation captured in formal rules. Works in robotics supported this criticism, showing that many everyday behaviors involving balance, motion, and navigation do not need high-level symbolic manipulation to be successful, because "the world is its own best model" (Brooks, 1990, p. 5).

The view that conscious symbol manipulation is, at best, only a small part of our intelligence is gaining ground in cognitive science. Evidence shows that cognition cannot be separated from sensory and motor processes. Language understanding, for instance, involves simulations of sensorimotor experiences rather than manipulating amodal symbols (Glenberg

& Kaschak, 2002). Sensorimotor input directly affects cognitive judgments about time (Casasanto & Boroditsky, 2008). Categorical knowledge is grounded in sensorimotor regions of the brain (Barsalou, 1999). And thoughts about abstract things, like the self, the mind, morality, emotions, causality, or mathematics, are grounded in the sensorimotor experience of the world (Lakoff & Johnson, 1999; Lakoff & Núñez, 2000).

Such evidence led to the view that cognition is embodied. Embodiment emphasizes that cognition is dependant on its concrete implementation in a human body, with specific sensory and motor capabilities. Connected to it is the idea that cognition takes place in the real world, that is, that cognition is situated, time-pressured, action-oriented, and emerges in interaction with the environment (Wilson, 2002). Hence, the clear demarcation between perception, action, and cognition cannot be sustained any longer, and large overlaps between these faculties exist (Figure 2).

Many of the general ideas in embodied cognition have entered third-wave HCI (cf. Dourish, 2001). As mentioned above, not all of them are clear-cut enough to be easily applied to human–computer interaction. Here, I will follow a notion of embodied cognition that describes how much of our thinking is influenced by past embodied experience. This idea is expressed by Zwaan and Madden (2005, p. 224): "Interaction with the world leaves traces of experiences in the brain. These traces are (partially) retrieved and used in the mental simulations that make up cognition. Crucially these traces bear a resemblance to the perceptual and action processes that generated them…and are highly malleable." In the remainder of the article, a theory will be introduced that is concerned with these "traces of experiences" and that calls these traces *image schemas*. Research will be presented that shows how image schema theory is valid and useful in a context of user–interface design.

IMAGE SCHEMA THEORY

Image schemas are abstract representations of recurring sensorimotor patterns of experience (Johnson, 1987). They are formed by and directly structure our experience with the world. The *container* image schema, for example, forms the basis of our daily experiences with houses,

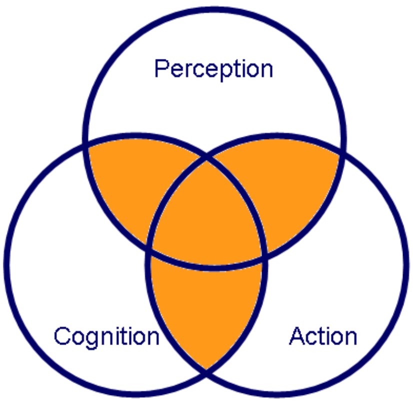

Figure 2. Embodied view of the mind, with large overlaps between cognition, perception, and action.

rooms, boxes, teapots, cups, cars, and so on. A container is characterized by an inside, an outside, and a boundary between them. Consider the many container events encountered in simple activities: "Take for example a child in a red dress who watches her mother put cookies into a jar. The child takes the lid off the jar and looks inside to search for the cookies. She reaches into the jar,…down into the cookies,…grasps a cookie (so that the cookie is now in her hand), and takes it out. She wraps the cookie in a napkin. She walks with the cookie through a door into another room, where she is picked up in her mother's arms and put into a high chair. She watches the mother pour milk into a glass. She then dunks her cookie into the milk (which is itself contained in the glass), and puts the cookie into her mouth" (Dewell, 2005, p. 371–372). These examples show that containers can have different forms and consistencies: They can be instantiated by fluids (the milk), collections of things (the cookies), or flexible wraps (the napkin). (See also the experimental evidence in Feist, 2000; Garrod, Ferrier, & Campbell, 1999). One of the entailments of the container image schema is that the content of a container is separated from what is outside the container. The container image schema and its entailments are reused when thinking about abstract categories. It surfaces in conventions when we talk about "being in Florida" or that someone is persuaded "to enter into the contract." Both expressions connote abstract containers without physical instantiations in the real world.

Table 1 lists a set of image schemas that are found in the cognitive science literature (Baldauf, 1997; Clausner & Croft, 1999; Hampe, 2005; Johnson, 1987; Talmy, 2005). The image schemas in Table 1 are separated into groups of *basic*, *space*, *force*, *containment*, *process*, *multiplicity*, and *attribute* image schemas.

Although most of these image schemas were derived from linguistic and philosophical analyses, they are proposed to stem from physical interaction with the world. As mentioned above, they can be transferred to the thinking about abstract, nonphysical entities. This transfer is called a *metaphorical extension* of the image schema. Metaphorical extensions are often grounded in bodily experience. For example, experiencing the level of liquid rising in a container when more liquid is added or seeing a pile of paper shrink when sheets are taken away leads to the metaphorical extension *more is up–less is down*. This correlation between amount and verticality is subsequently generalized to abstract entities like money or age, as can be seen

Table 1. List of Image Schemas.

Group	**Image Schemas**
BASIC	object, substance
SPACE	center–periphery, contact, front–back, left–right, location, near–far, path, rotation, scale, up–down
CONTAINMENT	container, content, full-empty, in-out, surface
MULTIPLICITY	collection, count–mass, linkage, matching, merging, part–whole, splitting
PROCESS	cycle, iteration
FORCE	attraction, balance, blockage, compulsion, counterforce, diversion, enablement, momentum, resistance, restraint removal, self-motion
ATTRIBUTE	big–small, dark–bright, heavy–light, smooth–rough, straight, strong–weak, warm–cold

in expressions like "My income rose last year," "Rents are going up," or "He is underage." Other metaphorical extensions of the up–down image schema are (Lakoff & Johnson, 1980):

> *Good is up–bad is down*: "Things are looking up"; "We hit a peak last year, but it's been downhill ever since."
>
> *Happy is up–sad is down*: "I'm feeling up"; "That boosted my spirits"; "He is really down these days"; "I'm depressed."
>
> *High status is up–low status is down*: "She'll rise to the top"; "He's at the bottom of the social hierarchy."

There are more than 40 image schemas, and each image schema gives rise to several metaphorical extensions: More than 250 metaphorical extensions have been documented in the literature (Hurtienne, Weber, & Blessing, 2008). Although much of this research was done on linguistic data, cognitive linguists claim that these metaphorical extensions are only expressions of underlying conceptual metaphors. Because this claim is very strong, research is necessary that provides evidence beyond pure linguistic analysis. (This is addressed more fully below.)

The universal character of image schemas, their—in the course of life—extremely frequent encoding in and retrieval from memory, and their subconscious processing make them interesting as patterns for designing user interfaces. A *left–right* image schema (along with an up–down image schema), for example, may be represented by a joystick on a toy car's remote control. When the joystick is moved leftward, the toy car turns left. A rightward move of the joystick lets the toy car turn right, thus a simple physical mapping. Metaphorical extensions of image schemas can be used to represent abstract concepts, such as using up–down in a vertical slider for controlling the intensity of the speaker volume (more is up) or to rate the attractiveness of a new car (good is up). This use of image schemas for representing abstract concepts is one of the major promises for user–interface design, because, in the mind of users, they subconsciously tie the location, movement, and appearance of user interface elements to their functionality. Thus they can provide an extra layer of meaning to physical properties of interfaces. The next section describes research into how image schema theory has been applied to user interface design.

IMAGE SCHEMAS IN HCI

As in any theory useful for HCI, image schema theory needs to fulfill the requirements of (a) making valid predictions in a context of user interface design, and (b) being useful in practice. Research that has addressed these requirements is reviewed here.

Validity

Image schema theory originates from the fields of cognitive linguistics and philosophy. In language, image schemas are found to motivate grammatical forms, underlie the meaning of prepositions, motivate verbs and adverbs, and motivate many metaphorical extensions of abstract concepts like causation, death, and morality (Baldauf, 1997; Gibbs & Colston, 1995;

Hampe & Grady, 2005; Lakoff & Johnson, 1980, 1999). The question is whether they are also valid outside a purely linguistic context.

Psychological experiments show that image schemas are mediating between perception, language, action, and cognition. Mandler (1992, 2004, 2005) describes research that shows how image schemas are involved in building up a sensorimotor representation of the world in the young infant and how they scaffold the acquisition of early concepts and language. Other studies show that nonverbal image schema instantiations interfere with sentence understanding when the sentence implies a different image schema (e.g., left–right instead of up–down) and facilitate understanding when the image schema orientation is consistent. These effects could be shown with visual, acoustic, and motor instantiations of a number of different image schemas (up–down, left–right, *front–back*, *near–far, rotation*; see Hurtienne, 2009, for a review). How image schemas are plausible from a neurocognitive standpoint was shown by Barsalou (1999).

The psychological reality of a number of metaphors of the up–down image schema was shown by Meier and Robinson (2004), Casasanto and Lozano (2006, 2007), and Schubert (2005). The metaphor *similar is near–different is far* was validated by Casasanto (in press). He found that people judge abstract words more similar when they are presented close together than when they are presented further away from each other. Meier, Robinson, and Clore (2004; Meier, Robinson, Crawford & Ahlvers, 2007) experimentally confirmed the relation between affective state and instances of the *bright–dark* image schema (e.g., *happy is bright–sad is dark*). Metaphors of time perception were investigated by Boroditsky (2000; Boroditsky & Ramscar, 2002), also under a complete avoidance of verbal material (Casasanto & Boroditsky, 2008). Metaphorical expressions in gesture replicate those found in speech (Cienki & Müller, 2008; McNeill, 1992, 2005). Neurological evidence for conceptual metaphor is discussed in Kemmerer (2005) and Rohrer (2005).

Despite the multiplicity of studies in linguistics and psychology, only a few studies validate the claims of image schema theory in the domain of HCI. The idea is that user interfaces consistent with metaphorical extensions of image schemas will be more effective (i.e., less error prone), more efficient (i.e., less time consuming), and more satisfying to use (i.e., they receive better ratings by participants) than inconsistent user interfaces.

Two studies (Hurtienne & Blessing, 2007) investigated metaphorical extensions of the up–down image schema with arrangements of buttons and sliders. In these, efficiency was measured by response times and satisfaction by subjective suitability ratings of different arrangements. In the first experiment, participants evaluated hotels along different dimensions. They did this with a simple two-button interface, with one button in the upper position and the other in the lower position (Figure 3). The results show that participants significantly preferred button arrangements consistent with the metaphors more is up–less is down, good is up–bad is down, and *virtue is up–depravity is down* over button arrangements that were inconsistent with these metaphors. In the case of good is up and virtue is up, response times were significantly lower when the buttons were arranged in a manner consistent with the metaphor than when they were inconsistent. No statistical difference in response times was found for the metaphor more is up.

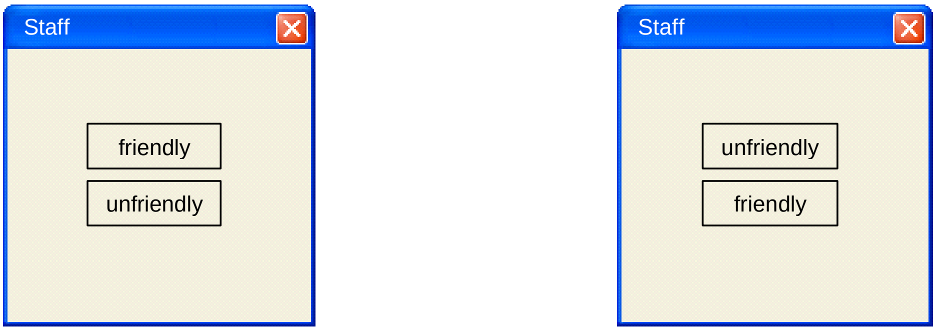

Figure 3. Button labels in a hotel evaluation task. Button labels on the left are compatible with the metaphor virtue is up; labels on the right are incompatible (Hurtienne & Blessing, 2007).

The second experiment investigated the metaphors more is up and good is up. Participants received a context-free task with vertical analogue sliders and they were to indicate in which direction they would push the slider when asked to adjust the slider to display more, less, better, or worse. The results validated the metaphors, showing that preferences were significantly higher and response speeds were significantly lower for the metaphor-consistent sliders than for the metaphor-inconsistent sliders. In both experiments, alternative explanations of the findings could be ruled out by control conditions in which the buttons and sliders were arranged horizontally.

Measures of all three usability indicators—effectiveness, efficiency, and satisfaction—were taken in an experiment that investigated the influence of the near–far image schema in judging the similarity of display values in pointer and number displays (Hurtienne, 2009). Well-known design principles like the proximity compatibility principle (Wickens & Hollands, 2000) state that values that are processed together during a task should also be placed near each other on the display. This principle, however, is in contrast to the metaphor similar is near–different is far, evident in expressions like “A and B are close, but they are by no means identical” or “the difference between A and B is vast.” This metaphor would predict that two displays showing differing values should be placed further apart, even if they belong to the same task. In these experiments it could be seen that in a comparison task in which display similarity varied along one dimension (display value) more errors were made and reaction times were slower when following the proximity–compatibility principle. Following the metaphor similar is near was more beneficial to performance. However, subjective suitability ratings were less distinctive between the two principles.

Across all three experiments (Hurtienne & Blessing, 2007; Hurtienne, 2009) effect sizes d (Cohen, 1988) were measured. Response times as efficiency measures show small- to medium-sized effects (average d = .45). Error rates as effectiveness measures were sometimes not available because the tasks were too easy. If there were error effects, they were in the medium to high range (d = .74). Expressed in percentages, this means up to 14% gains in speed and 50% fewer errors in the metaphor consistent conditions. Suitability ratings as measures of satisfaction show very large effects (average d = 2.28) and could swing from a strong rejection of the inconsistent to a strong acceptance of the consistent interfaces.

Image schemas are useful not only for conveying functional information, but they also can be used for conveying aesthetic information (van Rompay, Hekkert, Saakes, & Russo, 2005). The expression of the image schemas up–down, container, and *balance* was manipulated in jugs and alarm clocks. Up–down, for instance, was varied by manipulating the height of the objects. Participants rated the expression of the objects on nine dimensions, for example, secure–insecure, introvert–extravert, and constricting–liberating. The results showed that the image–schematic variations in product appearance influenced the ratings on the abstract dimensions. Unfortunately, the study was not based on specific metaphorical extensions derived from theory, so it provides no evidence for or against the validity of specific metaphors.

In a recent study, 29 metaphorical extensions of five attribute image schemas (big–small, bright–dark, *warm–cold*, *heavy–light*, and *smooth–rough*) were investigated (Hurtienne, Stößel, & Weber, 2009). Participants received simple objects (Lego bricks of different sizes, colors, and textures; small bottles filled with hot and cold water; or a light and a heavy match box) and were given an abstract word for which they should find the one object that best represents this word. For example, they received black and white Lego bricks and should say which best represented the word *happy*. Here, the metaphor happy is bright–sad is dark predicts that people will choose the white brick as an answer (indeed, 88% did). Other examples of metaphors under investigation are *important is big–unimportant is small*, *good is bright–evil is dark*, *emotional is warm–unemotional is cold*, *problematic is heavy–unproblematic is light*, and *polite is smooth–impolite is rough*. Averaged over all 29 metaphors, 78% of the participants' answers were consistent with the metaphors' prediction, a value that lies significantly above chance agreement (50%). There were, however, great variations in strength between the metaphors and the presentation styles of image schemas. The metaphor good is bright–evil is dark, for example, received 100% agreement when using black and white Lego bricks, but only 67% agreement when using light-blue and dark-blue bricks, suggesting that the specific instantiation of image schemas plays a great role in whether metaphors are valid or not.

Altogether, the evidence on the validity of image schemas and their metaphorical extensions inside and outside the context of user interface design is promising. Further research will be necessary to replicate these findings under different circumstances, to detect the effects of context and conflicting metaphors, and to refine the theoretical predictions. Much of the potential has not been tapped so far and many hypotheses are still hidden in the 250 metaphorical extensions that have been documented by cognitive linguists.

Because these metaphorical extensions are hypothesized to derive from correlations in basic sensorimotor experience, they should exhibit a high degree of universality across cultures. In a comprehensive survey of linguistic metaphors, Kövecses (2005) shows that metaphors about emotions, event structure, time, and the self are consistent across languages of different families (such as English, Chinese, Hungarian, Japanese, Polish, Wolof, and Zulu). Only minor variations occur, for example, in the word forms that are used (e.g., nouns instead of verbs) or in the different salience of parts of the metaphor. In our own studies (Hurtienne, 2009; Hurtienne, et al., 2009) participants with different native languages (Chinese, French, Polish, Spanish, Japanese) produced results that were not noticeably different from the majority of subjects whose mother tongue was German. Although such results are promising regarding the universality of conceptual metaphor in the HCI context, the issue awaits further study in the form of dedicated comparative studies.

Practicality

If image schemas are at the basis of much concrete and abstract thought, as the theory suggests, they might be usefully employed as a language to describe users' mental models, their tasks, and the user interfaces. Having established that image schema theory makes valid predictions, the concern now is how designers can use image schemas in their daily design work and how useful image schemas are. This section reviews previous research regarding a model of the human-centered design process, as proposed by ISO 13407 (International Organization for Standardization, 1999; see Figure 4). The process starts with a planning phase (goals, time, budget). Then the four core design activities are (a) understand and specify the context of use, (b) specify the user and organizational requirements, (c) produce design solutions, and (d) evaluate designs against requirements.

In the first phase of the cycle, the context of use typically is analyzed in situ. Characteristics of the task to be solved (including user goals), the current technological support, the characteristics of the target user group, and the general organizational context are analyzed. Several studies show that image schemas can be extracted from users' utterances, thus revealing parts of their mental models. Maglio and Matlock (1999), for example, analyzed users' mental models of the World Wide Web (WWW) using image schemas. Although the WWW is usually described as a *collection* of web sites (*locations*) that are connected via *links*, the users' utterances revealed many *self-motion*, container and *path* image schemas. The use of path metaphors increased in line with the participants' greater experience in using the WWW.

In other studies, the mental models of people were examined when navigating in airports (Raubal, 1997; Raubal & Worboys, 1999). Image schemas were extracted from the utterances

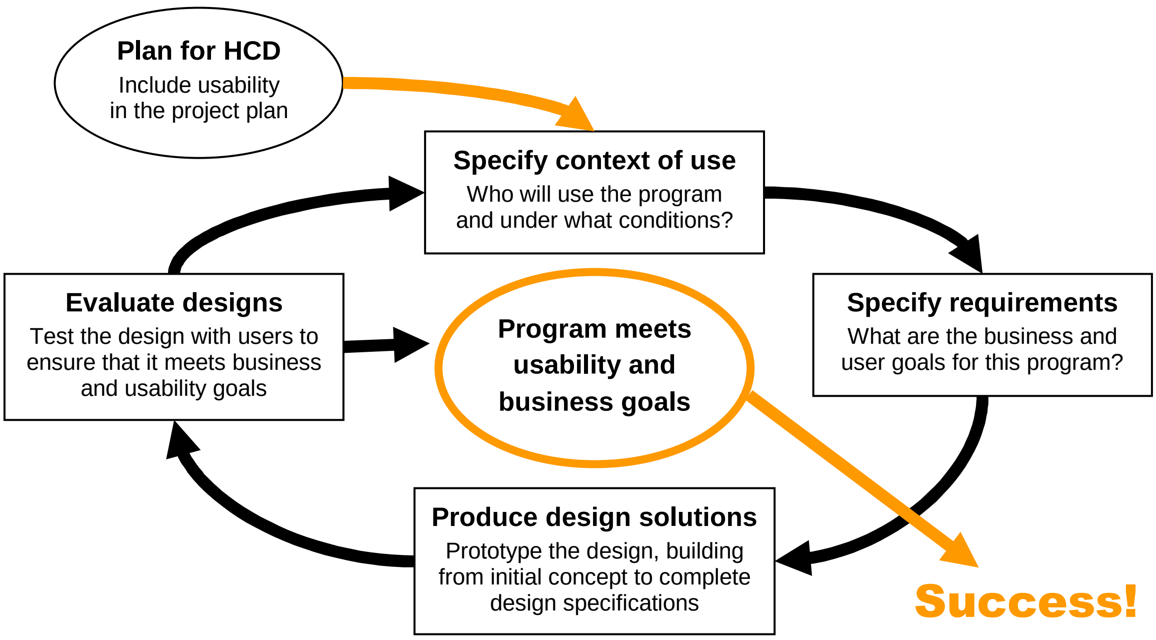

Figure 4. The human-centered design (HCD) process according to ISO 13407 (ISO, 1999).

the users made while finding their way through simulations of these airports. Image schemas could be extracted from almost all utterances of the participants, and suggestions for the redesign of the airport navigation system could be derived from the results by the researchers.

Image schemas were also used to analyze and describe user interface metaphors (Kuhn & Frank, 1991). Zooming, for instance, instantiates both a near–far image schema that mediates a *part–whole* image schema. Similarly, desktops and clipboards are instances of the *surface* image schema; and folders and trashcans instantiate the container image schema. The results of a large number of image–schematic analyses, for example, of airplane cockpits, ticket and cash machines, tangible user interfaces, business software applications, or software widgets, have been collected in a database called ISCAT (Image Schema CATalogue; Hurtienne, Weber et al., 2008). The database was built to provide designers with examples of image schema uses and their effects on the usability of products.

Image schemas and their metaphorical extensions also have been proven effective in the design phase of prototypical applications. One application, SchemaSpace (Lund, 2003), is a collection of WWW bookmarks organized in a hierarchy (Figure 5). Semitransparent cones in an information landscape represent different categories of bookmarks, thus drawing on the metaphor *categories are containers*. The more bookmarks there are in one category, the taller the cone is (more is up). The relevance of single bookmarks in a category is conveyed by the metaphor *important is central*. Connections between cones (link) indicate the relations between subcollections of bookmarks. Higher level categories are located higher in the landscape (e.g., on a hill) and lower level categories are located lower in the landscape drawing on the metaphor *abstract is up–concrete is down*. Finally, similar categories (cones) are located near each other and dissimilar items are located far from another (similar is near–different is far).

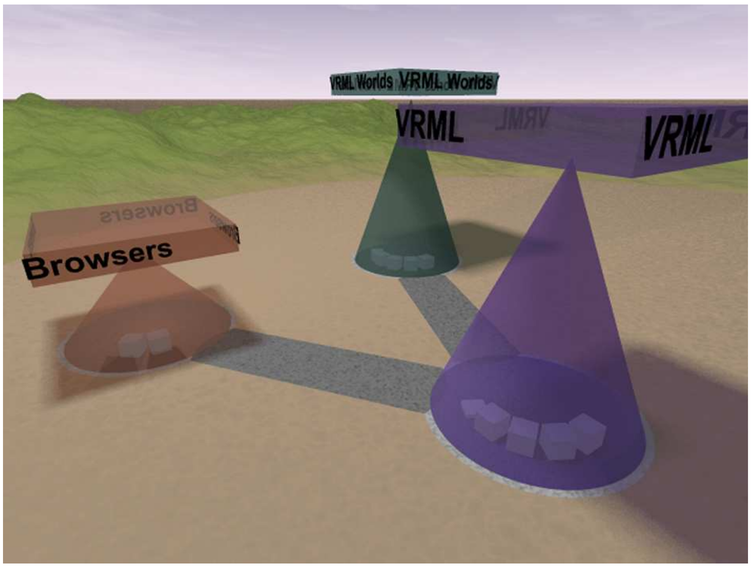

Figure 5. SchemaSpace, a personal information browser, illustrating the image-schematic metaphors categories are containers, more is up and connectedness is linkage (Lund, 2003, p. 150; used with permission).

The SchemaSpace prototype was evaluated by a number of users who solved information finding tasks; the same users also solved the same tasks with an information-equivalent hypertext prototype (Lund, 2003). The results showed that the SchemaSpace prototype elicited significantly more comments containing the image schemas center–periphery, container, link, near–far, part–whole, path, and up–down than the hypertext prototype. The hypertext prototype, in contrast, elicited only more comments containing the image schema surface. The author concluded that implementing metaphorical instantiations in user interfaces profoundly influences how users think about the interface.

The first application of image schemas covering all phases of the user-centered design cycle (i.e., from the context-of-use analysis via requirements specification, producing design solutions and evaluation) has been done in the redesign of a business application for accounting (Hurtienne, Weber et al., 2008). Image schemas were used to gather requirements from a context-of-use analysis of task steps, current user interfaces, and interaction steps, as well as the users' utterances. The strength of the image schemas was that they allowed a direct translation of requirements into design solutions.

For instance, in thinking aloud, users' often used front–back relations to describe their use of additional information, such as lists of contact persons in the company or additional order information. However, the current system presented this information either in left–right fashion on different monitor screens or *split* the information into several containers that had to be accessed separately. Consequently, putting any supplemental information into one container in a position behind the main screen (front–back) was posed as one of 29 image–schematic requirements.

It showed that image schemas were able to prescribe the structure of the interface without constraining the creativity of the designer in how image schemas become instantiated. For example, if main and supplementary information should be shown as an instance of the front–back image schema, the designer is free to creatively develop different forms of front–back appearance (Figure 6). Concrete design solutions were developed in the same way for other image–schematic requirements and the most suitable solutions were selected and combined to form the complete user interface concept. To show the flexibility of image–schematic requirements, the same set of requirements was used to develop a graphical user interface solution (Hurtienne, Weber et al., 2008) and a tangible user interface (Hurtienne, Israel, & Weber, 2008). In the subsequent evaluation with users, both solutions were rated as significantly higher in hedonic and pragmatic quality compared to the current solution.

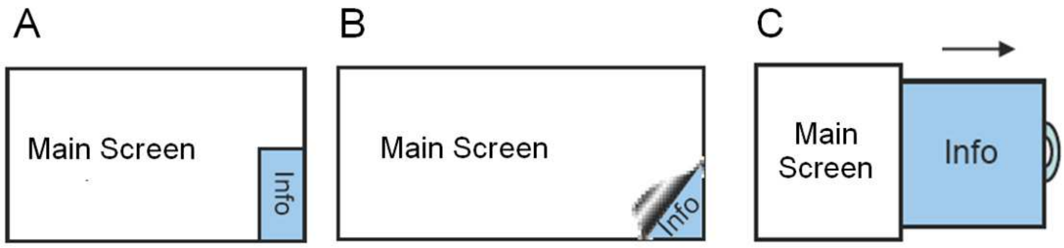

Figure 6. Design variants of front-back arrangements of main (front) and supplementary information (back).

SUMMARY: WHAT HCI CAN LEARN

First, although originating from research in cognitive linguistics, many image schemas and their metaphorical extensions are also valid within a user interface design context. Metaphorical extensions can provide design rules that were unknown until recently. They can point out the limits of current design principles, like the proximity compatibility principle and provide alternative explanations instead.

Second, as the practicability studies show, image schemas enhance insights during a user-centered design process. They allow the description of tasks, mental models, requirements, and design solutions to be conceived in a common language. They facilitate the transfer from requirements to design solutions by providing the structure of the prospective user interface.

Third, analyzing image schemas in user interfaces may lead to insights into implicit design rules and can help make them explicit. For instance, specific interactions and dependencies between image schemas emerged during the analyses for the ISCAT database. Among these are

- rules of image schema co-occurrences (e.g., *blockage* needs to be followed by *restraint removal*; *attraction* is resulting in *diversion*);
- image schema transformation rules (e.g., up–down is readily substituted by front–back relations); and
- typical problems (e.g., user interface elements that belong to the same task are often far away from each other without communicating their relation via a link or a common container image schema).

Fourth, there are a number of metaphorical extensions that are able to capture the “softer” aspects of human–computer interaction. Because computers today are increasingly used as tools for human–human communication, aspects such as social relationships, emotions, and personality traits need to be expressed through user interfaces. Metaphorical extensions of image schemas show how this could be done. Metaphors—*social relationships are links, intimacy is closeness, sinning is diversion from a path, affection is warmth, desire is attraction, intelligent is bright*, or *problems are heavy*—point to interesting ways on how one could build user interfaces for intangible domains of use.

Finally, image schemas have been used for building graphical and tangible user interfaces alike. This shows that they are flexible enough to be useful also for designing newer forms of interaction. Indeed, my present research extends the application of image schemas towards the design of haptic force-feedback interaction employing the group of force image schemas.

CONCLUSION

Cognition certainly is not and will not be the only discipline contributing to HCI. This review shows at least two contact points to the other schools of thought.

One point of contact with ergonomics and human factors engineering is the concept of population stereotypes. Population stereotypes describe ways in which people, often subconsciously, expect user interface elements to function. The ergonomics literature, however, documents only a few population stereotypes that were derived from user surveys. With image schema theory, however, the current number of documented stereotypes can be increased tenfold with known metaphorical extensions. This number may even be higher with further analysis (Hurtienne et al., 2009) inspired by the theory.

Another point of contact is with applications of third-wave HCI. Metaphorical extensions of image schemas provide a way to map the abstract realms of emotion and experience, which are more important in nonwork user interfaces, to spatial and physical properties of user interface elements. In the discussion of the validity, it has been shown that design with image schemas can enhance classical measures of effectiveness, efficiency, and satisfaction, as well as convey aesthetical attributes (van Rompay et al., 2005). Other studies have shown that image schemas are easily applied to third-wave user interface paradigms such as tangible interaction. Indeed, the image schema language is general enough to be useful in the design of other user interface styles as well (including artistic installations that intentionally violate common image schema usage).

Finally, this review shows that new theories of embodied cognition, when applied to HCI, can make cognitive science productive and interesting again. Cognition can still deliver theories with concrete predictions on what will be useful in design, methods that can readily be applied to the design process, and concrete design rules. As long as cognitive science develops, and someone in HCI listens, the story may go on.

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All correspondence should be addressed to:
Jörn Hurtienne
Chair of Human-Machine Systems
Technische Universität Berlin
Franklinstr. 28-29, Sekr. FR 2-7/1
10587 Berlin, Germany
hurtienne@acm.org

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COGNITION IS NOT WHAT IT USED TO BE: RECONSIDERING USABILITY FROM AN EMBODIED EMBEDDED COGNITION PERSPECTIVE

Jelle van Dijk
Research Centre for Product Development, Utrecht University of Applied Sciences
and
Faculty of Industrial Design, Eindhoven University of Technology
The Netherlands

Abstract: *Embodied embedded cognition (EEC) has gained support in cognitive science as well as in human–computer interaction (HCI). EEC can be characterized both by its action-centeredness as well as its roots in phenomenology. The phenomenological aspects of EEC could be seen as support for trends in design emphasizing the user experience. Meanwhile, usability issues often are still approached using traditional methods based on cognitivist assumptions. In this paper, I argue for a renewed focus on improving usability from an EEC perspective. I draw mainly on a behavior-oriented interpretation of the theory, the key aspects of which are reviewed. A tentative sketch for an* embodied embedded usability *is proposed, doing justice to the embodied embedded nature of interaction while retaining the goal of developing technology that is easy to use in everyday practice.*

Keywords: *embodied embedded cognition; usability; human–computer interaction.*

INTRODUCTION: THE END OF USABILITY?

In cognitive science (Clark, 1997), as well as in human–computer interaction (HCI; Dourish, 2001), the theoretical framework of *embodied embedded cognition* has gained influence as a serious alternative to cognitivism, the traditional foundation of cognitive science (Fodor, 1983; Newell & Simon, 1972). Embodied embedded cognition (EEC) holds that intelligent behavior is *embodied* in the internal milieu and action possibilities of the body, as well as *embedded* in the structure of the environment. This is often contrasted with the view in which behavior is seen as the result of an internally constructed plan based on a mental representation of the world (Clark, 1997). Cognitivism has been a foundation for usability practice in HCI (Newell & Card, 1985). One might therefore be tempted to believe that an alternative theoretical paradigm, such as EEC, has serious consequences for usability as a practice. As it happens,

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major industries have been changing their focus from "usability engineering" to what is called "user experience design."[1] Consider this quote from a designer's blog:

> User-experience is not like usability—it is about feelings. The aim here is to create happiness. You want people to feel happy before, during and after they have used your product. ... It is a touchy feeling kind of thing. Why, for instance, does an Audi S6 give you a much better user-experience than a Ford Focus? I mean, in terms of usability they are pretty much the same. (Baekdal, 2006)

Such talk is in stark contrast with the aims of traditional usability practice, namely, improving functionality and ease-of-use (Nielsen, 1993). The user experience trend and the rise of EEC as a cognitive theory could be seen as independent developments had it not for the influential work of Paul Dourish (2001). Dourish explains how, based on an embodied interaction perspective, experience should indeed become the grounding concept for interaction design. Yet, a focus on experience, as a consequence of adopting the EEC perspective, is not straightforward. Several traditions can be discerned within the community. For the purposes of this paper, it is important to distinguish between two lines of thought. The first line of thought has its roots in phenomenological philosophy (Heidegger, 1927/1986; Merleau-Ponty, 1962; Verbeek, 2005). It rejects the existence of an objective, external world, favoring instead the metaphysical priority of experience. This is the tradition in which Dourish (2001) can be positioned. Dourish speaks about interaction mainly on the level of phenomenological reflection. He is concerned with the experiences that emerge in the user's mind during interaction with technology. He uses the term *embodiment* to "capture a sense of phenomenological presence" (Dourish, 2001, p. 115). I call this the *phenomenological approach* to embodied cognition (Dourish, 2001; cf. Merleau-Ponty, 1962; Varela, Thompson, & Rosch, 1991). In contrast, a second line of thought within EEC builds on the idea that cognition emerges in action, contingent on direct, ongoing interaction between the brain, body, and local environment. It is a materialist perspective that deals mainly with subconscious behavioral pattern formation. I call this the *behavior-oriented approach* to embodied cognition, paraphrasing Brooks' behavior-based robotics (Brooks, 1991; Clark, 1997). The behavior-oriented approach is central to the argument developed in this paper.

In order to get a feel of the difference between the two approaches, consider the Wigo (Bruns, Keyson, & Hummels, 2008). The Wigo is an interactive object vaguely resembling a pint-size milk bottle (see Figure 1). It is one of the *tangible* media that are currently gaining attention in HCI (Ullmer & Ishii, 2000). Wigo automatically detects patterns in the way you wiggle and roll it in your hand, and then provides haptic feedback on the basis of these patterns. If you feel stressed, this will show in your wiggling and rolling patterns. In turn, Wigo will start to counter your stressed movements with haptic feedback.

Wigo's designers are foremostly interested in the affective experience that the Wigo elicits (Miguel Bruns, personal communication, February 20, 2008). The Wigo is intended to make one conscious of one's own bodily state. One must then consciously decide to take action in order to reduce stress, for example, by taking a walk in the park or signing up for yoga. With the focus on eliciting an embodied experience, Wigo's designers implicitly adhere to the phenomenological approach to embodiment. Their strategy may be very useful, but it is

Figure 1. The Wigo: a tangible interactive device responding to manual activity patterns with haptic feedback. (Image used with permission from Bruns, Keyson, & Hummels, 2008.)

not the only possible design approach that results from taking an EEC perspective. Instead, the behavior-oriented approach offers an important alternative that is not directed at creating experiences at all. Thus, when Dourish writes, "Embodiment does not simply mean physical manifestation. Rather, it means being grounded in and emerging out of everyday, mundane *experience*" (Dourish, 2001, p. 125; emphasis added), the behavior-oriented approach would replace the word *experience* with *actions* or *behavioral patterns*. The behavior-oriented approach does not (necessarily) need the concept of experience to explain user–technology interaction.[2] For example, envision an alternative version of the Wigo: the Wigo-Act, which controls the user's stress-levels directly, without the user even noticing it. The design objective of Wigo-Act would not be to elicit a user experience. It would instead be directed at creating an interactive behavioral coupling, which in turn maintains a desired bodily state. Such a system in principle could bypass conscious experience, not unlike the workings of a common pacemaker. But, unlike a pacemaker, Wigo-Act would not (necessarily) have to be positioned inside the body.

In fact, many of today's common tools elicit comparable effects, effects that may take place largely out of our immediate awareness. Consider the subtle ways in which using keyboard and monitor instead of pencil and paper may affect writing style, or even the content of the writing. Here, the user's experience does little in explaining how the tool influences her behavior. Likewise, the Wigo-Act does not have to be an object in the user's experience for it to work, just like the blind man's cane completely withdraws into the "experiential background" when it is used normally (cf. Merleau-Ponty, 1962). Most importantly, whatever the specific form a Wigo-Act may take, the quality of the interaction would be assessed primarily by its functionality and ease-of-use: Does the product produce the desired behavioral results without serious disturbances?

Reconceptualizing Usability from an EEC Perspective

Is usability practice still possible once EEC has been adopted as a theoretical foundation? This paper argues that accepting EEC as a theoretical framework does not mean rejecting usability as a goal. Even today, many of our tools (software and hardware) continue to create serious obstructions in everyday use. Too often devices do not work as expected, fail to provide the functionality needed, cannot be controlled as intended, or will not give useful feedback. In short, usability is still highly relevant (Landauer, 1995). In this paper, therefore, an EEC-based interpretation of usability is explored that does justice to the embodied, embedded nature of interaction, while at the same time retaining the original behavior-oriented objective of making products easy-to-use in practical contexts. In order to develop this interpretation, I claim the benefit of drawing on the behavior-oriented approach to embodiment.

Outline of the Paper

The remainder of the paper is organized as follows: The next section discusses some of the problems of traditional HCI and usability practice. The section that follows introduces EEC. Three related lines of research are reviewed: (a) the materialist, behavior-oriented view (Brooks, 1991; Chiel & Beer, 1997; Clark, 1997); (b) distributed cognition (Hutchins, 1995; Kirsh & Maglio, 1994) and situated cognition (Suchman, 2007); and (c) phenomenology proper (Dourish, 2001; Heidegger, 1927/1986; Merleau-Ponty, 1962; Varela et al., 1991; Verbeek, 2005). Next, the consequences of these developments for HCI are discussed, working towards an *embodied embedded usability*. The paper closes with a short discussion of the possibility of modeling embodied embedded interactions.

PROBLEMS IN TRADITIONAL USABILITY PRACTICE

The classic usability practice, grounded in the information-processing view of user cognition, aims to identify a set of tasks that the user[3] needs to carry out while using the technology in question in order to reach goals (Nielsen, 1993). Associated with each task is a set of mental representations of the aspects of the world relevant for carrying out the task. On the basis of perceptual input from the world, the user activates the relevant mental representation. On the basis of this representation, the user creates a plan for action that specifies which actions should be carried out and in which order. The actual behavior itself is conceived as the “mere” execution of an otherwise internal cognitive process (Newell & Simon, 1972). According to the vision of Newell and Card (1985), the success of HCI would depend on how well one could formally model this human computational system, based on a thoroughly objective, quantitative measurements of its behavioral output (Newell & Card, 1985).[4] Although the framework has provided a firm basis for a large tradition of HCI practices, there are also various shortcomings associated with the framework, which I will discuss presently.

Action Precedes Perception. In most traditional models, perception is seen as a process prior to action. That is, action is modeled as the consequence of the internal processing of a perceptual input. As Gibson (1979) and others (e.g., Merleau-Ponty, 1962) have shown, perception itself emerges in the context of one’s actions. A turn of my head opens up a new world for me to perceive. My running speed creates a correlated optic flow on my retina (Gibson, 1979). Standard computer desktops provide little opportunity for creating such action–perception couplings (Keller, 2005; Wensveen, 2005). Instead, action and perception are often explicitly conceptually separated, as input to the computer and input to the user, respectively, or command and feedback (Albrechtsen, Andersen, Bødker, & Pejtersen, 2001; Dourish, 2001).

Knowledge is Not in the Head. Furthermore, the purported set of mental representations and computations that models the world quickly grows exponentially large for even the simplest of tasks, leading into problems of search and relevance: How to have access to the relevant knowledge at the right time (Haselager, 1997; van Rooij, 2008)? In contrast, as Don Norman (2002) famously showed, in many practical circumstances representations need not be in the head as internal models at all. People make use of all kinds of externally represented knowledge. This is information that is not stored in the brain but off-loaded onto the environment itself: for example, when one quickly writes down a telephone number on the back of a matchbox. The drawback however is that if the environment is not accessible (if one should lose the matchbox), the knowledge is lost (see Norman, 2002, p. 79). I will return to the embedded nature of knowledge representation when I discuss the framework of distributed cognition in the next section.

Action is Prior to Planning. The plan-like character of the way people carry out tasks has been attacked quite radically by Lucy Suchman, who shows that, in practice, people often use ad hoc, improvisational means to reach goals. Plans are constraining forces that emerge out of the real-time interaction itself, not preconditions for behavior (Suchman, 2007). That is, action is prior to, or at least in parallel with, planning. The procedural character of traditional models, such as in use-case diagrams (Bittner, Spence, & Jacobson, 2003) or hierarchical task analysis (HTA; Diaper & Stanton, 2003), tend to ignore the fact that most of the actual behaviors of users are messy, improvised, and thoroughly pragmatic. People often use serendipitous opportunities available in the here-and-now, which can never be modeled by an HTA (Suchman, 2007).

Tasks are (Bad) Descriptions. The notion of a task itself is in some way problematic, as has been discussed by others as well (e.g., Procter & Williams, 1992). A strong focus on describing activities in terms of tasks might lead one to believe that these tasks actually represent some real underlying cause. The cognitivist model is in part responsible for this belief, since in its strongest form it conceives of behavior as the outcome of internally represented computational procedures (Newell & Simon, 1972). Research shows that the actual causes of the observed behavior often do not correspond to some observer-defined computational procedure at all (Hutchins, 1995; Suchman; 2007; Wakkary & Maestri, 2007). As Randall, Hughes, and Shapiro (1991) state,

> aspects of work do not come conveniently labeled as adhering to one or another task, and in practice activities will spill out promiscuously into each other and fan out into an unending succession of elements which relate more or less vaguely with ramified sets of tasks and subtasks. (p. 4)

Randall et al. (1991, p. 4) conclude that "designing on the basis of these judgments will in the event prove disruptive rather than supportive of work activity." If this is true for work activity, the problematic nature of task analysis might be even stronger for less constrained activities, such as in the home environment or in the public domain (cf. Wakkary & Maestri, 2007). Tasks might therefore best be seen as observer-dependent, normative descriptions of what users are doing (Blomberg, Giacomi, Mosher, & Swenton-Wall, 1993).

The Context Issue. Following a classical modular line of reasoning, Newell and Card (1985, p. 14) stated, "the human-computer interface is, in fact, a psychologically limited micro-world. Many issues of the wider world ... do not arise." However, in their everyday practices, people tend to carve up the world into parts that were not foreseen by the design model. The user who reads the password of a sticky note attached to the monitor before manually copying it into a dialog box in a software application conceives of the physical sticky note and the digital dialog box as an integrated whole, part of the same interaction (Jacob, Ishii, Pangaro, & Patten, 2002). Moreover, subtle contextual elements in the global setting do in fact influence user activities in unexpected ways: Context matters (Moran & Dourish, 2001; Norman, 2002).

In conclusion, classical usability practices are confronted with several problems. These problems pertain to difficulties in separating action from perception; defining the knowledge representation, action-plans, and user-tasks; and addressing how to deal with context effects. Interestingly, the theory of EEC emphasizes the way action and perception are coupled, as well as how knowledge may be grounded in the local environment and the bodies' local action possibilities. EEC therefore may hold the potential to overcome at least part of the problems in traditional usability.[5] I now turn to a more detailed introduction of this alternative theoretical framework.

EMBODIED EMBEDDED COGNITION

This section introduces several research traditions within the general EEC philosophy. It highlights those aspects that are of direct importance to a behavior-oriented reinterpretation of usability in HCI.

Basic Tenets of EEC

EEC rejects the classic internalist character of cognitivism (Clark, 1997; Keijzer, 2001; Thelen & Smith, 1994). Instead, EEC holds that intelligent behavior is an emergent property arising out of situated, historically determined dynamics within a network of interrelated factors (Kelso, 1995; Skarda & Freeman, 1987; Thelen & Smith, 1994). This causal network transcends the brain to include not only the neural processes but also the musculoskeletal constraints of the body, homeostatic variance in the body (with strong influence on the brain's emotional systems; cf. Damasio, 1994), and, last but not least, the physical and cultural constraints present in the environment (Clark, 1997; Hutchins, 1995).

Materialist Embodied Cognition: Inspiration from Robotics

The materialist version of EEC (Clark, 1997; van Dijk, Kerkhofs, van Rooij, & Haselager, 2008; Haselager, van Dijk, & van Rooij, 2008) draws mainly from work in robotics (Beer, 2008; Brooks, 1991; Chiel & Beer, 1997). Behavior-based robots (Brooks, 1991) show how intelligent behavior arises from the coupling between a creature's body and the physical constraints of its immediate environment. These robots need no internal knowledge representation of the task. In fact, "representations and models simply get in the way" (Brooks, 1991, p. 1). Brooks (p. 1) famously proposed instead to "use the world as its own model." Andy Clark (1997) elaborated on this idea, showing how people go about their daily affairs mostly "on autopilot" (van Dijk et al., 2008), guided by local dynamic couplings. Clark coined the "007-principle": An intelligent agent knows "only as much [it] needs to know in order to get the job done" (Clark, 1997, p. 46). If the environment provides clues for action at the right place and time, there is no need for costly computations over internal representations. Likewise, Don Norman (2002) discussed the related concept of *knowledge in the world*, and how behavior is guided by external constraints, affordances, and natural mappings, often in favor of *knowledge in the head* (Norman, 2002).

EEC emphasizes that cognitive action arises out of a continuous and parallel flow of input and output between organism and environment (Kelso, 1995). It claims that the classic metaphor of discrete message passing is wrong. Perception is not the passing of a message from the environment to the brain, and action is not the passing of a message to the environment (Clancey, 1997). This is an important concept for HCI since the standard metaphor has been precisely that: Users are telling the computer what to do and computers are telling people what state they are in (Abowd & Beale, 1991; Newell & Simon, 1972).

Materialist EEC tries to explain intelligent *behavior* (Clark, 1997), not experience as such. The ad hoc, embedded, autopilot nature underlying the bulk of human behaviors is emphasized. The brain relies on information being locally available as people interact with the environment (Beer, 1997). Conscious, deep thoughts should be seen as an additional control layer upon—and contingent on—more basic situated body–world dynamics (Brooks, 1991, van Dijk et al., 2008; Haselager, et al., 2008). In sum, materialist EEC tells us that much what is usually called intelligent action might in fact be based on local couplings between bodily structure and environmental constraints, not unlike the way less complex organisms operate (cf. Godfrey-Smith, 2002).

Distributed and Situated Cognition: Inspiration from Cultural Studies

A separate line of research originates in sociocultural investigations (Hutchins, 1995; Suchman, 2007; see also Clancey, 1997; Winograd & Flores, 1986). Suchman's situated cognition has explicit phenomenological roots (Dourish, 2001). Based on careful analysis of conversations between users while they collaboratively engaged with machines, Suchman concluded that, in the normal case, our behaviors are not at all caused by internally created plans for action based on mental models of the world. Like in Brooks' robots, in Suchman's account of cognition, action in the world is given priority as an explanatory concept to planning and internal representation. In the normal case, through our actions in the world, plans evolve in an ad hoc, improvised manner. One may, of course, engage in explicit planning activities, but these are, according to the situated cognition approach, the exceptional cases that require effort and are in any case not natural to our normal ways of dealing with the everyday world. As discussed earlier, this may have serious consequences for the traditional method of task analysis.

Hutchins's (1995) distributed cognition is based on ethnographic analyses of behavior and talk aboard a navy ship. Activities such as making a location "fix" on a chart are coordinated achievements of *systems*, consisting of the brains and bodies of several people, as well as the physical tools used. That is, cognitive processes are distributed processes. Hutchins, like Clark (1997) and Clancey (1997), argues that internal representations should not be assumed when this is not necessary for explaining behavior. Moreover, behavior is often not directed at carrying out some task directly. Rather, the user's behavior is geared towards providing the necessary complement to the autonomous workings of external tools, such as charts and tables. In other words, a user does not have to know how the tool works, only how to work the tool. This is precisely what makes tools handy: One can off-load part of the cognitive load onto the environment. Likewise, David Kirsh distinguishes between pragmatic versus epistemic actions (Kirsh & Maglio, 1994; Neth et al., 2007). Pragmatic actions directly contribute to achieving a goal state, whereas epistemic actions reorganize the world in such a way that further action will be less computationally burdening. Taking out a pen and paper would be an epistemic action that makes a hard calculation less difficult, because what one needs to know in order to do a calculation on paper is less complex than what one needs to know in order to do the calculation in the head (Wilson & Clark, 2008). Again, we see a correspondence to the way Donald Norman (2002) showed how people not only use, but also create, knowledge in the world, such as remembering to take something needed outside the home by putting it near the door so it will be stumbled over as one is leaving.

Situated and distributed cognition often deal with the user's intentions and (explicit) thoughts.[6] This is understandable, since conversation analysis is based on statements in natural language made by people about themselves and their environments. The focus is therefore somewhat different from the robot-inspired models of behavioral dynamics discussed earlier; it also does not stress the idea of embodiment. Yet, when the question concerns how intelligent behavior comes about, both lines of research are consistent in their emphasis on the embeddedness of cognitive processes.

Embodied Experience: Inspiration from Phenomenology

While phenomenology is considered to be the prime philosophy of experience, important lessons nevertheless can be drawn from how users and technology interact behaviorally. Consider Heidegger's famous example of the carpenter who, involved in his hammering, is not directed at the hammer but rather at the work he is producing through the hammer (Heidegger, 1927/1986, p. 69). The hammer is seamlessly integrated into the carpenter's activities, and thus is "withdrawn" (Heidegger, 1927/1986; see also Dourish, 2001; Dreyfus, 1990; Verbeek, 2005). The product is said to be "ready-to-hand" (*zuhanden*; Heidegger, 1927/1986, p. 69). Another example in this regard concerns the blind man who reports sensing the pavement directly with the tip of his cane, without explicitly interacting with the cane itself (Merleau-Ponty, 1962, p. 165). Now, when the cane becomes wet and slippery, the blind man becomes aware of the grip of his hand on the cane, turning his focus toward the cane and not the pavement. Heidegger would state the cane is now "present-at-hand" (*vorhanden*): an explicit object to be inspected (Heidegger, 1927/1986, p. 73).[7] Note that many tools work satisfactory precisely when they are ready-to-hand, managing the interaction between user and environment in the background. The tool itself is however withdrawn, that is, it is not at all present in one's experience. In contrast, when a product is present-at-hand, meaning when it comes back into one's consciousness, open to reflection, it often does so because of a problem. Fine tools operate much like a well-mannered butler: discretely, effectively, and reliably present in the background, but not drawing explicit attention.

A related view is that of Varela's *embodied mind* (Varela et al., 1991), rooted in the works of Merleau-Ponty (1962). Varela's biologically inspired work is based on the premise that the main objective of organisms is to maintain themselves. In this continuous struggle, the niche that the organism inhabits is not formed independently from the creature's own behavioral and evolutionary history. Organisms "make a living" based on their sensory capacities and behavioral repertoire, creating at the same time their niche, or what Uexkull has called an *umwelt* (Haselager et al., 2008; von Uexkull, 1934; Ziemke & Sharkey, 2001). The organism, therefore, enacts not only itself but also its world. Selecting an appropriate action is taking place in an environment with which the organism already has an intimate relationship. In line with the distributed cognition thesis, this means that it is impossible to draw a strict line between the user and the technology.

EMBODIED EMBEDDED USABILITY

In this section, I take the first steps towards describing an interpretation of usability that is based on EEC. This interpretation is nonetheless oriented toward user behavior, with the principle objective to improve functionality and ease-of-use.

User Cognition

In the EEC view, users generally do not hold internal representations of the task environment, nor do they plan their actions internally before executing them. From the materialist perspective, it was determined that autopilot behavior often comes before deep thought and the workings of mental representations. Emergent behavior depends heavily on the available knowledge in the world (Clark, 1997; Norman, 2002). Many tangible interaction designs (Hornecker & Buur, 2006; Ullmer & Ishii, 2000) make use of this principle. As an illustration, consider just one example, the design of a video recorder power outlet by Djajadiningrat, Wensveen, Frens, and Overbeeke (2004). Figure 2 shows how manipulating the physical form of a power-outlet creates a *natural mapping* (Norman, 2002) between the user's actions and the resulting effects on the system. By turning the knob, the pattern of lines can be made to either continue smoothly, suggesting that electrical current can flow through, signaling that the machine is on. Or, the line pattern can be broken, which suggests blocking the flow of electrical current (as if making a dam), thereby turning the machine off. The tangible form thus creates an environmentally embedded representation of the electronic state (power on or off).

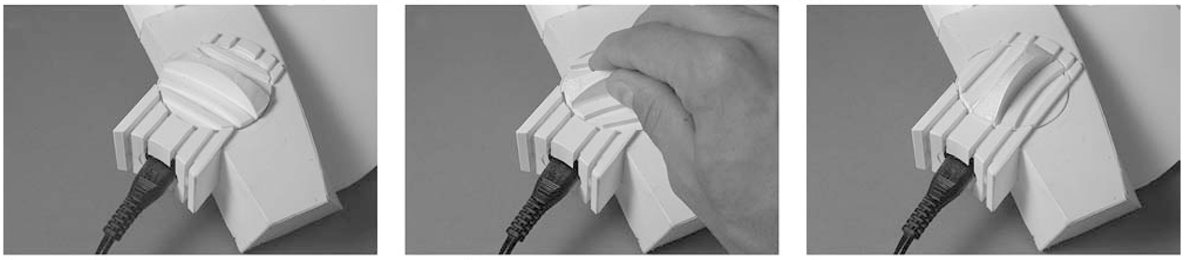

Figure 2. A tangible power-outlet, in the off position (left), being turned on (middle) and in the on position (right). (Images from Djajadiningrat, Wensveen, Frens, & Overbeeke, 2004; used with permission.)

Consider that the meaning of common LED-signals on today's machines has to be actively learned and remembered, since their visual form connects purely arbitrarily, not intrinsically, to the meanings they encode. One realizes this whenever one is in doubt on whether the flashing red light of a DVD player means that the system is off, or in stand-by mode, or perhaps demanding battery charge, or any other arbitrary meaning that the designer decided upon. The literal form of a red light presents no intrinsic bias towards one or the other optional meanings. In contrast, as in the power-outlet discussed above, the on/off state of the machine does not have to be remembered, since it is readily available for visual inspection. Nor is this state transferred from the system to the user in the form of an arbitrary symbolic relation. Instead, using natural, tangible mappings, the state of the machine relies on intuitive perceptual affordances.

One of the drawbacks of a reliance on embedded structure is, of course, that people are quickly confused or frustrated when this structure turns out not to be present at the right time and place (Norman, 2002). One challenge for the design of computational devices is precisely to overcome that problem, and let computing power and network technology create environments where information is externally available precisely at the locations and times when it is needed by a user who is operating in autopilot mode. Current developments in mobile and context-aware systems are investigating this problem (e.g., Steen, van Eijk, de Koning, & Reitsema, 2009; Streefkerk, van Esch-Bussemakers, & Neerincx, 2008).

Interaction

EEC implies that, in our everyday interactions, there needs to be no explicit message passing from human to machine and back. People and technologies interact much more directly, in analog ways, grounded in the way their bodies interact, situated in the physical environment. Even cognitive interaction is in many ways very much like dynamically steering a bicycle (Dreyfus & Dreyfus, 1990). The appropriate metaphor is not so much message passing as it is "structural coupling" (Chiel & Beer, 1997). In this view, interaction emerges as a self-organizing process within sets of constraints (Kelso, 1995). Hence, designers might be better off creating such constraints (Norman, 2002), rather than attempting to specify (by means of procedural models) how the interaction should unfold. Several attempts have been made at tapping into the low-level body–world couplings more directly (see e.g., Hummels & Overbeeke, 2008; Ishii et al., 2004; Underkoffler & Ishii, 1998). The current popularity of the commercially available Wii controller has given rise to interesting new strategies for interaction using the whole of the body.[8]

What the User Does

People act on improvisation, guided by local, ad hoc opportunities (Suchman, 2007).[9] One of the consequences is that abstract task definitions do not necessarily map onto the actual dynamic structure that determines the user's behavior in situ (Suchman, 2007). Users may temporarily suspend tasks, or even drop certain goals altogether, if the effort needed for achieving them turns out to be outweighed by other emerging opportunities for action (Haselager, 2004). Although a rough description of a task may be very useful in defining the design problem, designers must not forget that task descriptions are ad hoc, loose descriptions, in which both the desired behavior under investigation as well as elements from the observer-dependent perspective are fused (Blomberg et al., 1993). Users need to be able to act epistemically (Kirsh & Maglio, 1994), creating their own environmental "scaffolds" (Clark, 1997) that in turn serve as useful external support for the unfolding cognitive process. One intriguing example of this is presented in Block, Haller, Gellersen, Gutwin, and Billinghurst (2008), who developed the means for users to create for themselves physical interaction controls on the fly, to be used instantly as interface elements for computer software. Some of these personal buttons might only serve a purpose for a particular user in a particular context; they would never have been developed on the basis of generic task analyses. Yet, such buttons can be highly functional and increase usability, that is, for that user in that context.

The (Designed) Environment

As discussed earlier, many tools operate best when ready-to-hand (Heidegger, 1927/1986). Whenever, for example, my mobile phone becomes present-at-hand, it is primarily when some problem occurs or when the thing requires my explicit attention in order to determine how I can get it to do what I want it to do. This is a case of low usability, where, in Norman's terms, the *gulf of execution* (i.e., the gap between the intention to make something happen and knowing what action to take in order to do so) is large (Norman, 2002). Designers do not always acknowledge the users' desire for a smooth, mindless, ready-to-hand relation with their surrounding technologies, perhaps because, for designers, the product is almost always present-at-hand: It is, after all, the explicit focus of their attention.

More generally, however, people are not passive consumers of fixed environments. Instead, they bring forth a world in which to maintain themselves (Varela et al., 1991). Traditionally, the usability of a device is seen as the property of an external object people need to address. Using a product is like solving a problem, and if the problem becomes too complex, usability is low (Norman, 2002). Following Varela et al. (1991), we can understand how technology, once it is integrated into one's practice (i.e., is ready-to-hand), becomes a genuine part of the user. If we conceive of devices as coming to function as an extension of the body (Merleau-Ponty, 1962), usability becomes an issue of internal harmonization between body parts, rather than something that happens between two systems (i.e., the user and the device). In ubiquitous computing and ambient technologies, we see the same reconceptualization of what we mean by the interface (Dey, Ljungstrand, & Schmidt, 2001). Here, the interface is both everywhere and nowhere (depending on the perspective), distributed as it is in space and time, and mediated by various kinds of physical structures in the environment that connect to all of the sensory-motor channels users have at their disposal (Dey et al., 2001, Weiser, 1994, but see Dourish, 2001, p. 200–203).

DISCUSSION

The fact that Don Norman's (2002) *The Design of Everyday Things*[10] is still heavily quoted and used in classrooms throughout the world already hints at the fact that basic usability is still an issue needing attention, even though significant progress towards more user-friendly systems has been made (Carroll, 1997). As described in this paper, the main difficulties stem from issues concerning the nature of knowledge representation, internal versus external computation, planning versus improvisation, and the role of context. I have discussed the potential virtues of the EEC as a promising alternative theoretical framework for HCI. In this I closely follow Paul Dourish (2001), who has advocated a similar move. In contrast to Dourish, however, the position taken in this paper is less focused on phenomenological experience than on the ways in which people behave with their bodies in the physical world. With this shift in perspective, I hope to be able to connect the insights from EEC more directly to the practical issues of usability that still confront interface designers today.

On User Experience

One might argue that usability is simply a *part* of user experience (Morville, 2008). Indeed, if the aim is to make people happy (Baekdal, 2006), then basic usability issues need to be solved in order to achieve happiness. But a designer/engineer can spend only so much time on any project, and usability has to compete with a multitude of other important themes huddling under the eclectic umbrella of user-experience design (cf. Sharp, Rogers, & Preece, 2007). Moreover, as the discussions of Heidegger's readiness-to-hand and EEC's autopilot behavior suggest, objects with good usability may not enter the user's experience at all. When one wants to design for absorbed, ongoing behavioral user-technology couplings, achieving this or that experience might just not be the relevant design goal.

All of this should not be seen as a plea against experience design, as such. Still, this paper distinguishes between on the one hand, the field of user-experience design, grounded in a phenomenology of experience and, on the other, an embodied usability practice, grounded primarily in a behavior-based version of EEC. I have made this distinction because it might otherwise be assumed all to quickly that once one adopts the EEC framework, the only option left is to start designing for experience, thereby abandoning usability as a goal altogether. On the contrary, an embodied embedded usability aims to untangle the various ways in which local constraints and affordances, history-of-use, epistemic actions, and ad hoc plan formation influence the basic autopilot-style behavioral couplings between users and technology.

On Formal Models

An issue left untouched until now is the question of whether (and, if so, how) it would be possible to formally model embodied interactions between users and technologies. Computer science has a special relation to formal models because, in a way, modeling is what defines the field. The possibility of abstract explanatory models of the observed behavior has been one of the main strengths of the information-processing account, also in HCI (Carroll, 1997; Fodor, 1983; Newell & Card, 1985). Some of the EEC research described above is actually sympathetic to an information-processing interpretation, albeit one that flexibly reaches out into the environment (Hollan, Hutchins, & Kirsh, 2000; Hutchins, 1995). However, there also have been various criticisms pertaining to the difficulty of modeling user behavior, precisely because it is embodied and embedded in nature. Consider this quote:

> Human behaviour ... is complex … subject to a broad range of influences ... poorly defined, hard to predict and highly contingent. ... As such it is impossible to capture and represent human social behaviour formally by the kinds of quantitative methods of mainstream HCI. (Procter & Williams, 1992, p. 3)

EEC seems at odds with the idea of formal models. As Dourish (2001, p. 189) states, "Embodiment is about … the peculiar rather than the abstract ... practice rather than theory, directness rather than disconnection." It would seem a daunting task indeed to create a formal model of something that seems to be just about everything a model is not (i.e., given that models are disembodied, abstract, theoretical, disconnected). In fact, in behavior-based robotics, much research is based on physical simulations, where the robot itself *is* the model (Brooks, 2002). We can see the same case-based strategy in tangible interaction design (Djajadiningrat et al., 2004).

Another strategy is to describe the behavioral dynamics of the system using the vocabulary of nonlinear dynamical systems (i.e., attractor state spaces, control parameters, order parameters, initial and boundary conditions; see Beer, 1997). Analogously, one could conceive of HCI research in which one does not define tasks but rather task spaces: systems of task-related variables in which certain goal-directed behaviors are likely to emerge in a self-organizing way. However, dynamical systems models (Beer, 2008) are a long way from being easily applicable to HCI in any practical sense (Neth et al., 2007).

In conclusion, taking embodied interaction seriously means asking the complex question of how to understand its workings, without losing "it" at the same time within a disembodying transformation. One speculative option is whether a participatory design process (Schuler & Namioka, 1993), in which users function as active participants in the design process,[11] could provide a loophole by which abstract models are bypassed altogether. In such a participatory set-up, users, designers, and design environments (prototypes, sketches, mock-ups) interact closely, on multiple iterations. The evolving product is always presented in a tangible form so as to be able to interact with it and make changes on it in an active, embodied way (Buxton, 2007). User and technology can thus be said to coevolve (Carroll, Chin, Rosson, & Neale, 2000), a process that, as a design strategy, would itself be embodied and embedded, reminiscent of Varela's *bringing forth*, or *enacting*, a world (Varela et al., 1991).

CONCLUSION

Once the design community accepts EEC as a theoretical foundation for HCI, some might feel that this necessarily entails a design for experience. Perhaps this is due to the explicit coupling of HCI to a phenomenological interpretation of EEC, most notably by Dourish (2001). The result is that user-experience designers are able to draw from the recent trends in embodied theorizing, while those interested in "good-old-fashioned" usability are dependent on traditional methods and principles. Meanwhile, many of today's interfaces are still not easy to use, and so improving usability is still a relevant goal. This has nothing to do with user experience per se. The main claim of this paper is that EEC can be seen as a theory about behavior and, as such, it has important things to say about how to conceptualize the behavior of users that are in the process of forming structural couplings with their technological environments. This, in turn, opens the way to an embodied embedded usability practice. It is presently an open question whether it is possible, or even necessary, to formally model embodied embedded couplings as part of a design project. In sum, this paper has presented a tentative sketch for an embodied embedded usability, doing justice to embodied practices without abandoning the original question: How to make technologies functional and easy-to-use in the everyday world.

ENDNOTES

1. See, for example, IBM's website (https://www-306.ibm.com/software/ucd/), as well as popular sources on user experience design (UXD), such as Peter Morville (http://semanticstudios.com/) and Jesse James Garrett (http://blog.jjg.net/).
2. This paper remains agnostic with respect to the question of whether and how conscious experience may affect ongoing interactions between user and technology.
3. In the remainder of this paper, I use the term *user*, simply because there seems to be no satisfactory alternative.
4. Their radical thesis was attacked by Carroll (1997).
5. Many of these problems are also addressed in activity theory, which grew out of an altogether different (i.e., Soviet psychology) tradition (Bødker, 1991). Although EEC is generally more focused at subpersonal explanations of cognitive processes and activity theory has a stronger focus on social settings and practices, they share many of the conclusions described in this section (e.g., Bødker, 1991).
6. Note that the field also explicitly discusses social and cultural embeddedness, which I leave unaddressed in this paper. See Dourish (2001) and Clancey (1997) for extensive accounts.
7. Heidegger's (1927/1986) language is dense and full of original terms he felt he needed to use in order to say precisely what he wanted. The original language regarding the ready-to-hand mode of the hammer showing up in the skilled carpenter's activity is "*Das Hämmerns selbst entdeckt die spezifische 'Handlichkeit' des Hammers. Die Seinsart von Zeug, in der es sich von ihm selbst her offenbart, nennen wir die Zuhandenheit*" (p. 69). Here, the word *Zeug* is translated by Dreyfus (1990) as equipment, to be placed in contrast to the kinds of things we usually call objects in our scientific mode of understanding, since the mode of being of equipment can only be understood as an "in order to" (an affordance, as it where; cf. Gibson, 1979), that is, linked to other equipment having a bearing on each other in a referential whole (Dreyfus, 1990). Sometimes interacting with the world leads to conflict, which then leads to another mode of being called present-at-hand: "*Das nächstzuhandene Seinde kann im Besorgen als unverwendbar, als nicht zugerichtetfür seine bestimmte Verwendung angetroffen werden. ... In solchem Entdecken der Unverwendbarkeit fallt das Zeug auf. Das Auffallen gibt das zuhandene Zeug in einer gewissen Unzuhandenheit. ...* [after which] *Die pure Vorhandenheit meldet sich am Zeug"* (Heidegger, 1927/1986, p. 73).
8. Several intelligent examples of using the Wii, engineered by Johnny Lee, can be found at http://www.wiimoteproject.com/
9. For many intriguing examples of what this amounts to in everyday life, see Suri & IDEO (2005)
10. The book was originally published in 1988 as *The Psychology of Everyday Things.*
11. In practice it is very difficult to really incorporate end users in the design process. The term *participatory design* has been used for various practices in which there is either more or less actual user involvement (Steen, 2008).

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All correspondence should be addressed to

Jelle van Dijk
Research Centre for Product Development
Utrecht University of Applied Sciences
PO Box 182, 3500 AD Utrecht,
The Netherlands
Jelle.vandijk@hu.nl

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THE EFFECT OF CUE MEDIA ON RECOLLECTIONS

Elise van den Hoven
Industrial Design Department
Eindhoven University of Technology
The Netherlands

Berry Eggen
Industrial Design Department
Eindhoven University of Technology
The Netherlands

Abstract: *External cognition concerns knowledge that is embedded in our everyday lives and environment. One type of knowledge is memories, recollections of events that occurred in the past. So how do we remember them? One way this can be done is through cuing and reconstructing. These cues can be internal, in our minds, or in our everyday environment. In this paper we look at memory cues in our environment by comparing the effect of cue modality (odor, physical artifact, photo, sound, and video) on the number of memory details people had from a unique one-day real-life event. Contrary to expectation, the no-cue condition (in effect, only a question asking the participants to write down their memories) created on average significantly more memory-details than the cued conditions.*

Keywords: *external cognition, memory cuing, autobiographical memory, augmented memory system.*

INTRODUCTION

Autotopography (González, 1995) studies personal collections of physical artifacts that serve as a memory landscape to the owner. These artifacts, such as photos, souvenirs, furniture, or jewelry, physically shape an autobiography because they link to memories that are important to the owner. Since those memories are important to the owner, the artifacts that link to them are also important; however, this link of significance is often imperceptible and unknown to other people. A collection of artifacts, its arrangement (such as a home altar), and its location (stored in the attic or placed in the middle of the living room) represent a part of the owner's memory, history, and thus identity (Cohen, 1996). At the same time, these artifacts might represent desire, identification, and social relations, and therefore establish a form of self-representation.

A concept related to autotopography is called distributed cognition (Hollan, Hutchins, & Kirsh, 2000; Hutchins, 1995; Perry, 2003; Rogers, 1997), which also studies the interaction between the physical world and human cognitive processes. *Distributed cognition* (Dcog) represents a system of activity that includes all relevant components of an activity, such as the people, the interaction between people, the media used, and the environment within which

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the activity takes place, including tools and artifacts. Dcog is a new and not yet well-defined framework for understanding human activity that arose from the idea that cognition is not limited to within the heads of people (internal cognition), but can also be brought into the real world (external cognition) of physical artifacts and their surroundings. *External cognition* was first coined in the context of graphical representations by Scaife and Rogers (1996) and, in a broader view, serves three functions (Preece, Rogers, & Sharp, 2002): (a) to simplify cognitive effort by using tools to compute for the individual, (b) to annotate and use cognitive tracing, such as writing shopping lists to support remembering or reshuffling the playing cards in your hand to see new game opportunities, and (c) to reduce memory load, for example, by using reminders or memory cues. Hollan et al. (2000) distinguish three types of distribution of cognitive processes: (a) distributed over members of a social group, (b) distributed over time, where earlier events influence later ones, and (c) involving coordination between internal and external (material/environmental) structures. One aspect of the latter type is the way external artifacts can be used to cue internal memory reconstruction, which is the focus of this paper.

Most of the Dcog research to date has been applied to collaborative and work environments. Therefore, a challenge for this field is to take the research outside the office into, for example, the home. In-home recollecting, which also involves cognition, people and physical artifacts, is the foundation of the experiment in this paper on the effect of different memory cues on memory recollections.

The autotopography and Dcog frameworks show that HCI specialists or interaction designers cannot focus simply on the interaction at hand: all related fields of the design-to-be must be studied. Therefore, when we had the opportunity to design a system that would support everyday recollecting, we started with a domain specialization into (autobiographical) memory by extensively researching the literature, terminology, and practices to pinpoint the key traditions within the field (Hoven & Eggen, 2005a; Hoven, Eggen, & Wessel, 2003). One of many things we learned from the field of autobiographical memory is that physical artifacts cannot “contain” memories but can serve as memory cues (for more information, see Hoven & Eggen, 2008), which is one means to retrieve memories. A cue (or trigger) is a stimulus that can help someone to retrieve information from long-term memory, but only if this cue is related to the to-be-retrieved memory. Anything and any type of information (spoken word, color, action, or person) could be a cue, as long as there is a link between the cue and the to-be-remembered event. Therefore, in this paper we look at what type of available media, specifically, photos, videos, sounds, smells, or physical artifacts, is most effective in cuing memories. Because our research background is in interaction design, we found it obvious that this should be tested in context. So-called real-life studies are not as straightforward as is typical in the autobiographical memory field, where memory is tested mainly with students under lab conditions. The following experiment, with accompanying literature overview and method development, will show that cognition definitely did not end as a source of information for interaction design, because we used and studied memory in order to inform the design of an interactive system (see Hoven & Eggen, 2008, for an overview of autobiographical memory theory resulting in design recommendations).

MEMORY CUING EXPERIMENT

Many people will recognize how browsing through a stack of old photos or revisiting childhood places brings back memories that may have not been thought of for many years. Indeed, a meta-analysis of the literature on context-dependent memory by Smith and Vela (2001) shows that, on average, reinstating a context has a beneficial effect on memory. This phenomenon is usually described in terms of the encoding-specificity principle (Tulving, 1983), which states that the probability of recall increases to the extent that environmental cues match the information that is stored in memory. Such a memory-enhancing cue may contain "item, associative, and/or contextual information that is encoded in the memory trace" (Smith & Vela, 2001, p. 206), and the process of recollection triggered by such cues is typically experienced as relatively involuntary and automatic (i.e., associative retrieval, Moscovitch, 1995; Schacter, 1996; or direct retrieval, Conway & Pleydell-Pearce, 2000).

Many previous studies on context dependency relied on college student samples, employing non-word letter combinations in laboratory settings (e.g., Chu & Downes, 2002; Rubin, Groth, & Goldsmith, 1984; Vaidya & Gabrieli, 2000). The question rises whether such results may be generalized towards everyday recollection. Only a limited number of studies examined the effect of real-life cues on autobiographical memory. In an influential case study, Wagenaar (1986) used only text as cue. He kept a diary of remarkable events happening each day over 6 years. More specifically, Wagenaar recorded for each event what happened, where, when it happened, and who was present. Later he tested which category of information was most efficient in cuing the complete set of information. He found that the "what" information was most helpful in retrieving the other categories, especially when followed by "when" information. However, the presentation of "when" information alone appeared quite useless.

Burt, Mitchell, Raggatt, Jones, and Cowan (1995) aimed at extending Wagenaar's findings by employing photographs as cues. The photos contained various combinations of what, where, and who information (activity, location, and participants, respectively). The authors concluded that the uniqueness of a cue determined, at least partly, its efficiency for retrieval (in terms of recall delays). Activity cues rendered the shortest and participant cues elicited the longest recall delays. Taken together, presenting people with information about what happened benefits memory recall better than any other information.

Another particularly effective cue for facilitating direct retrieval is odor. The phenomenon that odors quickly bring back memories has been dubbed Proustian memory (see, e.g., Chu & Downes, 2002), following novelist Marcel Proust's description of how smelling a Madeleine biscuit dipped in tea resulted in the sudden emergence of a powerful childhood memory. This Proustian phenomenon has found support in several laboratory studies (see Chu & Downes, 2002, for a short overview). Likewise, odors seem to facilitate autobiographical memory in a number of different ways. Rubin et al. (1984) presented participants with an odor, a verbal label, or a photograph corresponding to 16 common artifacts (e.g., baby powder, banana, peanuts, coffee, and cigarettes). After the cue presentation, participants had to describe the memory that it evoked and rate various qualities of that memory (e.g., vividness, emotionality, and rehearsal, the latter representing thoughts recalled or spoken of in the past). Although memories brought about by different cues were similar in terms of vividness and emotionality, odor-evoked memories were less rehearsed than memories cued by verbal labels and photos. In a more recent cross-modality cuing study, Herz and Schooler (2002) found that odor-cued autobiographical memories were rated as more emotional than memories triggered by visual and verbal label cues. In addition, odor tended to make participants feel more "brought back" to the original event. Thus, these results suggest that odor-evoked memories differ from memories triggered by other cues with respect to subjective qualities (i.e., sense of reliving).

Rationale for the Experiment

Various studies have investigated augmented memory systems (e.g., Balabanović, Chu, & Wolff, 2000; Frohlich & Murphy, 2000; Glos & Cassell, 1997; Piernot, Felciano, Stancel, Marsh, & Yvon, 1995; Shen, Lesh, & Vernier, 2003; Stevens, Abowd, Truong, & Vollmer, 2003), but the majority focused on "recording" memories (e.g., Bush, 1945; Clarkson, Mase, & Pentland, 2001; Fleck et al., 2002; Gemmell, Bell, Lueder, Drucker, & Wong, 2002; Ikei, Hirose, Hirota, & Hirose, 2003; Lamming & Flynn, 1994,) rather than on "retrieving." Some studies focused on "searching" and "finding" previously recorded information (e.g., Starner et al., 1997), which is not the same as retrieving memories. No interaction design study known by the authors focused on personal memory retrieval or reconstruction (although work by Schütte, 1998, and Harman, 2001, is related) done by means of cuing. Therefore, this is the focus of the experiment presented in this paper.

In addition to odor, photo, and artifact cue types, we included audio and video cues. The reason behind this decision originates from the industrial context in which this research took place. This study was part of a larger research project (Hoven, 2004; Hoven & Eggen, 2003) aiming at designing a future augmented memory system for in-home use through which a user can support his or her personal recollection process, that is, to help remembering past events. The cues employed in the present paper are expected to be available to users for recording and playing back from such a device in the near future. In addition, these modalities represent all the categories of media that have been addressed in prior augmented memory systems (Hoven & Eggen, 2008), and we have shown that these physical artifacts can be denoted as souvenirs, where the word *souvenir* means to remember (Hoven & Eggen, 2005b). As far as we know, there are no studies that *cued* autobiographical memory with audio or video. Our interest in which cue type generated the most memories or memory details, and therefore was most suitable to implement in an augmented memory system, resulted in the following research question: What is the effectiveness of the following five media types (artifact, picture, odor, sound, and video) on cuing 1-month old recollections of a real-life event?

Real Experiences and Memories

Obviously, the content of the memories that are retrieved spontaneously in response to cues is not comparable between participants. A solution to this problem, suggested by Chu and Downes (2002), is to arrange a series of naturalistic or real-life events for participants to experience. There are a number of studies that examined memory for standardized naturalistic events. To begin with, Hudson and Fivush (1991) joined kindergarten children on a 2-hour class field trip to a museum of archaeology. The children engaged in tasks such as digging for artifacts with archaeological tools and making clay models of the artifacts they found. Their memory was tested on the same day of the week, 6 weeks later, 1 year later, and 6 years later. After 6 weeks children had a good free recall of the event (i.e., to the posed question, "What happened when we went to the Jewish museum?"), but after 1 year, the children did not. However, when they were presented with photographs of their trip, 87% of the children retrieved a considerable number of additional details that could not be seen in the photos, even after 6 years. Pipe and Wilson (1994) took a somewhat different approach and studied autobiographical memories of pairs of children who took part in a magician's act. One of the children had to observe (observer role) while the other child was taught to be the magician's assistant (participant role). Ten days and 10 weeks later, the children were interviewed. The results show that action and artifact recall were facilitated by the presence of relevant cues (i.e., items relating to the magic tricks, e.g., a magic wand and magic gloves) but not by contextual cues (i.e., the same room, or items such as pink curtains and the magician's hat). In a second study following a similar design, Gee and Pipe (1995) found that children in the participant role (participants), who were interviewed using artifacts, recalled more correct information than the participants without artifacts and the observers in any of the two conditions. Interestingly, the authors report that "objects did not simply encourage children to repeat more correct information in free recall; rather, objects prompted children to report information that had not previously been reported" (p. 751).

Finally, Aggleton and Waskett (1999) studied adults' memory of a visit to a specific Viking-museum that included a fixed tour through several scenes with distinctive odors (burnt wood, apples, rubbish acrid, beef, fish market, rope/tar, and earthy). On average 6 years later, the participants filled in questionnaires about the various displays in the museum tour, regarding, for example, types of clothing and jewelry worn by the Vikings. Compared to a baseline no-odor condition, the presence of the original museum odors during testing rendered more correct information than the presence of other odors that had not been present during the original tour. Thus, in addition to evoking qualitatively different autobiographical memories (i.e., judgments of emotionality or sense of reliving; Herz & Schooler, 2002), odors seem to improve the recall of details of real-life events.

All in all, reminiscent of results of laboratory studies on context-dependent memory, studies on the effectiveness of retrieval cues on autobiographical memory suggest that offering reminders of the encoding context, such as artifacts, photographs, or smells, facilitates recall. However, the question rises as to what type of retrieval cue is most effective in terms of eliciting the most detailed recollection. The aim of the present study was to directly compare the detail of autobiographical memories triggered by retrieval cues of different modalities, specifically odors, physical artifacts, photos, audio, and video.

Because our interest was in the effect of different cuing types on autobiographical memory detail (i.e., the event memory was defined as one memory, the differences in cue types could only be found in the details of this memory), we devised a method to quantify the number of generated memory units based on the model of autobiographical memory proposed by Conway & Pleydell-Pearce (2000). They specified three basic levels of autobiographical knowledge, namely (a) life-time periods, usually spanning years, (b) general events, taking place over several days up to months and, (c) event-specific knowledge (ESK), where the event lasts seconds, minutes, or at most hours. Since the present study asked the participants to recall a unique one-day event, the analysis of their written accounts specifically focused on ESKs.

In sum, the present study aimed at comparing the effect of different cue types on autobiographical recall of a real-life situation. For that purpose, participants engaged in standardized activities during a visit to a history-themed park. One month later, their recall of those activities was tested, employing a photograph, artifact, odor, audio, or video cue.

Experiment Method

Participants

Participants were 34 employees or students at the Philips Research Laboratories Eindhoven or the Eindhoven University of Technology. They responded to e-mail and company newsletter announcements inviting people to take part in an outing to a historical theme park (Archeon; see below). In order to approach a true day out, participants were instructed to bring at least one person of the other gender (not necessarily their spouse), resulting in a total of 69 participants. One participant dropped out prior to a final testing session (due to insufficient knowledge of the Dutch language, which was a requirement for the participants since the study was conducted in Dutch) resulting in a total of 59 participants (28 men, 31 women) in the cue–no cue conditions and 9 participants in the control group (no cue–no cue condition), to check for order effects solely. Unless indicated otherwise, the data in this paper are from the 59 participants in the cue-no cue conditions. None of the 69 participants had visited the Archeon theme park before.

Apparatus

The devices used during the test session (see below) were (a) Sennheiser HD 500 "fusion" headphones, (b) Philips AX 1001 portable CD-players, and (c) Philips NO. 21PV715/39, 21-inch BlackLine color TV-VCR combinations. The devices were provided for each participant individually in the appropriate cue conditions (sound and video cues).

Materials

Free recall was tested by means of two questionnaires, each containing two questions. Each questionnaire asked for a complete and detailed description of the event "making felt" or "making a fibula," activities that all participants engaged in during their visit to Archeon. Participants were encouraged to write down anything that came to mind related to the particular event and to use as much paper as required, without a time limitation. The second question asked for other memories that were not directly related to the initial question but that came up while answering the first question (associations). All participants had to complete both questionnaires, one for each activity and one with cue, the other one without. Activity and cue choice were counterbalanced across participants. A control group of participants (n = 9) formed the no cue–no cue situation.

Five types of cues were used to aid recall for the condition groups. Two variants of each cue type were used, each referring to one of the two standardized events (making felt or a fibula). Cues were (a) the felt bracelet or the ancient-design copper-wire safety pin (fibula) handcrafted by the participants themselves during the event (artifact cues); (b) a 10 x 15 cm color photo of one of the two activities, showing the activity, the location, and the participants (photo cues); (c) vanilla incense or olive-soap water in small jars with punctured lids (odor cues); (d) a 20-second audio clip from either event containing voices, activity-related sounds, and background noise, presented through a CD-player and headphones (sound cues), and (e) a 20-second color video clip from either activity (also showing the activity, the location, and the participants), presented through a TV, VCR and headphones (video cues). The cues were specific for each tour group, meaning that the artifact, photo, audio, or video used as cues during the questionnaire phase were the result of that participant's group experience during the Archeon tour phase.

Procedure

The study consisted of two phases. The first phase (Archeon visit) consisted of a trip to Archeon,[1] a history-themed park in the Netherlands. The architectural styles of the park's areas reflect various periods from the past (i.e., prehistory, Roman period, and the Middle Ages), thus creating a unique setting. The Archeon visit took place while the park was closed to other visitors. Throughout the day, every participant took part in five handcrafting activities, each lasting 20 minutes, at five different locations and explained by Archeon employees in historical costumes. The activities were (a) making a fibula by using a hammer, a pair of nippers, and a piece of wood, while the room was smelling of vanilla incense; (b) making felt by turning washed sheep's wool into felt while using olive soap, and knotting a felt bracelet; (c) making a candle by heating a wax plate between one's hands, rolling it up with a taper in the center, and finishing the edges; (d) making a rope with a special tool in which three thin ropes were twisted into one stronger rope, and (e) writing in calligraphy, using a feather and ink to write in a special ancient typeface, with excess ink removed with sand.

The participants were divided into small groups of 12 people, who participated in the activities in the fixed order described above, although each group started with a different activity. Two experimenters accompanied each group in order to videotape and take photographs of the activities, which would later be used as cues. At the end of the day, the experiment leader collected the handcrafted artifacts and explained to the participants that they would get the artifacts back after filling in questionnaires later. During the first phase, the memory-oriented character of the authors' research objectives was not mentioned to the participants.

The second phase of the study (test session) consisted of completing two questionnaires. Each questionnaire asked for recall of one of two standardized activities ("making a fibula" and "making felt"), selected after pilot testing of the activities and the questionnaires with two pilot participants at Archeon. Each participant completed a questionnaire for one of these activities in the presence of one of five recall cues (artifact; picture; odor; sound; video) of the corresponding situation (cue condition). The questionnaire for the other activity was completed in the absence of any recall cues (no-cue condition).

To approach a real-life situation, the participants were tested in the living room of HomeLab, a controlled laboratory environment closely resembling a three-bedroom house, located on the premises of the Philips Research Laboratories in Eindhoven. The participants were tested with the same cue condition in small groups (a maximum of five participants). Participants sat at a large living room table, adapted by means of wooden panels and headphones such that they could not see each other or perceive any cues from the others. In the conditions involving audio, the participants were told to wear the headphones at all times and keep the volume level fixed, in order to prevent them from hearing other participants' cues. At the end of the session, participants were debriefed and received the artifacts that they had handcrafted during their Archeon visit.

DATA CODING AND ANALYSIS

Comparing written accounts from different people describing their unique memories is not an easy task: Even if people participate in the same event, they can write about completely different topics or issues, depending on what they remember at that point in time. Comparing accounts quantitatively over different events is even more complicated. Still, developing a quantitative method for the analysis of written accounts is important for research on autobiographical memory, since it makes it possible to compare recollections from different people in different experimental conditions.

Most studies conducted to compare recollections from different people or different conditions focus on the validity of the memories, for instance, by asking questions about facts and checking whether the answers are "right" or "wrong" (e.g., Aggleton & Waskett, 1999; Gee & Pipe, 1995; Wagenaar, 1986). Other studies focus on aspects other than the content of the memories, for instance, the vividness or emotionality of the recollection (e.g., Herz & Schooler, 2002; Rubin et al., 1984).

For this paper, we explored six existing methods for the analysis of free recall accounts. They will be described in order of increasing complexity. The first coding procedure for autobiographical memory-cued recall is described by Chu and Downes (2002). They transcribed spoken responses and used single sentences as the unit of analysis. If sentences were long, they were split up into smaller units, when appropriate. Chu and Downes used a double-cuing methodology, which means that twice the participant was asked for free recall of a specific event, where the first time no cue was present and the second time a cue was present; Chu and Downes chose an odor. Later, the first free-recall accounts were used as a measure for verbosity, and for the second accounts the sentences were scored on the content being either old, meaning it was mentioned before, or new. The focus of this method was on a quantitative measure of the number of new sentences produced in 3 minutes of free-recall speech after the second cue, while checking the validity of the utterances.

The second method categorizes remarks. Pipe and Wilson (1994) asked children to freely recall a specific activity in which they had participated. After transcribing the interviews the statements were first checked for validity and later content-wise coded for "valid" categories, such as people, actions, artifacts, the context of the event, the accident (part of the activity the children took part in), and "error" categories, that is, distortions (based on actions that did occur but were changed), intrusions (based on actions that did not occur) and artifact errors. The same method was used by Murachver, Pipe, Gordon, Owens, and Fivush (1996) but with two additions: First, they added the category "generalizations," which was used when one utterance contained several actions or artifacts, and second, they checked whether the order of the utterances corresponded to the original order of the activity's events.

A more precise method, by Hudson and Fivush (1991), contained one additional coding rule compared to the previous two examples. That is, it started with the basic coding unit, which they called a "proposition." A proposition was defined as a statement containing an argument and a predicate. After the propositions were identified in the transcribed speech accounts, they were analyzed based on the content. The "valid" propositions were coded as either an act (action), description (of the environment), or elaboration (repetitions including supplementary information), and the "error" propositions as intrusions (based on actions that did not occur). Meanwhile, the free-recall account method by Brown and Kulik (1977) was the only method that involved participant-written free-recall accounts and did not involve checking for validity. Brown and Kulik studied personal shocks and flashbulb memories—vivid and detailed memories of dramatic world events, such as the 9/11 attacks—asking their participants to write down their free-recall accounts. They analyzed the stories by counting the total number of words as an objective measure on elaboration and by coding the content into the following categories: place, ongoing event, informant, affect on others, own affect, and aftermath.

Finally, Poole and White (1993) used syntactic units (SU) in their method for analyzing narrative responses. They defined an SU as the words that describe either an actor (he), an action (took), a direct object (a pen), physical traits (he is tall), qualifiers (he is not very tall), prepositional phrases (in the chair), temporal information (then), or they used quotes from the encoding event, where each of those categories is counted as a single unit. In addition to the category, the words were also marked as accurate, inaccurate, or uncertain. The interrater agreements for these three judgment categories were 84%, 81% and 87%, respectively.

The method described in our analysis, however, was developed to compare different free-recall accounts quantitatively, and therefore did not check any of the recall accounts for validity, thus making the error and generalization categories by Pipe and Wilson (1994), Murachver et al. (1996), and Hudson and Fivush (1991) superfluous. The content of the accounts was checked for the following categories: actions, objects, and context, as well as perceptions and reflections. The latter two types were included because, together, those five categories were assumed to cover the majority of utterances. Location was not used as a coding category because in this cuing study, location was part of the primary recall cue ("making felt at Archeon" or "making a fibula at Archeon"). The objective measure from Brown and Kulik (1977), which counts the total number of words per free recall, was incorporated in our method to have an objective measure of elaboration but, since this is rather straightforward, it will not be elaborated in this paper. In addition, our method drew on only the detail-level component of Poole and White's (1993) SU method, although it is not based on content but rather on grammar. Our approach, then, makes it possible to quantitatively compare free-recall accounts of different events.

Analysis Method

The objective of this study was to determine the influence of cues on recall of personal recollections in a social setting; therefore the validity of the recollections was not of interest. It is possible that a person recalling memories can consciously or unconsciously alter the truth but that is his/her responsibility. Because the method was intended to be objective and quantitative, it was decided not to interpret the contents of the written accounts but rather use a method based on grammar. In this specific situation, the texts were in Dutch and thus the method implemented Dutch grammar, but it is believed that the structure and background of the method would also hold for other languages. Participants' accounts were made anonymous and scored by two independent raters, who were trained for about 10 hours each on pilot experiment accounts.

With the intention to be able to quantify memories objectively in free-recall accounts, the specificity theory of Conway and Pleydell-Pearce (2000) was applied. This theory describes three hierarchical levels in autobiographical memory, namely: (a) lifetime periods, spanning years of one's life, (b) general events, which recur over a time span of days or months, and (c) event-specific knowledge (ESK), lasting seconds or at most hours. ESKs are the details in recollections, the lowest level of specificity, and thus suitable for counting free-recall accounts of a one-day unique event. We decided to make ESKs the starting point of the method, which consisted of three phases. The first phase concerned identifying an ESK, the second phase involved counting the details within the identified ESK, and the third phase categorized the general content of the ESK. Each sentence of the written accounts was analyzed according to the three phases.

The first phase of the method involved reading the sentence and checking whether it contained a description of a memory. If a sentence described something other than a memory, it was not an ESK and was removed from further analysis. For example, the statement "I am not so sure about that" refers to the previous sentence, but is no actual recollection. However, if the meaning of the statement was in doubt, the sentence was counted. The same held for repetitions: If two sentences were exactly the same and following each other, one of them was not counted. In the material evaluated, repetitions did not occur, and non-memory remarks were made in only a small number of cases. When a sentence contained a description of a memory, the method was implemented by identifying the ESK as the finite verb (*persoonsvorm* in Dutch), the accompanying subject (*onderwerp*) and direct or indirect object (*lijdend*/*oorzakelijk voorwerp* or *belanghebbend voorwerp*). This means that, in most cases, one ESK was represented by one sentence, although sometimes two sentences formed one ESK or one sentence formed two ESKs, depending on the number of finite verbs. Often a sentence with more than one ESK was easily recognized by conjunctions (*voegwoorden*). In the texts, ESKs were notated with square brackets (i.e., [ ]), making it possible to check the analyzed texts afterwards.

Since one ESK can contain many more details than another but is counted as one memory unit, it was decided to score each ESK on the number of ESK details. This was implemented in the second phase by counting the number of information-providing words. To facilitate this process, we developed a custom-made document containing a list of word-counting instructions and examples for diverse words and sentence structures. This document was given to the raters as a work of reference for the ESK-detail counting rules. We do not claim that this list is exhaustive nor in accord with linguistics standards; nevertheless, it was complete enough for the method described in this paper.

In short, this is the articulated process for counting ESK details[2] that we applied in our study. The finite verb (even if it was implied, which rarely occurred) and subject were always counted as one detail each. Articles were never counted and most other words were counted as one detail. There were some exceptions for the remaining words, though. In Dutch, compound, reflexive, progressive, and perfective verbs can consist of two words but were counted as one detail. Inchoative verbs can contain four words and were counted as two. Modal verbs were counted, whereas auxiliary verbs were not. Since diminutives, created by adding a few letters to the end of a noun, are often used in Dutch spoken language, and therefore also in the accounts, they were not counted as extra details. In order for the method to be clear and not too complicated, it was decided that both coordinating and subordinating conjunctions were not counted. Relative pronouns were not counted when they referred to words in the same sentence (without adding information). On the other hand, when they referred to the previous sentence (which does add information), they were counted as one detail. Demonstrative adjectives and demonstrative pronouns were counted. Adverbs were counted as one detail and prenominal adverbs (junctions of several adverbs in Dutch) were counted as two details. Adjectives and nouns were usually counted as one detail unless the word was a junction of two information-adding words that could also be used as two separate words; these were counted as two details. The final category contained a number of expressions that could be replaced by one word and therefore had to be counted as one. The notation for the ESK details concerned cumulative numbers between angle brackets behind the word counted. For example, “[I <1> used <2> an old <3> hammer <4>.]” consists of 1 ESK and 4 ESK details.

In the third phase of the method, each ESK had to be categorized. The rationale for this step was to check for effects of cues on the general content of recollections, without interpreting the accounts or the validity. Based on suggestions by Martin Conway (personal communication, spring 2003), the following types were designated as useful descriptors of ESK information: (a) perceptual information, describing the senses, such as, “There was a strange smell in the room” (perception-specific knowledge, PSK); (b) reflection, opinion, or emotion-related information, such as “I was thinking to myself...” (reflection-specific knowledge, RSK); (c) state information on the situation or the environment, such as “The room looked ancient” (state-specific knowledge; SSK); (d) action information, such as “He bent the copper wire” (action-specific knowledge; ASK), and (e) object information, such as “The fibula consists of two parts” (object-specific knowledge; OSK). However two further issues complicated the outright application of these descriptors: First, some ESKs could contain more than one ESK type, and, second, the OSK was an exceptional case in this study (i.e., the foundation for the memory accounts was based on the activities of making felt or a fibula, thus biasing this type of ESK). To address these concerns, a hierarchical order was determined. Based on the analysis of the pilot test, we found that some ESKs were mentioned less frequently than others (e.g., the PSK was anticipated to be mentioned less often then the RSK). And, to prevent an OSK bias from influencing the results for the other knowledge types, the hierarchy was ordered based on an assumed increasing frequency, in which the raters first checked for a PSK, presumable the type with the lowest probability. If this ESK type was not found, the raters then checked for an RSK, then an SSK, followed by an ASK, and finally for an OSK. For the notation during the free-recall analysis, the identified knowledge types were written on the accounts above the corresponding ESK. In Table 1, a part of one of the coded accounts is shown as an example.

Results of the Analysis Method

In order to calculate the interrater reliability for each of the three phases of the method, the two raters assessed all free-recall accounts from this study. For an overview on the descriptive statistics of an average account, see Table 2. This table shows that an average account contained 164 words, 18.5 ESKs, and 127.1 ESK details. These 18.5 ESKs can be subdivided into 0.5 PSKs, 1.6 RSKs, 3.9 SSKs, 11.3 ASKs and 1.2 OSKs.

Table 1. Example of Notations and Scoring for Event-Specific Knowledge.

Original Dutch Account	Text Translated into English	Notation Style in the Original Account	Scores
In het gebouwtje liepen we door naar achteren, waar we in een nogal rokerige en warme ruimte kwamen met een open haard.	We walked to the back of the building, where we came in quite a smoky and warm room with a fireplace.	[In <1> het gebouwtje <2> liepen <3> we <4> door <5> naar <6> achteren <7>], [waar we <1> in <2> een nogal <3> rokerige <4> en warme <5> ruimte <6> kwamen <7> met <8> een open <9> haard <10>].	ESK = 2 ESK-details = (7+10) 17 ESK-types = 2 ASKs words = 22

Note: An example of coded text, according to the method described in this paper (Column 1). In Column 2, the Dutch text is translated into English, in Column 3 the notation style is shown, and in the last column the total number of ESKs, ESK details, ESK types, and words counted in the text are given.

Interrater reliability was high for both the number of ESKs (Intraclass Correlation Coefficient, *ICC* = .97) and the number of ESK details (*ICC* = .99). Overall, ASKs were the most frequently identified ESK type in the free-call accounts. More information on this coding method is provided in Hoven (2004).

Table 2. Summary of Interrater Reliability.

	Average number *n* (min, max)	Interrater reliability
words	164 (22, 455)	N.A.
ESKs	18.5 (3, 50)	0.97
ESK details	127.1 (18, 340)	0.99
PSK	0.5 (0, 4)	0.78
RSK	1.6 (0, 9.5)	0.84
SSK	3.9 (0, 14.5)	0.76
ASK	11.3 (0, 28.5)	0.90
OSK	1.2 (0, 5.5)	0.49

Note: The average numbers per account (Column 2) and interrater reliability (Column 3) of ESKs (Row 2), the number of ESK details (Row 3), the numbers for each SK type (Rows 4-8), and the number of words (Row 1). The numbers between parentheses (in Column 2) show the minimum and maximum number counted.

RESULTS OF THE MEMORY-CUING EXPERIMENT

Table 3 summarizes the results for the number of ESKs, number of ESK details, and associations (other memories that were not directly related to the initial event). In order to address the question of what cue type was most effective, the data were analyzed by means of

Table 3. Average Number of ESKs, ESK Details, and Associations for the Artifact, Photo, Odor, Sound, and Video Cue Groups Under No-Cue and Cue Conditions.

		Artifact (*n* = 12)	Photo (*n* = 12)	Odor (*n* = 12)	Sound (*n* = 11)	Video (*n* = 12)
ESK	No Cue	19.88 (7.35)	19.54 (9.36)	21.54 (9.93)	16.82 (8.26)	16.33 (12.94)
	Cue	15.33 (4.56)	17.54 (10.54)	19.67 (11.02)	15.55 (9.01)	17.33 (14.45)
ESK-details	No Cue	7.01 (0.81)	6.71 (1.22)	6.89 (0.81)	6.14 (0.96)	6.74 (1.18)
	Cue	7.07 (0.70)	6.59 (1.23)	7.16 (1.45)	6.82 (0.99)	6.55 (0.94)
Associations	No Cue	3.63 (2.59)	6.00 (3.25)	3.92 (4.36)	2.73 (1.85)	2.92 (2.70)
	Cue	5.04 (3.90)	4.13 (3.57)	2.88 (2.85)	3.18 (3.11)	3.83 (3.04)

Note: Standard deviations are in parentheses.

five (cue type: artifact, picture, odor, sound, video) x 2 (condition: cue vs. no-cue) ANOVAs with repeated measures on the last factor. The analyses of the number of ESKs and number of ESK details rendered rather similar results in that a significant main effect for condition emerged, $F(1, 54) = 4.62$, $p < .05$, and, $F(1, 54) = 4.69$, $p < .05$ for number of ESKs and for number of ESK details, respectively. Contrary to expectation, however, cuing elicited lower numbers of ESKs and ESK details than the no-cue condition. For both analyses, the cue type by condition interaction remained non-significant, $F(4, 54) = 1.22$, $p = .31$ and $F(4, 54) = 1.78$, $p = .15$ for numbers of ESKs and ESK details, respectively. As for the number of associations, the 5 (cue type) x 2 (condition) repeated measures ANOVA did not show significant effects, all *F*s < 1.4.

The free-call recollections data was collected during a period of 29 to 43 days after the Archeon visit. On average, four participants per day completed the questionnaires, resulting in the latter participants recalling their Archeon visit a full 2 weeks later than the early participants. In order to see whether differences in delay affected the results, separate correlations between time since their Archeon visit and the total number of ESKs and association ESKs were calculated. Both correlations did not reach significance (ESK: $r = -0.13$, $p = 0.28$; Association ESKs: $r = -0.07$, $p = 0.58$).

DISCUSSION

Memory-Cuing Experiment

The goal of the present study was to explore which type of retrieval cue is most effective in eliciting details of autobiographical memories of a real-life event. In light of earlier findings, it was expected that artifact and photo cues would generate more detailed memories (i.e., more ESKs of this event; see Gee & Pipe, 1995; Hudson & Fivush, 1991) than a no-cue (or text) situation, and that odor cues would generate more detailed memories than other cue modalities (see Aggleton & Waskett, 1999). However, the results show that no particular cue type elicited superior recall. Contrary to expectation, the absence rather than the presence of a retrieval cue-enhanced autobiographical recall in that more ESKs were reported. This finding is similar to the results of Chu and Downes (2002), who indicated that visual cues elicited fewer sentences than verbal cues. However, the present finding that, overall, fewer units of ESKs were reported in the cue condition is inconsistent with previous reports that recall is enhanced by the use of concrete cues (i.e., odor, Aggleton & Waskett, 1999; odor, Chu & Downes, 2002; photo & artifact, Hudson & Fivush, 1991; artifact, Gee & Pipe, 1995; Pipe & Wilson, 1994). How may this discrepancy be explained? One possibility is the use of different scoring methods. We devised a scoring method that was specifically aimed at quantifying ESKs (Conway & Pleydell-Pearce, 2000) and quantifying information-carrying words in these ESKs based on grammar instead of content. This method seems to deviate from other scoring methods and therefore makes it difficult to compare the results. The methods employed in previous studies categorized free-recall responses into (broad) categories (e.g., Brown & Kulik, 1977; Chu & Downes, 2002; Hudson & Fivush, 1991; Murachver et al., 1996; Pipe & Wilson, 1994), used answers on multiple choice items (e.g., Aggleton & Waskett, 1999), focused on validity (e.g., Aggleton & Waskett, 1999; Gee & Pipe, 1995; Hudson & Fivush, 1991; Murachver et al, 1996; Pipe & Wilson, 1994; Poole & White, 1993; Wagenaar, 1986), or emphasized the qualities of the recollections, such as vividness (e.g., Herz & Schooler, 2002; Rubin et al., 1984). Thus, possibly, the ESK quantification method employed in the present study provides a relatively sensitive measure to detect subtle differences in detailed recall.

Whether the ESK quantification method influenced the results of this study is difficult to confirm. Comparing this method with other methods is difficult because these other methods either do not have specific rules or they focused primarily on validity. Only one method (in a different type of study) can be more or less compared with the method used in this paper: However, while Brown and Kulik’s (1977) method did organize written accounts into useful content categories for their topic of flashbulb memories, the method did not check for ESKs or ESK details. In general, one can say that, to the authors’ knowledge, the method described in this paper is the most precise and detailed one for quantitatively counting ESKs in written free-recall accounts; perhaps that is why it yielded high interrater reliability scores.

The mechanism underlying the current finding, that the no-cue condition elicited more memory details than the cue conditions, also could originate from the cues used. They might not have been comparable, for example, in aspects such as properties, typicality, or uniqueness. For example, we know from word cues that certain properties, such as imagery, concreteness, and meaningfulness, have an effect on the age of the recalled autobiographical memories (Rubin & Schulkind, 1997). And for prospective memory, it was found that cue typicality (Mäntylä, 1993) and cue target uniqueness (Mäntylä & Nilsson, 1988) both have an effect on the numbers of successfully recalled memories, in the sense that typical and unique cues were more successful. All of these cue aspects could have played a role in the experiment described in this paper. However, as far as the authors are aware, these effects have not been studied comparing cues consisting of different combinations of modalities.

More problematic methodological difficulties arise when cuing memories from real-life events are the topic of investigation. In real-life events, the possibilities for systematically manipulating different cue aspects are limited because the cues should be a natural part of the context of the event to guarantee ecological validity. Moreover, it should be possible to retrieve cues from the actual recordings of the real-time event that took place in the past. For the study presented in this paper that aimed at comparing different combinations of modalities, there was not much choice as far as the cues were concerned, in that the activity objects were fixed, just as the smells were. During each activity, one particular smell was present in the room and each participant created one object. For the videos, a short clip was selected that contained footage showing an overview of the room, a still of such an overview was printed for the photo cue; the sounds in the video clip were the typical sounds of the activity, and these same sounds were used as the sound cue. Even though cue aspects, such as typicality and uniqueness, could well have played a role in the results of our experiment, we do not see how we could have manipulated these cue aspects in such a real-life event.

Another interpretation may be that presenting cues makes people restrict their focus to certain perceptual aspects of their autobiographical memory. For example, looking at a photograph might prompt people to focus on what can be seen in that particular picture only and to not think about the events before or after the photo was taken. Chu and Downes (2002) speculate that visual cues induce a selective search strategy. Alternatively, according to Conway and Pleydell-Pearce's (2000) model, perceptual cues trigger autobiographical recall through direct retrieval. More specifically, direct retrieval involves the activation of autobiographical knowledge at the bottom level of recall (that of ESK), spreading to the upper levels of general events and lifetime periods. Perhaps when memories are elicited in this fashion, people do not easily engage in a more deliberate search strategy that would produce more or other types of detail. In contrast, a free-recall question, such as employed in the no-cue condition, would prompt a more generative search strategy, in which the ESK is accessed from upper levels of the hierarchical autobiographical knowledge base. Perhaps such a top-down search strategy is more flexible, leaving room for more ESK details to emerge. Future studies could shed more light on this issue.

Another explanation for the result that the no-cue condition generated more memory details than the cue conditions could be that external cues in themselves already contain rich sources of information that people might find unnecessary to repeat in their memory description. This perspective can be difficult or even impossible to extract by outsiders. For example, when an audio recording of an event includes the sound of heavy rains, this weather condition might be obvious to the person who hears it as a cue, but he/she might not note this in a memory description because this information is already provided by the cue itself. On the other hand, an outsider who was not present during the recording might not recognize the sound as being rain. Therefore it is hard, if not impossible, for the experimenter in memory studies to judge how much embedded information in the cues remains unarticulated or unperceived by the participant.

A methodological issue that deserves consideration is the fact that each participant had to bring a friend, which makes them more likely to talk about their experiences and thus rehearse their memories together in between the Archeon visit and the test session. This may have obscured condition differences. Another issue is the rather small number of participants in the various cue conditions, which leaves room for influences of personal preference and age. Nevertheless, it is not obvious how the finding that the cue condition had fewer ESKs than the no-cue condition can be attributed to a lack of power.

Analysis Method

The main conclusion from evaluating the new method presented in this paper is that raters can objectively quantify the number of ESKs and ESK details in free-recall written accounts. This means that a workable definition of ESK has been found. In addition to the first two phases of the method, the identification of ESKs and ESK details, there was a third phase of subdividing the ESKs into different categories, namely: perception, reflection, state, action and object-specific knowledge. The value of this third phase could not really be evaluated, since the test-study's accounts focused on activities, leading to 61% ASKs. It has to be shown in different experimental settings whether these distinctions are useful for psychological research, especially the SSK, since Pipe and Wilson (1994) found that very few statements in free recall related to the context of the experience.

Comparing the results presented above with results from previous studies is difficult since only one study can be more or less compared with this method, namely Brown and Kulik (1977). The other studies either did not have specific rules that can be compared or they focused too much on validity, making their categories incomparable with the ones used in this paper. Brown and Kulik's method, on the other hand, did not check for ESKs or ESK details, but it did organize written accounts into useful content categories, such as place and informant. Their interrater agreements (also based on two raters trained for this one-time experiment) were high, namely 90%, but not as high as for this method. This lower value might be due to the fact that they did not work out in detail which unit would be used for the categorization, as we did for our ESKs. In general, one can say that the method described in this paper is the most precise and detailed one known to the authors for quantitatively counting ESKs in written free-recall accounts that also yielded high interrater reliability scores.

What Does This Mean for the Design of an Augmented Memory System?

Contrary to expectations, the no-cue condition (text cue) was most effective in generating ESKs. Because ESKs are the smallest units of memory, they therefore have to be supported by an augmented memory system. The results of this experiment suggest that when designing systems or experiences for "remembering as much as possible," text should be the main cue type.

However, remembering-as-much-as-possible is only one aspect of the recollection process. Therefore, it might be unwise to rely only on text cues if the goal is to capture other aspects of remembering or to surface multiple aspects of recollection, since many dimensions of recollecting were not tested in this experiment. Examples of these additional dimensions are pleasure while recollecting, the ability to change the user's mood, the intensity of the memory, the effect of cues a long time after the memory-creation, the speed of the memory recall, and potential personal preferences for certain cue types. Although these dimensions were not investigated in this study, we believe that, for example, the pleasure of the recall process is larger with photos than with text only, especially in a situation where someone is communicating his/her memories to somebody else.

All in all, contrary to previous research, the present study shows that the no-cue condition (only text) for the recall of a real-life event generated significantly more ESKs compared to any of the cue conditions (artifact, picture, odor, sound and video). It may be that these cues have a filtering effect on the internal memory search, resulting in fewer autobiographical memories. But at the same time, we presume that these cues can be beneficial for the recollection process in certain conditions. Future studies may shed light on these possibilities.

What Does This Mean for Autotopography and External Cognition?

The issue mentioned in the Discussion section that an external cue might already be a rich source of information that people do not identify or communicate easily, or would discount because it is self-evident, could be an interesting field for further study. Because "just as a photograph can take me back to a specific time and place, so can a pressed flower, a small seashell, or even a theater ticket stub" (Kollenbaum, 2002, p. 8); external cognition seems ubiquitous from a memory-recollecting perspective. Any physical artifact, environment, or even a person can serve as external cognition to a number of people. And this knowledge could be used while designing interactive systems. For example, incorporating existing artifacts that people already use and have a mental model of into the interaction with new systems, such as our souvenir interaction (Hoven & Eggen, 2005b) will open up new potential for design. For example, learnability could be lower and pleasure of use could be higher when incorporating artifacts that people already have decided to keep in their vicinity. In general, autotopography and Dcog should be studied in greater detail, for example, working on concept definitions and making inventories of the areas, since little research has been done so far. Future directions could also be based on combining the methods used in the DCog work with the topic of study described by the autotopography concept, particularly through experiments, more descriptive and observational approaches, or qualitative studies, such as ethnography. The strength of autotopography related to the topic of this paper is that it shows how important artifacts are for recall and that the use of these artifacts in the home is often implicit. Further development of the DCog concept would help, for example, to clarify the relation between autobiographical memory cuing and external cognition and make clear what distinguishes one from the other and how they complement each other.

CONCLUSIONS

A method was developed in order to analyze the number of autobiographical recollections in written free-recall accounts, without checking the validity. This method focuses on ESKs (Conway & Pleydell-Pearce, 2000), which were identified based on a grammatical method, thereby avoiding interpretation of the accounts. In addition to identifying individual ESKs, the number of details contained in each ESK was counted, and a general ESK type was identified (describing perception, reflection, state, action or object).

Following the raters' 10-hour of training on the method, the raters completed evaluation of each account within 5 to 10 minutes, on average, demonstrating the method's rather straightforward and ease of use. In addition, the high interrater reliability (.97 for the number of ESKs) shows that this method is an objective and reliable measure for a quantitative analysis of written accounts.

The purpose of the memory-cuing experiment was to examine what role various types of retrieval cues play in eliciting autobiographical memories. This knowledge is considered crucial for the design of a future hand-held device that supports users in reconstructing and sharing personal memories in their home environment. (For more information, see Hoven, 2004; Hoven & Eggen, 2008). An experiment was set up in which 69 adults participated in a novel, real-life event (i.e., a visit to a history-themed park). One month later, recall was tested in a laboratory living room setting using one of five cue types (photos, videos, sounds, odors, artifacts) and a no-cue baseline. Experimental results showed that the cue type groups did not differ with respect to the number of units of ESKs recalled. However, overall, cuing rendered a significantly lower number of ESKs than that provided by no cue (only text). This suggests, first, that providing cues as part of an augmented memory system may hamper the level of detail of autobiographical memories, and/or, second, that cues contain information that people may think is obvious and therefore might not want to repeat in their memory descriptions.

In general, we believe that text cues could result in reconstructed memories that provide the structure of a story. Simultaneously, other types of media could serve as a support for this story by filling in detailed aspects of these memories, that is, by means of physical artifact, photo, smell, sound, and video cues.

ENDNOTES

1. The website for Archeon is http://www.archeon.nl and includes information in English.
2. The grammar terms presented here are English translations of Dutch concepts. Therefore, the terms may not equate directly to similar terminology or linguistic application in English or any other language. Nevertheless, the rationales behind the articulated process for counting ESKs could be transferrable to the unique grammar applications of other linguistic codes.

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All correspondence should be addressed to:

Elise van den Hoven
Industrial Design Department
Eindhoven University of Technology
P. O. Box, 513
5600 MB Eindhoven
The Netherlands
e.v.d.hoven@tue.nl

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LESSONS LEARNED USING THEORY OF MIND METHODS TO INVESTIGATE USER SOCIAL AWARENESS IN VIRTUAL ROLE-PLAY

Lynne Hall
Department of Computing, Engineering and Technology,
Sunderland University, UK

Sarah Woods
School of Psychology,
University of Hertfordshire, UK

Marc Hall
Department of Computing, Engineering and Technology,
Sunderland University, UK

Abstract**:** *Theory of mind (ToM) methods were used to investigate children's interpretations of the social and emotional states of synthetic pedagogical characters, focusing on children's cognitive and affective empathic responses to characters in bullying scenarios and their social awareness and understanding of the characters' situations. Although cognitive approaches typically do not consider user social awareness and emotional understanding and their roles in interaction, this is critical for our research on empathic engagement. We present a novel approach focusing on story and character comprehension using concepts from ToM methods to understand children's interpretations of characters within virtual role play scenarios and compare these with an adult perspective. Our results identify that ToM methods offer considerable potential for determining user social awareness and emotional understanding, particularly highlighting that adults and children have different perspectives on how victims and bullies feel.*

Keywords: *Theory of mind, virtual role play, emotional understanding, synthetic characters, bullying.*

INTRODUCTION

Social learning is strongly related to cognitive development (Vygotsky, 1978), with emotions driving attention, learning, memory and other important mental and intellectual activities (McCombs, 1997, 2004), having a significant affect on cognitive processes (Picard, 1997). Social learning involves the development of an infinite set of intertwined abilities that continue throughout the lifespan and are moderated by experience and exposure.

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A range of approaches have been taken to support social and emotional learning, with increasing recognition of the potential of intelligent computer-assisted role-play environments (ICARPEs) to provide effective, appropriate, engaging, and pedagogical experiences (Imholz, 2008). ICARPEs provide virtual learning environments (VLEs) populated by synthetic characters engaged in role-play scenarios that can offer users safe and compelling access to sensitive social and emotional experiences (Dautenhahn, Bond, Canamero, & Edmonds, 2002). A key issue in the evaluation of such VLEs is determining whether the children's responses are those that are intended by the creators of the VLE (Veletsianos, Scharber, & Doering, 2008), and whether children are demonstrating social awareness of character intentions (Berry, Butler, & de Rosis, 2005).

A wide variety of cognitive, social, and affective factors have significant impact on social learning, with empathy having been identified as critical for underpinning the emergence and consolidation of social and emotional understanding and awareness (Payton et al., 2000). Empathy can be defined as "an observer being exposed in some way to a target, after which some response on the part of the observer, cognitive, affective, and/or behavioural, occurs" (Davis, 1994, p. 12). Empathy is regulated by both cognitive and affective elements, interacting in a systemic manner to produce emotional understanding, and is essential for personal, social, and emotional learning (Payton et al., 2000). The affective capacity a person has indicates the level to which they are able to share in another's feelings, whilst cognitive ability specifies the degree to which a person can understand another individual's feelings and perspective.

When the focus of interaction is on exploring social rather than cognitive activities, then inevitably we must move away from cognitive approaches and grounding (Rogers, 2004). Cognitive theories and approaches have resulted in interfaces that reflect cognitive limitations and requirements and that contribute to effective task achievement through underpinning cognitive activity. Several cognitive approaches have been extended to consider the interplay between user, domain, environment, and work tasks (Dourish, 2001; Nardi, 1996; Theureau, 2003). However, such approaches consider tasks that are purposeful and focus on skillful completion rather than on social and emotional elements. A further issue with the relevance of cognitive approaches to social learning is that most ignore the developmental aspect of cognition, a key factor for social learning.

Empathy, and particularly empathic cognitive abilities, requires the ability to represent the mental states (thoughts, feelings, desires, hopes) of others, skills that have been referred to as theory of mind (Leslie, 1987). Theory of mind (ToM), or metacognition, refers to the ability to understand the thoughts, beliefs, and intentions of others, an important ability in order to explain and predict behavior in the social world around us (Premack & Woodruff, 1978). From a natural and inclusive perspective, ToM is "simply having an ability to engage in our everyday folk psychological practices of attribution, interpretation and prediction" (Davies & Stone, 2003, p. 82). Yet ToM abilities reveal an understanding of an interconnected network of mental states, with emotional understanding critical for social functioning (Astington, 2003). Although much ToM research has focused on young children and autistic spectrum disorder children and adults, work with older children highlights that older children understand and focus on other people's motives and emotions rather than judging beliefs and mistakes (Cutting & Dunn, 1999; Dunn, 1995). Children have a sophisticated and complex understanding of emotions and of their social interpretation, with

ToM studies revealing that children of any age can readily take another's perspective in the case of desires and emotions, even where that perspective results in actions or desires different from the child's (Denham, 1986; Wellman & Woolley, 1990).

Computer-based learning where children's metacognitive development has been considered has typically focused on complex cognitive tasks rather than social factors. For example, Clements and Nastasi (1999) focus on the potential of computer environments to enhance metacognitive skills related to problem solving and learning. The importance of social factors for metacognition was recognized particularly in terms of collaborative working and the necessary social coordination to achieve this cognitive end. However, the focus of our research is not on the children's social awareness but rather on the contribution of social activity to the purposeful task engaging the child.

ToM is a concept closely interlinked with empathy and can be used to determine children's perceptions and interpretations of others, permitting a consideration of both the affective and cognitive elements of empathy. ToM abilities are pertinent to competent social interactions, as they enable us to view and make sense of other people's thoughts, beliefs, and behavior. ToM abilities have an impact on social competence (Lalonde & Chandler, 1995), with studies highlighting that children with good mind-reading skills tend to have more successful social relationships and interactions. In studies focused at typically developing children and adults, belief understanding and emotion understanding are closely related (Dunn & Hughes, 1998; Hughes & Dunn, 1998). Whilst there are cognitive approaches that also focus on social and affective aspects, most seek to account for decisions and actions. However, where empathy is being considered, the task and information structures to support it become woefully inadequate as a means of understanding human interactions.

In this paper, we discuss a novel approach for story and character comprehension using concepts from ToM methods that focuses on children's cognitive empathy, their social awareness, and their understanding of a variety of synthetic characters and various situations within virtual scenarios. ToM methods offer considerable potential for determining whether a child has appropriately interpreted and understood the emotional and social content from a range of virtual role play situations with synthetic characters. Firstly, we consider the use of virtual role play as an approach to provide social and emotional learning, followed by a discussion of ToM methods. We then discuss our study methods and procedures for understanding and evaluating children's social and emotional interpretations with FearNot! software. The Results and Interpretation Section addresses the merits and problems of this approach, which is then followed by our conclusions.

USING ROLE PLAY IN SOCIAL AND EMOTIONAL LEARNING

Cognitive, affective, and behavioral learning is achieved through experience (Kolb, 1984; Kolb, Boyatzis, & Mainemelis, 2001), with knowledge emerging "from the combination of grasping and transforming experience" (Kolb, 1984, p. 41). One of the fundamental processes for empathy to develop is role taking, "the attempts by one individual to understand another by imagining the other's perspective" (Davis, 1994, p. 4), which is supported through role-play, an experiential technique in which attitudes, feelings, and social interaction can be explored, providing an understanding of another's perspective (Pohjola, 2004).

In role-play, social interaction is used as the stimulus for challenging and changing existing beliefs (Piaget, 1972) and can result in significant behavioral changes (Lewin, 1951), making it highly relevant for social and emotional learning (Davison & Arthur, 2003; Henriksen, 2004). The high level of drama in role-play approaches, such as Theatre in Education (Jackson, 1993) and Forum Theatre (Boal, 1979), result in an immediacy that is more likely to evoke emotion than other learning approaches (van Ments, 1983). The basic premise of role-play is that it is easier to empathize with how another person might feel under certain circumstances if one has experienced something similar, even symbolically as part of role-play (Robertson & Oberlander, 2002). However, it can be difficult to support role-play in the classroom (Brookfield, 1990), even with the use of advanced technology.

Although educational role-play using synthetic characters has been explored for social and emotional issues, it has mainly focused on language learning (Prendinger & Ishizuka, 2001) and educational drama and story telling, such as Ghostwriter (Robertson & Oberlander, 2002), Teatrix (Machado & Paiva, 2001), Virtual Puppet Theatre (Andre, Klesen, Gebhard, Allen, & Rist, 2000), and Oz (Bates, 1994). Recently, results have highlighted the potential of synthetic characters for empathic engagement (Gratch & Marsella, 2001; Marsella & Johnson, 2003), providing children with a safe environment for experiential social and emotional learning (Aylett, Paiva, Woods, Hall, & Zoll, 2005; Paiva et al., 2004), and allowing the user to experience the character’s emotions and problems in a distanced way, while being at the same time engaged in what happens to the characters.

The research reported here is occurring within the European project eCIRCUS (**E**ducation through **C**haracters with Emotional-**I**ntelligence and **R**ole-playing **C**apabilities that **U**nderstand **S**ocial Interaction). In eCIRCUS we are aiming to support social and emotional learning within personal and social education through virtual role-play with synthetic characters in a 3D environment that establishes credible and empathic relations with the learners. In this paper, we focus on a showcase software program developed in eCIRCUS: FearNot! (**F**un with **E**mpathic **A**gents to **R**each **N**ovel **O**utcomes in **T**eaching). This application focuses on exploring bullying and coping strategies for 8- to 12-year-olds. Children interact individually with FearNot! by watching the synthetic characters interact in bullying scenarios and providing feedback or advice to the victim character via interactive options, thus taking the role of an “invisible friend.”

In attempting to understand the impact of virtual role-play on social and emotional learning, our evaluation has focused on a variety of research questions linked to the domain of bullying and, in more general terms, focusing on emotional responses, understanding storylines, empathic responses to the synthetic characters, and so forth. Whilst much of earlier work has focused on the implementation of a cognitive and affective architecture and user experience, here we consider the impacts of virtual role play on cognitive empathy. This paper discusses the use of ToM methods, emphasizing that a social approach is more appropriate for gaining insight into cognitive empathy than focusing simply on cognition. We have used this approach for the interpretation of interactions with FearNot!, focusing on interpreting children’s responses in an environment for exploring strategies for coping with bullying.

USING THEORY OF MIND

ToM is the ability to predict and explain other people's behavior through referring to mental states, with this ability to correctly attribute beliefs, desires, goals, and percepts to others being a key factor in human interaction and social dynamics. Without such metarepresentational abilities, we would be unable to understand the behaviors of others in many social situations. ToM provides a crucial step in human development, typically emerging in early childhood (Fodor, 1992), as we develop an awareness that others may have different knowledge, beliefs, and goals than our own.

ToM is a vital aspect for social interaction, and where ToM does not develop, as in the case of many autistic individuals, this presents serious challenges (Baron-Cohen, Leslie, & Frith, 1985). Studies have identified that, for many autistic individuals, the understanding and interpretation of others' social and emotional behaviors is very limited and may continue to be so throughout the lifespan (Jarrord, Butler, Cottingtin, & Jimenez, 2000), leading to significant social and communicative challenges.

There is abundant evidence from experiments using false belief tasks (Wellman, 2002) that preschoolers begin to develop a ToM and, by age 6, they should have a sound understanding of first-order ToM abilities (Wellman, Cross, & Watson, 2001). First-order ToM is typically examined using a false belief task. For example, a child is shown the contents of a Band-Aid box and an unmarked plain box. The Band-Aids are in the unmarked box and the Band-Aid box is empty. The adult introduces the child to a puppet and asks the child to predict where the puppet will look for the Band-Aids.

During middle childhood, ToM abilities become more elaborate and complex, and children typically acquire the ability to solve second-order ToM tasks. Second-order ToM abilities require the child to understand that his/her beliefs about other people's beliefs can be wrong, and studies of these abilities invariably involve complex stories given to the child (Astington, Pelletier, & Homer, 2002).

Although first-order ToM abilities are said to be a good predictor of social skills (Jenkins & Astington, 2000), equivocal evidence has been reported from other studies. Dunn (1995) found that competent false belief understanding at age 3 was related to reports of behavioral and peer difficulties at age 6. Specifically, children reported problems in making and keeping friends, and avoiding social activities with peers. In contrast to popular belief, it was the children who were slower to acquire ToM abilities that reported greater peer popularity. Yet others have reported that children who have ToM deficits have problems with peer rejection and show heightened aggression (Hughes, Dunn, & White, 1998; Peterson & Siegal, 1995).

Some studies (e.g., Happe & Frith, 1996) have not found any differences in first-order ToM abilities between normally developing children and conduct-disordered children, who typically have problems with aggression and are rejected by peers. Other research focusing on the perpetrators of bullying behavior reported that bullies frequently show sophisticated ToM abilities and labeled them as possessing "a theory of nasty minds" (Sutton, Smith, & Swettenham, 1999, p. 124).

Social and emotional understanding as a key aspect of ToM was highlighted through Dunn's (1995) paradox, where children who clearly had appropriate ToM as expressed through their emotional and social interpretation were unsuccessful on typical ToM tasks. Children are particularly able at understanding other's emotional perspectives and the impact on related actions, even when that response would be different from their own. Studies focusing on the social and emotional interpretative aspects of ToM have identified that older children's ToM is based on their interpretation of other's motives and emotions (Astington, 2003), with this emotional interpretation having a greater impact on ToM than an attribution based on other's beliefs.

In virtual role-play, understanding children's interpretations of social interactions with and between characters remains problematic. However, methods based on ToM offer considerable potential to evaluate whether these interactions do result in the desired personal, social, and emotional learning outcomes that will result in the improved cognition required by educators and stakeholders. The ToM methods (e.g., the Sally-Anne task; Baron-Cohen et al., 1985; Premack & Woodruff, 1978) that are used to assess and investigate mental state attribution and its impact on social interpretation also offer potential for investigating the same phenomena in children interpreting synthetic characters in virtual role play situations.

ToM offers considerable advantages when compared to cognitive approaches. Even approaches such as activity theory (Nardi, 1996) and distributed cognition (Hutchins, 1995), which also consider social and contextual aspects, have significant limitations for understanding user social awareness and empathy. Whilst activity theory provides an interconnected set of concepts that can be used to frame and explore interactions and provides a historical and cultural analytical framework, the hierarchical model of activity that this theory applies has little relevance in the social context. Both distributed cognition and activity theory are intended for the workplace and apply less readily to a less structured task space, nor do the analytical frameworks provided readily support the investigation of the personal, social, and emotional activities engaged in social learning.

Cognitive approaches have been applied to learning, but not to social learning. Scaife and Rogers' (1996) framework of cognitive interactivity focuses on a design that ensures effective task completion for cognitively effortful learning tasks. However, we are attempting to understand children's interpretations of social interactions with and between characters, a task neither cognitively effortful nor possible from which to identify what constitutes "effective task completion." Indeed, even the user does not consider the activity to be a purposeful task, but rather a social interaction. ToM methods offer considerable advantages, allowing the user to engage in non-goal-oriented interactions rather than in a purposeful task with a clear structure, as required by most cognitive approaches.

The ToM assessment in eCIRCUS evaluates children's perceptions of the synthetic characters and their behaviors. A variety of approaches have been used to explore children's metacognition, including dynamic interviews, think aloud, and video analysis (Clements & Nastasi, 1999). However, ToM provides a more subtle approach that allows us to investigate whether children could appropriately recognize and interpret the synthetic characters' behaviors, appearance, and affect, without explicitly focusing on this information. The approach allows one to determine what children understood and interpreted from the characters, and what goals and intentions they ascribed to characters. It also provides some insight into cognitive empathy, that is, whether children can understand another individual's feelings and perspective.

METHOD

Participants

The program Virtually Friends took place at the University of Hertfordshire in the summer of 2004 and involved 345 children: 172 male (49.9%) and 173 female (50.1%). The sample age range was 8 to 12, with a mean age of 9.95 (*SD* = 0.50). The sample comprised children from 10 primary schools in Hertfordshire, UK. Each class participated in the all-day event (2 classes per day), including interactions with robots, FearNot! and storyboarding software.

Procedure

A large screen overhead projector was used to give a presentation introducing the participants to the day's activities and to the evaluators. Prior to engaging with the FearNot! scenarios, children completed several questionnaires assessing empathy, bullying behavior, and emotion recognition.

The participants were placed at a standard Windows-enabled PC, one per participant, each running FearNot! Each child then individually interacted with FearNot! for approximately 30 minutes. Our work has identified considerable gender variations in responding to the characters and scenarios (Hall, Woods, Wolke, & Dautenhahn 2007) and the scenarios provided were gender specific, with boys interacting with a physical bullying scenario (see Figure 1) and the girls with a relational scenario (see Figure 2). Relational bullying is typified by social exclusion, verbal and emotional harassment, and isolation (Crick & Grotpeter, 1995), while physical bullying is typified by aggressive behavior. Each scenario incorporated 4 episodes and began with an introduction to the characters, school, and situation.

The process of interaction with the FearNot! software is significantly similar for the physical and relational bullying scenarios. In the physical scenario, after the introduction, the user views a bullying incident involving physical and verbal aggression, with Luke (the bully) bullying John (the victim). John then seeks safety in the school library, where, through the software program, he then engages the child user, seeking advice for his bullying situation. Within the initiated advice dialogue, the user selects an item of advice from a list of coping

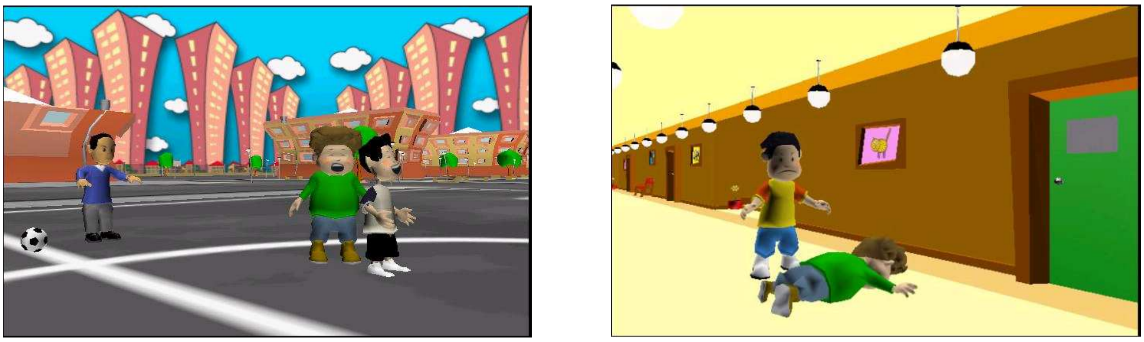

Figure 1. Scenes from the physical bullying scenario in FearNot!

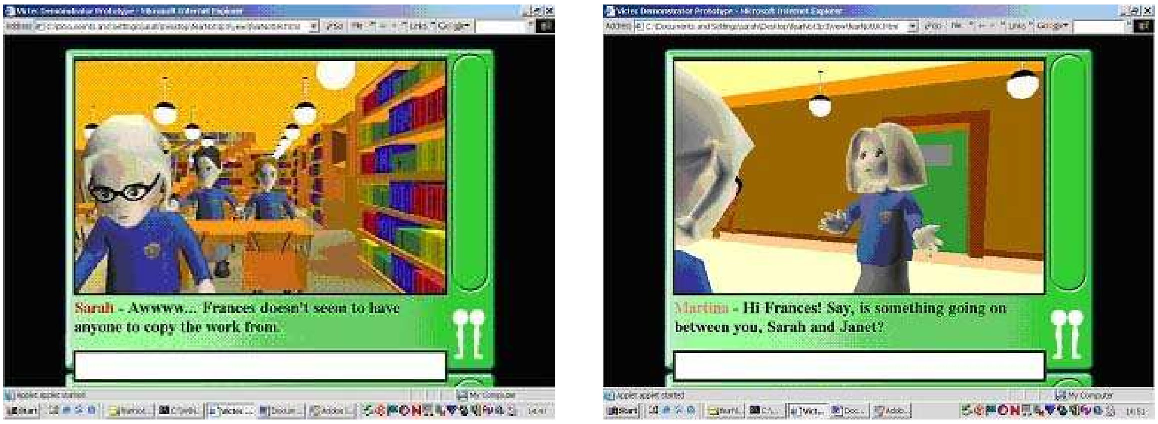

Figure 2. Scenes from the relational bullying scenario in FearNot!

strategies from a drop-down menu. In the free-text portion, the user explains his/her selection and what he/she thinks will happen after having implemented the selected strategy. The user's recommendations to the victim character may have an impact on the victim character's interaction, with the victim possibly selecting the coping strategy suggested by the user, although this is not certain. Whether the user's responses impact the success of the character's approach to coping with bullying depends on the strategy suggested. If the child suggests an appropriate coping strategy—for example, telling someone, a bystander or adult in the scenario setting—the scenario will reflect the proactive help to the victim in combating the bullying. If the user selects a strategy deemed likely to be unsuccessful by the victim, such as to run away or fight back, the victim character will then reject the help in the final episode. To ensure an appropriate educational message provided by the software, no matter which strategy is selected, and in line with the requirements of teachers and school bullying policies, FearNot! ends with a positive message identifying that an appropriate strategy for coping with bullying is to tell someone you trust.

The relational scenario provides the introduction, bullying incident, advice dialogue, further episodes and dialogues, and positive final message. Since relational bullying typically involves a bully who is supported in the verbal bullying by others (Salmivalli, Lagerspetz, Björkqvist, Österman, & Kaukiainen, 1996), this scenario involves a bully assistant (Sarah) who engages in the bullying activity with the bully (Janet) against Frances (the victim). As in the physical scenario, after this incident Frances goes to the library and engages in a dialogue with the user.

After the interaction with FearNot!, children completed the ToM assessment. Finally, participants completed a questionnaire on their interaction with FearNot! and participated in a brief discussion about their experience.

Measures

The ToM questions were devised by experts in the field and were based on the first-order and second-order false belief questions used by Happe and Frith (1996). They were extensively piloted in terms of child comprehension and validity with other measures. Piloting took place in Hertfordshire, UK and involved classes representative of the sample used in Virtually Friends, predominantly composed of UK natives. They included questions about inferring the emotions, mental states, and intentions of the main characters in the story, and were presented in an electronic format to the child immediately after they had interacted with FearNot! The ToM assessment included screen shots from FearNot!, providing the child with memory anchors from action scenes within the scenarios, such as Luke (the bully) physically bullying John (the victim).

The ToM assessment comprised two response formats: categorical responses, where the child was instructed to select the correct response box, and text responses, where the child was instructed to write brief sentences. In the first format, the child was instructed to click the button they thought represented the emotions of the character. These were provided as drawn faces with emotional expressions, based on a subset of Ekman's (Ekman & Friesen, 1986) six identified emotions: happiness, sadness, anger, and fear. Surprise and disgust were removed as options after a pilot study indicated that children had difficulty in clearly identifying these (Woods, Wolke, Nowicki, & Hall, in press). In addition, a "Neutral" face was provided.

The emotion questions, with the exception of the first question, permitted the generation of frequency and percentage data. The ToM assessment also included open-ended questions about the children's various cognitive and affective perspectives, drawn here as an example from the physical bullying questions:

- *Comprehension*. The first question related to story comprehension: Does the child recognize this as a bullying event?
  - What do you think is happening in this scene?
- *Initial emotion questions*. These relate to character emotions at the beginning of the interaction with FearNot! and directly after the main bullying incident(s).
  - How does Luke (bully) feel at the beginning of the story?
  - How does John (victim) feel at the beginning of the story?
  - How does Luke (bully) feel after he has hit and pushed John over?
  - How does John (victim) feel after Luke has hit and pushed him over?
- *Bullying event questions*. These questions follow the initial emotion questions and refer to the main bullying incident(s).
  - What does Luke (bully) think about John (victim)?
  - What does John (victim) think about Luke (bully)?
  - If you were John (victim), why do you think that Luke (bully) is doing this?
  - If you were Luke (bully), why is he doing this to John (victim)?
- *End emotion questions*. These questions follow the bullying event questions and ask the child about the characters' feelings at the end of the scenario (once coping styles have been tried, etc.).
  - How does John (victim) feel at the end of the story?
  - How does Luke (bully) feel at the end of the story?
  - How do you [the child] feel at the end of the scenario?

Assessing Theory of Mind Skills

The analysis approach involved considering the data generated by the children to identify frequency and percentage data from the categorical ToM questions. However, whilst this frequency and percentage data enabled us to identify the most and least typical emotional responses, it did not indicate whether the children's understanding was appropriate nor whether their responses revealed effective ToM skills. Because ToM skills develop throughout life, we took the view that adults would be more likely to select the appropriate emotional response. To determine the level of appropriateness of the possible responses, we developed a scale of correctness for both the relational and physical bullying scenarios.

The scale of correctness for each of the scenarios was created through pooling the data from six researchers. All six were familiar with the eCIRCUS project and our aims with FearNot! Each adult followed the same research procedure as the children, that is, interacting with both of the FearNot! scenarios and completing the ToM assessment for each, interpreting what the various characters were feeling at specific points in the scenario.

The adults were then asked to rate the appropriateness of the five emotions for each of the ToM assessment questions on a simple 5-point scale ranging from 1 (*most correct*) to 5 (*least correct*). This correctness relates to the pooled adults' views of how the character would be feeling. The pooled results were used to create scales for each of the scenarios based on what adults considered a correct emotional response through to an incorrect interpretation. Although multiple correct perspectives (for example that the victim might be sad and angry) are possible, high consensus was found among the adults, with one of the emotions being typically seen as the most appropriate. The following section focuses on a comparison of children's responses with the adults' pooled responses as represented through the scale of correctness.

RESULTS AND INTERPRETATION

Here, we present key findings regarding a comparison of child and adult perspectives on character ToM. Additional results can be found on the bullying scenario (Hall, Woods, Aylett, & Paiva, 2006) and on the relational scenario in Hall, Woods, Hall, and Wolke (2007).

Emotional Interpretations at Scenario Start

All six of the adults believed that the physical bully would be happy at the beginning of the scenario. While there was less consensus for the relational bullies, happiness was the dominant state, although some adults identified that the relational bullies may be angry and, for one adult, that the bully assistant was neutral. Nearly 50% of children stated that the bully in both the physical and relational bullying scenario felt happy at the beginning of the story, followed by feeling angry or neutral. Thus, whilst adults overwhelmingly took the view that the physical bully would be happy, children were less convinced, with 24.3% believing he would be angry. A few children even stated that the bully felt sad at the beginning of the stories. A similar pattern was found for children's emotion interpretations for the relational bully assistant, with 44% stating that she felt happy, followed by 27% stating that she felt angry at the start of the story. As Figure 3 shows, the children generally are displaying an appropriate perspective (as defined from an adult perspective) of the bullies' emotional states; however, they are more likely than adults to view the bully characters as angry.

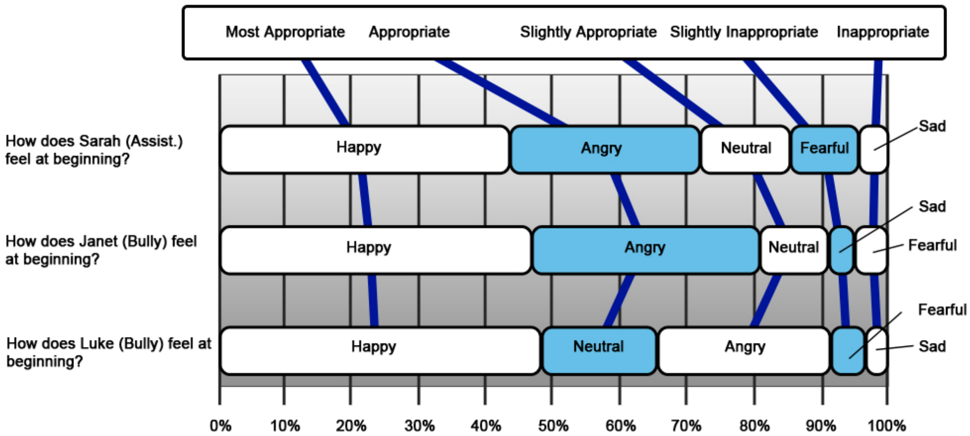

Figure 3. Children's interpretation of bullies' emotions at scenario start.

Adults stated that the victims would feel sad or fearful, see Figure 4. Sadness was the dominant emotional state identified by the children, with approximately 70% of children interpreted the victim in both the physical and relational scenario as feeling sad at the beginning of the story, followed by around 20% stating that the victim felt fearful.

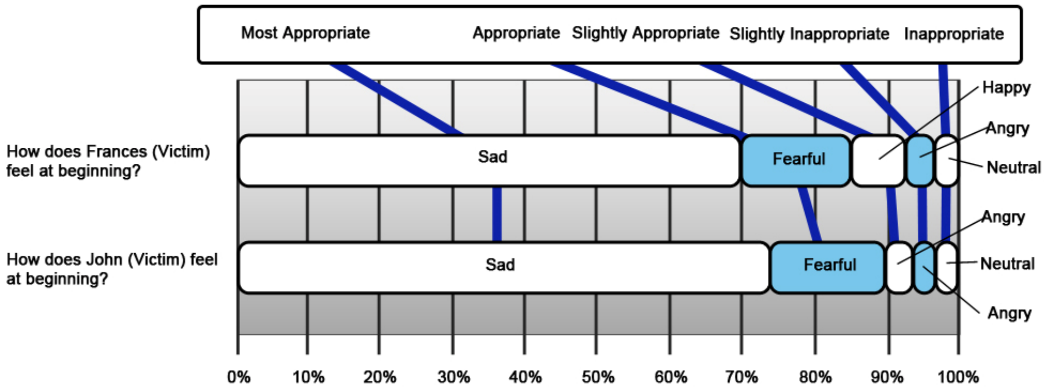

Figure 4. Children's interpretation of victims' emotions at scenario start.

Emotional Interpretations after Bullying Incident

Adults interpreted the emotional state of both the relational and direct bullies after the bullying incident as typically being happy, with anger also being appropriate. For the bully assistant (in the relational scenario), adults identified that the most likely state was happy with the second most likely state being neutrality. For the children, happiness was felt to be the dominant emotional state of the bullies, with just under 80% of children responding that the bully character in both scenarios felt happy after the successful bullying, see Figure 5. Whilst

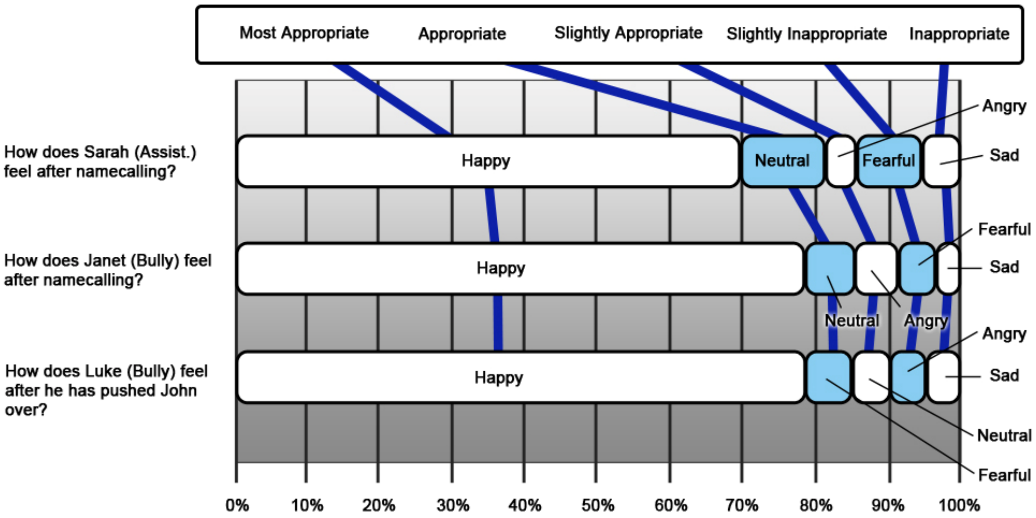

Figure 5. Children's interpretation of bullies' emotions after incident.

the bully assistant was typically seen as being happy, some children indicated that she could be sad or fearful.

The outcome of the relational bullying was very clear for both the adults and the children (see Figure 6), with 85% of children interpreted that the victim felt sad after being called nasty names. Although adults agreed that the physical bullying victim would typically be sad after the incident, the children were less convinced, with 61.5% feeling that the victim would feel sad and just under a third of children indicating the victim would be angry or fearful. No adult thought that the victim in the physical scenario would be angry.

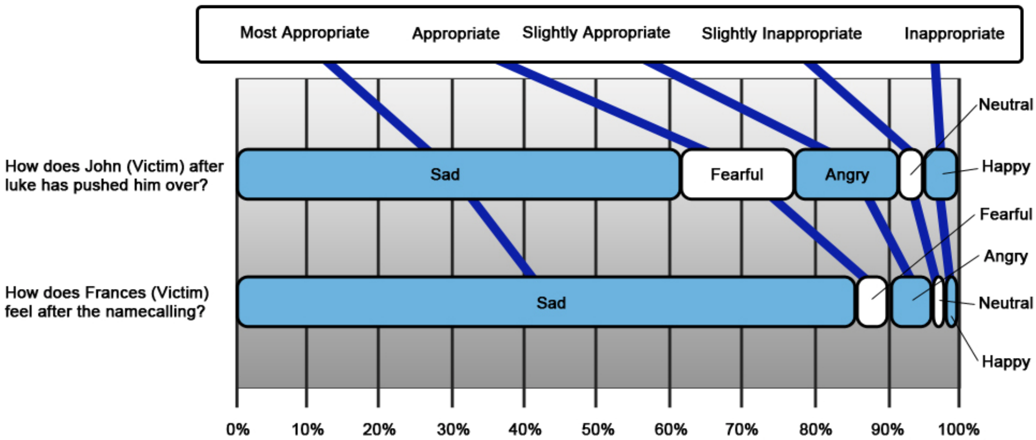

Figure 6. Children's interpretation of victims' emotions after incident.

Emotional Interpretations at Scenario End

These results relate to how the characters could have felt at the very end of the scenario. At the end of the physical scenario, all of the adults perceived that the physical bully was feeling happy. In the relational scenario, adults mainly felt that the relational bully was feeling happy, although anger and neutral were also identified as possible emotional states. However, the children's perspective of the emotional state of the bullies was quite different in the range of emotions being identified (see Figure 7). In the physical and relational scenarios, 35% and 38% of the children, respectively, stated that the bully felt angry at the end of the story, followed by 25% & 29%, respectively, who said that the bullies felt happy. This was followed by around 20% of children believing that the bullies felt sad at the end of the story.

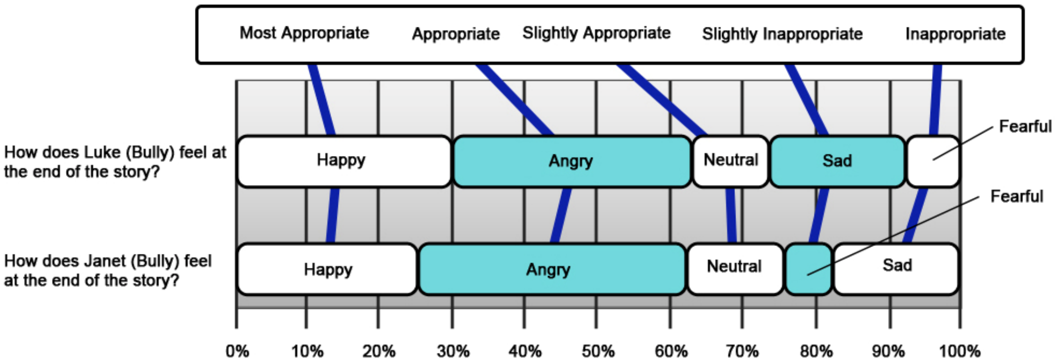

Figure 7. Children's interpretation of bullies' emotions at stories' end.

With regards to how the victim characters felt at the end of the story (Figure 8), around 60% of children responded that the victim in both scenarios felt happy, and over 20% believed that the victim felt sad. This is in marked contrast to the adults, who had a completely different ToM of the victim character at the end of the scenario, with happiness identified as an inappropriate emotion.

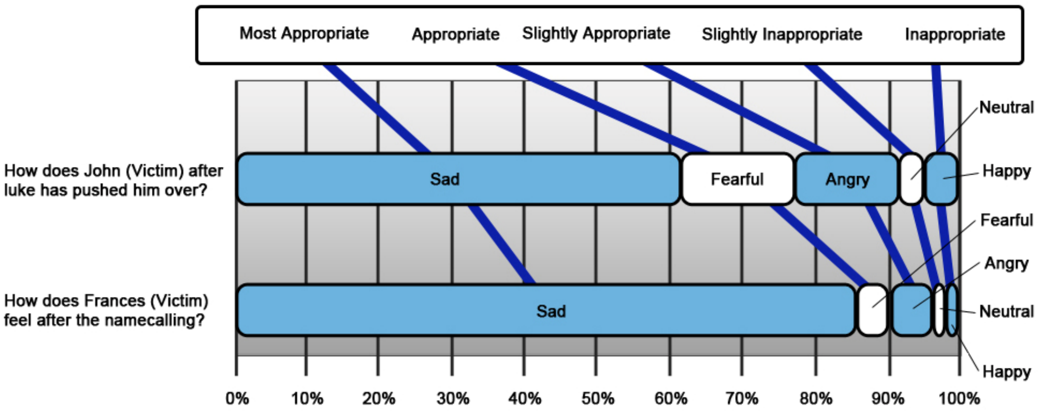

Figure 8. Children's interpretation of victims' emotions at stories' end.

Scenario Profile: Character's Changing Emotional State

Children viewed the bullies in both scenarios as being happier at the beginning of the scenario as compared to the end, with most happiness experienced immediately after the bullying incident (see Figure 9). The relational bully assistant had similar ratings as the relational bully, but that information is not included in the following diagrams for clarity. The physical and relational bullies are seen by many children as frequently being angry, not only during a bullying incident but also at the beginning and end of the scenario. There is considerable similarity in children's interpretations of ToM in both scenarios.

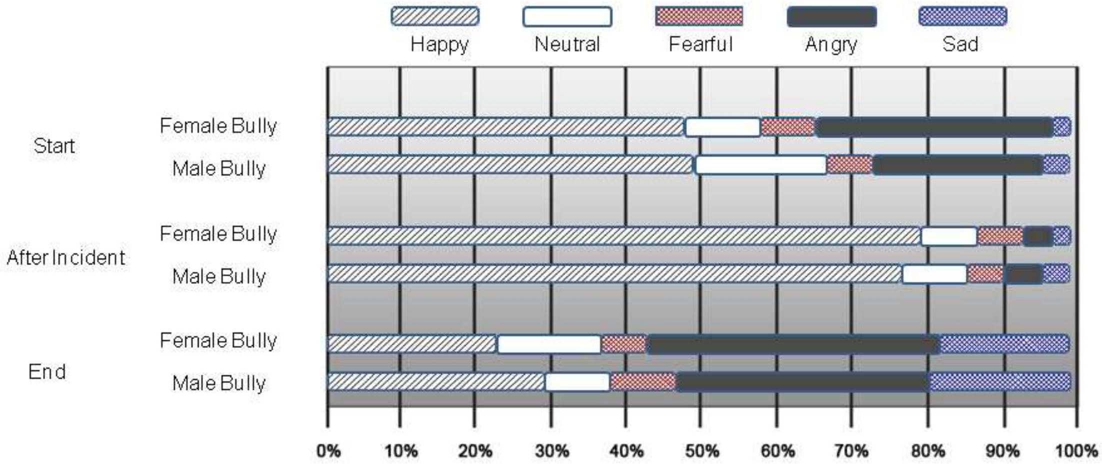

Figure 9. How children thought the bully felt at the beginning, during, and end of each scenario.

Children's views of the victims' emotional states at the end of the scenario were unexpected (see Figure 10). Both victims are seen as sad at the beginning and after the bullying incident, but by the end of the scenario they are viewed as happy.

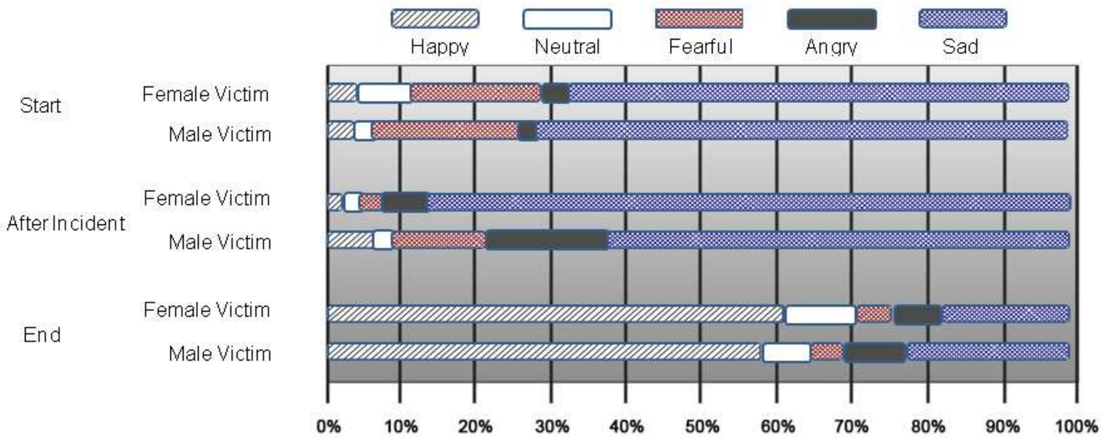

Figure 10. How children thought the victims felt at the beginning, during, and at the end of the scenario.

DISCUSSION

Our focus in this paper has been on the use of ToM methods as an approach in HCI research to gain insights into children's social and emotional interpretation of synthetic characters. Such methods offer an alternative to cognitive approaches, providing a focus on the social aspects of understanding metacognition regarding children's abilities to correctly attribute beliefs, desires, goals, and percepts to others. In this study, the focus was on the children's perceptions of bullying in a virtual scenario, where the participants were synthetic characters rather than actual children participating in a real experience. The purpose with this research was to investigate whether children could exhibit emotional response to the synthetic characters within this VLE, not whether these emotions reflect the real emotional experiences of either bullies or victims. The results detailed here focus on the categorical data collected, relating primarily to first-order ToM in children when compared with adult views of character ToM. The scale of correctness, based on knowledgeable adults' interpretations, was intended as a measure to identify whether the scenarios were generating the appropriate or expected emotional and social interpretation from children. There was some consensus between adults' and children's interpretations and tendencies within both sets of data. We have also identified that adults' views of the characters' emotions diverge, particularly in relation to how the characters are feeling at scenario end.

The emotional perspectives of the characters at the beginning of the scenario are supported through a voice-over of the back story for each of the characters as they are making their way to school. In these character introductions, the victims are clearly presented as being isolated individuals in a challenging social situation where they are experiencing bullying. As expected, at the beginning of the scenario, children viewed the victims as being sad or fearful, showing social understanding and awareness that being bullied will have a negative emotional impact on the victim.

Although the relational bully was viewed as happy, many children indicated that the physical bully was angry. This view relates in part to the introduction to the characters, where Luke is presented as an angry child, known for "pushing others around" and "in trouble for fighting." The introduction to Luke provided in the first episode of the physical bullying, shows him with a gang of friends and his face projects more angry and neutral facial expressions than happy. Whilst the relational bully and bully assistant are also identified as being unpleasant, with behaviors such as "name-calling" and "being unkind and unfriendly," their introduction is less negative, with them having mainly happy and neutral facial expressions.

Whilst adults and children had similar views about how the victim is feeling after being bullied in the relational scenario, there were differences in the interpretation of the physical victim's emotional state. The adult perspective was that victims would feel sad and fearful after being bullied; however, many of the children thought that the victims would feel angry. This result is possibly at least partially the result of difference of social and cultural values between children and adults, with anger rarely viewed as acceptable in an adult context and thus a less appropriate response. Ensuring ToM and the affective elements of human interaction are designed appropriately for the age group requires that values incorporated into the characters and scenarios are credible, believable, and appropriate. This highlights a major challenge faced in designing software such as FearNot!, with participatory design seen as key to achieving ICARPEs that result in a positive user experience that fulfills pedagogical aims. Current work focuses on extending our participatory design methods to further investigate the design of personal, social, and emotional factors in characters intended for children and teenagers, with the aim of bestowing virtual agents with behaviors that better facilitate empathy in the users.

In both scenarios of FearNot!, children interacted with the victim, aiming to support him/her in improving life through coping with the bullying. The open-ended questions identified that advice given by users is based both on their interpretation of the victim's social and emotional state and on their view of what a successful strategy might be in light of the bullying context. The ToM assessment identified that, in the case of the relational bully, children recognized that she is not happy at the end, implying that, even for the perpetrator, bullying is not a positive interaction style, a perspective that we had hoped to achieve with FearNot! In this study, children interacted with FearNot! for only a single session, followed by a short discussion of the bullying experience to reinforce learning. To assess the learning impact of FearNot!, we have conducted a large scale, classroom-based longitudinal evaluation of FearNot! This has recently identified that interacting with FearNot! does have a positive impact on coping with bullying behavior (Sapouna et al., in press).

In the physical scenario, children appeared to view the bully as a flawed, angry individual; this perception impacted their views of the successfulness of coping strategies. For example, hitting back was advocated by many children as a way of dealing with the physical bully Luke, reflecting the view that responding in kind is a valid response to aggression. Anger was also identified as a likely emotional state for the victim to feel after the bullying incident. This clearly is not the response desired by educators and parents. Thus, the bully's introductory scenes in FearNot! Version 2.0 have been slightly modified, aiming to provide a happier, less aggressive character with friends with whom he enjoys sports, rather than the bullying gang cast in the version of FearNot! discussed here.

The children's different perspectives of the relational bully and her assistant reflect findings (Salmivalli et al., 1996) that assistants often have poor social and emotional abilities that result in angry, confused individuals frequently involved both in bullying and being bullied. Thus the children's interpretation of the bully assistant, who displayed very similar emotional expressions as the bully throughout the scenario, reflects their awareness and understanding of bully assistants.

However, the most surprising results were achieved at the end of the scenario, where the adult and child views of the characters' emotional states can be seen to have little consensus. Regarding the bullies, the adults believed that these characters would be happy, while the children typically did not see this as the final emotion, but rather anger and sadness being identified as likely emotions. This divergence applies also to the victims' final emotional states at the end of the scenarios: Whilst adults considered happiness to be inappropriate, this was the dominant emotion identified by children.

Adults had a similar view of the victims' states at the beginning and end of both scenarios, interpreting that the victim characters were sad. However, the children felt that the victims were far happier at the end of the scenario than at the start. The most likely reason for this perspective is that the child user believes that, through an intervention provided by the FearNot! program, he/she has helped and supported the victim and improved his/her life, and thus the characters' happiness is derived from having interacted with the user. Whilst this may sound unlikely, almost all children believed that they had helped the character, even if the character ignored their advice (Hall, Woods, Aylett, & Paiva, 2006).

The scale of correctness was based on the view that the adult perspective would provide the most appropriate ToM. As ToM develops throughout life, becoming increasingly refined, we assumed that the more sophisticated adults would have a greater (and implicitly better) social understanding of the situation and of how the characters were feeling. However, the use of this instrument has identified that children's perspectives are considerably different from those of adults, particularly in relation to how a child victim is perceived to feel at the end of a bullying scenario. These results illustrate differences in engagement with the scenarios and in terms of the adult and child perspectives of bullying. This difference in bullying perspective has been identified in other studies, recognizing that children's view of bullying and its impacts can differ significantly from those of adults (Rigby, 2002). With FearNot!, the adult perspective is mediated both by the social distance between adults and children and by social expectations (e.g., not to display anger), whilst the child's perceptions display greater social proximity to the characters and engagement in the scenarios. In attempting to understand this difference, it seems likely that the adults gauged the emotional state of the characters in a detached manner, not really empathizing with the characters nor really experiencing the suspension of disbelief achieved by children. The results highlight that a ToM can be derived through interaction with synthetic characters in affective scenarios. However, this ToM and the children's emotional response to the characters was not necessarily that anticipated by adults. In related studies we have further investigated this issue, identifying that children exhibit greater empathy with the FearNot! characters than do adults, and that adult researchers were being more empathic than teachers or the public (Paiva et al., 2004).

The adult response shows a lack of engagement with the characters, with children responding with a higher level of empathic engagement. Effectively, the children seemed to be viewing the social complexity of the situation and thinking more about the victim characters than the adults did, imagining what it might be like after (yet another) unpleasant encounter with the bully. For example, although the relational bully is seen as being happy throughout most of the scenario, at the end many children saw her as angry or sad, suggesting that the bullying is having a negative rather than a positive impact on her emotional state. For the victim, the child user knows that he/she had experienced a supportive, appropriate interaction (with the child) and it seems likely that this may be the underpinning reason for the victim characters' happiness.

Through the interaction with FearNot!, we are aiming at providing children with exposure to coping with bullying with the intention of providing those children with the impetus and understanding that will permit them to reduce and prevent bullying situations. If children view their interaction with a victim as having had a positive impact, notably that the victim is seen as being sad at the beginning of the scenario but happy at the end, due to the input from the user, then the children can learn from this experience that helping someone to cope with bullying engenders a positive outcome.

Our approach using ToM methods has been highly insightful, revealing that the use of such methods offers considerable potential for exploring the user experience in technology-enhanced social and emotional learning experiences. The results from our study have contributed to the redesign of FearNot! In FearNot! Version 2.0, children are offered the opportunity to help and advise the victim over several weeks, extending the interaction. Even where the bullying situation is not resolved, a final dialogue still occurs in which the victim thanks the user for his/her advice, ending the interaction with a positive comment. This is intended to increase the likelihood that users feel that they have had a positive impact on the bullying situation for the victim. FearNot! Version 2.0 has recently been evaluated with 800 children in classrooms in the UK and Germany (Sapouna et al., in press).

FearNot! reflects cultural and social norms, expectations and the preferred bullying coping strategies used in Europe. The scenarios and character interactions in the UK and German versions are similar, with the appropriate response to bullying being to tell someone and to reduce the victim's isolation. FearNot! has been developed for European schools and has a Western bias in terms of what is considered to be an acceptable way of intervening in a bullying situation and how to support the victim. FearNot! is currently being adapted for use in a number of countries, including China, America, Mexico and Poland. Results from these studies will indicate FearNot!'s relevance to different cultures.

We have incorporated ToM methods into a range of instruments in FearNot! Version 2.0. Currently, the interaction logs generated through the use of FearNot! Version 2.0 are being analyzed using a ToM framework based on the work presented in this paper. The analysis focuses on interaction data to understand children's social and emotional interpretations of characters and the possible transfer of positive coping strategies into their school situations. The scale of correctness has been redesigned and now is based on the aggregated results from all children, rather than on an adult perspective, as was presented in this paper. This revised scale enables us to identify if a child's responses are "correct" in relation to their peer group, that is, typical for the age group. This change reflects the considerable differences in ToM between the age group and adults identified in this study.

The identification of children's interpretation of virtual characters in social learning scenarios provides opportunities to redirect potentially inappropriate perceptions to more socially acceptable through effective affective teaching within VLEs. Our current research focuses on analyzing data from the large scale evaluation, seeking to understand the impact that longer term interactions with FearNot! have on a child's ToM and the implications that this has for the design of characters and scenarios aiming to improve children's social interactions.

CONCLUSIONS

Whilst cognitive approaches have been of considerable benefit for understanding and improving HCIs, their applicability to interactions focused on social activities is relatively limited. With the increase in applications intended to support social and recreational activities, there is a clear need to extend HCI by including alternative approaches to understanding users. ToM methods offer an approach that enables an insight into social awareness and emotional understanding of interactions involving social interactions rather than purposeful tasks. Such insights are crucial in ensuring that appropriate interactions, dialogues, and experiences are integrated into social and emotional applications.

In this paper, we have identified that ToM methods offer considerable potential for understanding how children interpret synthetic characters' social and emotional states. Further, our results highlight that adults and children have different perspectives on how victims and bullies are feeling. Understanding the child's view has enabled us to improve FearNot! in Version 2.0, providing children with an emotionally positive experience, that of helping a victim, and increasing their well-being.

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All correspondence should be addressed to:
Lynne Hall
Department of Computing, Engineering and Technology
Faculty of Applied Science
University of Sunderland
SR6 0DD United Kingdom
lynne.hall@sunderland.ac.uk

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MENTAL MODELS, MAGICAL THINKING, AND INDIVIDUAL DIFFERENCES

Phil Turner
Centre for Interaction Design,
School of Computing,
Edinburgh Napier University,
Edinburgh, UK

Emilia Sobolewska
Centre for Interaction Design,
School of Computing,
Edinburgh Napier University,
Edinburgh, UK

Abstract: *Broadly, there are two mutually exclusive accounts of how people (non-specialist users) reason about and conceptualize interactive technology. The first is based on classical cognitive psychology and is characterized by the term* mental model. *The second, drawing on concepts from social cognition, observes that people often anthropomorphize technology. We argue that people are able to exhibit both of these quite different styles of cognition, which Baron-Cohen has described as systemizing and empathizing. The former is associated with the drive to analyze, explore, and construct a system, whereas the latter is the ability to spontaneously tune into another's thoughts and feelings. The propensity to systemize might give rise to a mental model, while the empathizing tendency might tend to anthropomorphize technology. We present an empirical study that lends support for the above position.*

Keywords: *human–computer interaction, cognitive style, mental model, anthropomorphization.*

INTRODUCTION

Interactive technology is one of the defining characteristics of modern society, and how we design, use, and think about it is, consequently, of considerable importance. To this end human–computer interaction (HCI) is a multidisciplinary field that has drawn on psychology, software engineering, anthropology, sociology, and philosophy. Indeed, in the preface of the first great HCI text, *The Psychology of Human-Computer Interaction* (Card, Moran, & Newell, 1983), we find, "The domain of concern to us, and the subject of this book, is how humans interact with computers. A scientific psychology should help us in arranging the interface so it is easy, efficient and error free" (p. vii). Recalling the early days of HCI, Carroll (2003, p. 3) observes that, "the initial vision of HCI as an applied science was to bring cognitive-science methods and theories to bear on software development." In due course, Card and his colleagues went on to propose the model human processor (as a means of modeling

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how people reason about and use technology) and to create an essentially task-based approach to the design of the user interface. This dual use of cognition has remained with us to this day.

Some 20 years later, HCI has successfully developed numerous cognitive models and psychologically plausible engineering models of human behavior (Gardiner & Christie, 1987; Hollnagel & Woods, 1983; Payne, 1991) that, to a greater or lesser extent, have proved to be able to model aspects of the behavior of people using interactive systems and devices. Strongly predictive models, such as the keystroke-level model (Card, Moran, & Newell, 1980), have, for example, been used to predict the time to complete a task for a skilled individual, while cognitively inspired tools like GOMS (goals, operators, methods and selection) have been used in the design and evaluation of user interfaces (John & Kieras, 1996). This "golden age of HCI" (Carroll, 2003) has also witnessed the adoption of mental models as a means of accounting for how we learn to use and conceptualize interactive technology (e.g., Gentner & Stevens, 1983; Norman, 1983). The term *mental model* first appeared in Craik's *The Nature of Explanation* (1943) and then reappeared in the 1980s, as Johnson-Laird (1983) and Gentner and Stevens (1983) independently adopted the term to describe complex cognitive representations. These models are very diverse and include systems (e.g., our knowledge of banking), devices (e.g., the operation of pocket calculators), physical forces (e.g., the nature of electricity), or a concept (e.g., the administration of justice). HCI mental models also have had the dual role of being used to reason about how to create an interactive system and as a means to represent people's understanding of a particular interactive device or system (e.g., Norman, 1983).

While subsequent research has moved beyond this exclusively cognitive stance (discussed below), there remains the assumption that cognition (mental models in particular) still has a role in how people use interactive technology. However a recent report in *New Scientist* magazine (Marks, 2008) reminds us of another aspect of our cognition that manifests as a tendency to treat inanimate objects like pets or even friends. The magazine cites a report of people's interactions with *Roomba,* a robot vacuum cleaner.[1] It was reported that some of the owners of this vacuum cleaner dressed it up, assigned it a gender and even gave it a name. It is suggested that this kind of behavior is commonplace. Indeed, a decade or so earlier, Reeves and Nass (1996) presented evidence that users treat computers, television, and other new media as though they were people, that is, response to or interaction with them is primarily social. We are, for example, polite (and rude) to interactive technology and these responses, they suggest, are the products of our "old brains" being misled amid the glamour of these new media. They also argue that media representations and techniques have been progressively designed over time specifically to activate these very social responses. For the purposes of this discussion, and in keeping with more recent research, we will characterize these descriptions as *anthropomorphic accounts* that arise from aspects of our social cognition.

So it appears we are potentially faced with a dichotomy. Either people conceptualize interactive technology by way of a mental model, which is characterized as set of processes that can be modeled, or as a friend—"superstitious" in character and comprising "magical thinking"—that is, ascribing agency, feelings, and intentions to technology. However, it could be both. Our treatment of this mismatch is to recognize that these two views reflect two distinct cognitive styles that appear to correspond with the distinction Baron-Cohen (1995, 2002, 2004) has named *systemizing* and *empathizing* cognition. Systemizing cognition is associated with the drive to analyze, explore, and construct a system and, as such, is a candidate for the mechanism (or mechanisms) responsible for creating a mental model. Empathizing cognition, in contrast, is the ability to spontaneously tune into another's thoughts and feelings. Empathizing cognition is closely related to what has been called theory of mind (Premack & Woodruff, 1978) and may be the source of our tendency to treat technologies as though they have thoughts, feelings, moods, and desires of their own. Baron-Cohen also has shown that this is not an either-or situation, but rather individuals having both abilities in different proportions. This observation may allow us to account for people being able to hold both positions with respect to interactive technology.

COGNITIVE ACCOUNTS, RATIONALISTIC APPROACHES

Most of the work on mental models was conducted in the 1980s and 1990s, but began to lose favor when a raft of new concepts in human–computer interaction appeared. Cognition itself is now recognized as being situated (e.g., Suchman, 1987), distributed (e.g., Hutchins, 1995; Hollan, Hutchins, & Kirsh, 2000), external (e.g., Scaife & Rogers, 1996), embodied (e.g., Clark, 1997; van Dijk, 2009, this volume; Valera, Thompson, & Rosch 1991), and even collective (e.g., Engeström, 1987, 1999). Although classical cognition, as typified by Fodor (1983), no longer has as much currency as it once had, it has proven to be remarkably resilient, as the work we have just cited are extensions to cognition, not evidence of its abandonment. As for mental models themselves, Gillian Crampton Smith, the doyenne of interaction design, notes the importance of a good mental model in the design of interactive technology, in that, "we need a *clear mental model* of what we're interacting with" (Crampton Smith, n.d., cited in Moggridge, 2007, p. xv).

As we have already noted, mental model accounts have been used both to inform design and as an explanatory medium, though this has not always been made explicit. A consequence of this, although there are other contributory factors, is that there is no agreement on the precise nature, function, or composition of mental models. Indeed Rouse and Morris (1986, p. 360) have noted,

> At present, this area of study is rife with terminological inconsistencies and a preponderance of conjectures rather than data. This situation arises, to a great extent, because a variety of sub-disciplines have adopted the concept of mental models, and proceeded to develop their own terminology and methodology, independent of past or current work in this area in other sub-disciplines.

Mental Models as the Basis of the Design of Interactive Technology

From the design perspective, Norman (1983) introduced a number of different forms of mental model. The first is the user-constructed model of the computer system (the target system) with which he/she is interacting. The target system should be designed in such a way as to communicate its underlying *conceptual model*. Later he revised this account (Norman, 1986) so that the target system becomes the *system image* that includes the physical model of the system: input/output devices, documentation, training, error handling, and so forth. The conceptual model becomes the *design model* created by the designer, and the *user's model* is now the result of interaction with the system image. Thus, good design is embodied and determined by the quality of the mapping between the system image and the resultant user's mental model. If the system image is not a clear reflection of the design model, then the user will end up with the wrong mental model.

Mental Models as the Basis of How We Reason about Interactive Technology

From the explanatory perspective, Young (1981, 1983), for example, explored a number of the properties of mental models through a series of empirical investigations. His studies investigated how people reasoned about the use of calculators. Of particular interest to Young were the role of analogy, the stability of mental models in long term memory, their propositional content, and the rules governing the operation (i.e., their "grammar"). Norman (1983, 1986) also concluded that (a) mental models are incomplete and unstable, since people forget details of the system; (b) people's abilities to "run" their models (in the sense of running an internal simulation) are severely limited and do not have firm boundaries; that is, similar devices and operations get confused with one another; (c) mental models are unscientific; and (d) mental models are parsimonious. People are willing to undertake additional physical operations to minimize mental effort; for example, people will switch off the device to reboot and start again rather than trying to recover from an error. Finally, Payne (1991) reported what he called a descriptive study of mental models. He recruited 16 participants who were interviewed about their beliefs and understanding of the mechanisms behind ATMs (automated cash dispensers). He was specifically interested in (and whether) people spontaneously create explanatory mental models about the ATM's operation. Following an informal content analysis of the resulting interviews, Payne observed that "it is clear that many subjects had already constructed mental models of bank machines—they had speculated about the inner working of the system in advance of being promoted to do so by a curious psychologist" (1991, p. 18). In all, he concluded that mental models can be used to predict behavior by means of "mental simulation," which in turn rely on analogy to function.

Despite the weaknesses of the mental model accounts of how people *think* about the operation of interactive technology, it is worth reiterating that no other widely held explanation has yet appeared to directly replace it, except, of course, when people think of interactive technology as their friends.

ANTHROPOMORPHIC ACCOUNTS

> The ascription of human-like characteristics to computing technology has become integral to our design, use, training, and communications with regard to computing technology and it has been argued to be the most common metaphor used in computing discourse. (Johnson, Marakas, & Palmer, 2008, p. 169)

Reeves and Nass (1996) were among the first to recognize that the way in which we treat interactive technology, television, and other new media is essentially social. In their *The Media Equation*, they show in a surprisingly wide variety of ways that the apparent blurring of real and mediated life is commonplace. They present evidence that we interact with media in the same way we respond to other people, using the same rules that govern face-to-face interpersonal interactions. This equation is recognized as being particularly remarkable and counterintuitive, since people know that the medium they are interacting with is not a real person.

Interactive technology is, of course, distinguished from other technologies by virtue of its very interactivity, a trait it shares with humans. Computers also use language. Computers are instructed to perform by way of programming languages. HCI designers are concerned with dialogue design, that is, how the interaction between person and interactive technology is structured. Computers can produce human-sounding voices (Nass & Moon, 2000; indeed it has been noted by many that the only really human character in Stanley Kubrick’s 1968 movie *2001: A Space Odyssey*, was HAL, the computer). Studies of social presence have revealed that users easily and regularly ascribe human characteristics, emotion, and behavior to avatars created within collaborative virtual environments (for a review, see Biocca, Harms, & Burgoon, 2003.) Perhaps most importantly, computers now fill roles traditionally held by humans. Computing technology is ubiquitous in our society, often mediating our basic daily interactions, such as communication, banking, paying bills and taxes, and governing much of our working lives. Winograd and Flores (1987) also have observed that computing technology has apparent autonomy, complexity of purpose, structural plasticity, and unpredictability—all of which are human-like characteristics.

Nass and Moon (2000, p. 86) have examined what they describe as the fundamental truth that “the computer is not a person and does not warrant human treatment or attribution.” They point out that computers do not have faces or bodies—unlike, say, a child’s toy—are unresponsive to human affect, and never express emotion themselves. Yet for all of this, there is abundant evidence that people mindlessly apply social rules and expectations to interactive media. In a series of experiments, they further found that people tend to “overuse human social categories” (p. 82), such as gender and ethnicity, politeness and reciprocity, and behave as though computers have personality traits, such as friendliness. People also have been found to use social rules and respond to computers with different voices (Nass & Steuer 1993), to feel psychologically close to or connected with a computer (Lee & Nass, 2005), to respond to computer personalities in a similar manner as they respond to human personalities (e.g., Brave, Nass, & Hutchinson, 2005), and even to respond to flattery from the computer (Fogg & Nass, 1997). Evidence shows that people with strong anthropomorphic beliefs are more likely to ascribe responsibility for their interactions with and outputs of a decision support system than those with weaker anthropomorphic beliefs, even though the ultimate interactions and decisions were within the control of all users (Johnson, Marakas, & Palmer, 2006). In all, there are fewer studies of this kind than the corresponding classical cognitive accounts and their findings are yet to be translated into design features. Nonetheless, their results are very robust. Next we consider these two different cognitive styles.

DIFFERENT COGNITIVE STYLES

Baron-Cohen’s (1995, 2002, 2004) systemizing–empathizing account of psychological sex differences is based on neurological differences in “male” and “female” brains. While Baron-Cohen emphasizes functional and structural brain difference, we, like others (e.g., Focquaert, Steven, Wolford, Colden, & Gazzaniga, 2007), are more concerned with the differences in the resulting cognitive style and their consequences for how people think about interactive technology. We approach this concept with some caution since we believe that this is first time Baron-Cohen's work has been applied to the domain of HCI.

Baron-Cohen claims that the female brain has a predominant propensity for empathy while the male brain is predominantly wired for understanding and building systems. In support of this position, he introduces evidence to suggest that male and female brains develop differently from conception. The source of these differences is the presence of prenatal androgens (male sex hormones) that can permanently affect the development of the neural structure and function of the brain. However, while male brains are more commonly found in men and female brains in women, this distinction is in no sense absolute. The propensity to analyze a system in terms of the rules that govern it in order to predict its behavior and the propensity to identify and understand the mental states of the other in order to predict his/her behavior, and to respond appropriately in either case, is found in both men and women (Baron-Cohen, 1995, 2002, 2004; Baron-Cohen & Wheelwright, 2004). Excepting a few extreme examples, no one would suggest that men are incapable of empathy, nor women incapable of understanding the workings of a system. Every individual has a propensity for each cognitive style in varying proportions.

Individual systemizing and empathizing quotients can be derived means of a pair of administered questionnaires that Baron-Cohen (2004) has developed (see Appendixes A and B). These questionnaires consist of 60 questions for either a Systemizing Quotient (SQ) or an Empathy Quotient (EQ), and are based on a Likert scale, with answers ranging from *strongly agree* to *strongly disagree*. The questions related to the SQ are of the form, "When I listen to a piece of music, I always notice the way it's structured" and "If I were buying a car, I would want to obtain specific information about its engine capacity," which are designed to capture a person's tendency to systematize. By contrast, the EQ questions are of the form, "I can easily tell if someone else wants to enter a conversation" and "I find it difficult to explain to others things that I understand easily, when they don't understand it first time" [*sic*]. Questions are scored 1 or 2 points on the respective scales, although there are also some null questions that afford no score. From the resultant scores, people can be categorized as high, average, or low empathizers or systemizers, remembering that the two scales are independent. These quotients can be interpreted using the guidelines, which may be found Table 1.

HOW PEOPLE THINK ABOUT THEIR MOBILE PHONES

Before describing the procedure we adopted, it is worth taking a moment to examine the methodology that inspired this work. It will be recalled (see Section 2) that Payne (1991) conducted a series of interviews with the intention of exploring the mental models people spontaneously create to mediate their interaction with technology. In his study, he interviewed people regarding their attitudes and understanding of ATMs. The interviews were conducted in an unrestrained manner. Payne's subsequent treatment of the data is not well documented but appears to be an informal content analysis.

Table 1. Interpreting the EQ and SQ Results (after Baron-Cohen, 2004, p. 216).

Empathizing Quotient (EQ) i.e., the ability to understand how other people feel and responding appropriately	
0-32	*Lower than average*
33-52	*Average ability*
53-63	*Above average*
64-80	*Very high ability*
Systemizing Quotient (SQ) i.e., the ability to analyze and explore a system	
0-19	*Lower than average*
20-39	*Average ability*
40-50	*Above average ability*
51-80	*Very high ability* (three times as many people with Asperger syndrome[2] score in this range compared to typical men, and almost no women score in this range)

Note: In the EQ scoring, most women score about 47 and most men score about 42, while in the SQ scoring, most women score about 24 and most men score about 30.

Research Questions

Modern mobile phones are no longer limited to simply making and receiving calls; they now routinely have a range of interactive functions and, as such, can be treated as interactive technology. Therefore, we propose that the SQ and EQ of the individuals in this study are indicative of their propensity to describe the operation of interactive technology (i.e., mobile phones in this instance) using language that is

- rich in technical, systemizing terms (for those with above average SQs), or
- filled with anthropocentric, empathizing terms (for those with above average EQs), or
- a mixture of technical and anthropocentric language (for those balanced in their SQ and EQ).

Although we have not proposed formal hypotheses for this study, it is worth considering the null, or alternate, hypothesis before proceeding to a discussion of the method. We have been careful to stress that while our research questions (described above) are indicative, myriad other factors may well mask these systemizing and empathizing propensities. While a formal experimental protocol may have been able to isolate and control for these factors, our interest was in (a) reproducing Payne's explicitly descriptive study, and (b) exploring the everyday, rather than the experimental, aspects of people using their mobile phones.

Method

Participants

In all, 16 males and 7 females agreed to participate. All were non-immigrant native English speakers. They were aged between 18 and 45 years, with median age of 22 years. These people had been recruited from the postgraduate research students and undergraduates from the School of Computing at the Edinburgh Napier University.

Procedure

All 23 participants first completed the two questionnaires that measured their individual EQ and SQ. These were scored by the second author using the guidelines that accompany them. Of the 23 participants, 13 achieved balanced score (EQ = SQ, which we operationally define as EQ = SQ ±5), 4 achieved an above average score in empathy abilities (EQ>SQ) and 6 people scored above average systemizing abilities (SQ>EQ). On the basis of these results, 12 people (4 above average EQs, 4 above average SQs, and 4 balanced[3]) were randomly selected to participate in the interview portion of the study.

The selected participants were individually taken aside to a quiet room to be interviewed. The participants were asked to complete a consent form and were informed that the collected data would be transcribed, analyzed, and may be submitted for publication. The participants were assured that this was not a test of their knowledge, and they were not obliged to provide the interviewer with an answer. An audio recording, using a Sony DAT recorder, was made of the interviews. The interviews themselves varied in length from around 10 to almost 40 minutes (varying with the loquaciousness of the interviewee). The interview procedure was designed to constrain the interviewee as little as possible, although some limited prompts were necessary. All were also asked to demonstrate and talk-through the typical use of their mobile phones. Participants were encouraged to discuss how they used mobile phones and the role of this technology in their lives. A full list of questions asked of every participant can be found in Appendix C.

As in much qualitative research, content analysis is fundamentally interpretive, meaning is often implicit and can only be understood through deep and repeated familiarity with the entirety of each participant's interview protocol. What follows are both illustrative and representative of the participants' answers to two of the questions we posed. The quotations were selected by the authors to reflect the participants' cognitive style, that is, whether they tended to systemize, empathize, or give balanced answers.

RESULTS

The question "What is inside a mobile phone?" was so phrased to more likely prompt a technical answer. We expected that those individuals with relatively high SQs would offer detailed technical answers.

Above Average SQs (40–50)

Of six participants with high SQs, all but one provided highly technical answers; the other gave answers using systematizing language, although it was considerably less technical.

> *What's in the telephone? Ummh--lots of transistors and chips and things, and the battery,* [pause] *and* [pause] *liquid crystal display for the screen and the speaker, and the microphone, and the camera* [pause]. (Participant 1, SQ = 40)

> *Many things, circuit boards, chips, transceiver* [laughs], *battery* [pause], *a camera in some of them, a media player, buttons, lots of different things.* [pause] *Well there are lots and lots of different bits and pieces to the phone, there are mainly in ... Eh, like inside the chip there are lots of little transistors, which is used, they build up to lots of different types of gates and/or "x" these types of gates or electronic gates. There are resisters and diodes;* [pause] *there's a fair amount of copper on, I'd imagine, on circuit boards. There are lights, some of which are light-emitting diodes; in fact they are all probably light emitting diodes. There's a camera, as I have already said. There's a battery, and in most modern mobile phones they use lithium polymer batteries, um… because they last longer and have greater capacity….* (Participant 4, SQ = 44)

> *What is in the phone? Um, all kinds of circuitry and devices. I know there's a camera in the phone, so there will be a light detector for that. And there is a wireless card, so there's a wireless interface for that. There's a memory slot, so there will be an interface for that. There's a SIM card; the SIM card contains your personal information, it's a sort of chip that contains your unique identifier for the network, so basically your phone number and such. Uh, it has onboard memory for storage; it has onboard memory, volatile memory for operating system use, umm, and it has the various hardware that drives the screen.* (Participant 6, SQ = 45)

> *In... inside the telephone? Well, I mean it's ... eh ... you know, you're going to have a printed circuit board, known as a PCB. Ahh ... that ... that allows for communications between the different, ah ... chips on the PCB for things like voice encoding and decoding, umm... so I can hear and speak ahh ... with people. Umm ... This also allows for power to come from the battery to the different elements, umm ... and obviously to the screen as well.* (Participant 7, SQ = 50)

Average SQs (20–39)

Participants with average SQ scores tended to be less loquacious, saying less about what is inside their phones than those with higher scores.

> *What's* in *it? It's a little computer; it's a microchip, and a screen, and shit like that.* (Participant 8, SQ = 24)

> *No.* [laughs] *A speaker and a microphone and a camera, if you got a camera* [laughs], *phone umm ... and a battery and a SIM card. That's about all I know.* (Participant 10, SQ = 27)

There were no participants with low SQs in the sample with whom we could compare accounts.

How People Think Mobile Phones Work

Following Payne's protocol, we asked, "How do you think the telephone works?" with the coda, "Pretend you are answering to the intelligent Martian who has no experience with the devices."

Balanced Individuals (EQ = SQ ±5)

All participants with balanced EQ and SQ scores tended to give answers that contained strong evidence of neither systemizing nor empathizing elements.

> *Ok* [long pause] *Umm... Ok... I... I... I...think like, Mmmh ... of course it's working over satellite and, mmmh ... it's provided with software for the text messages, like that I can use T9 and stuff like that. And I think it's almost just based on software and this, umm … code is transferred over satellite.* [pause] *And the, the, the calling is just like with a normal phone but it's not transferred over a landline but over umm satellite, that's… yeah.* (Participant 11, SQ = 33**,** EQ = 38)

Participant 11, unlike those scoring above average on the systemizing scale, shows little or no evidence of having a detailed mental model of the phone's operation. Instead she describes the operation of a mobile phone coherently but in a high level, fairly general manner.

Above Average EQ (55–63)

All highly empathizing participants provided similar sorts of answers to the same question that tended to highlight the surface features of their phones.

> *It flashes the lights, screen flashes, and the buttons lights up, and it vibrates. It comes to life on the inside and it comes to life on the outside, and you talk to the one side and someone is answering on the other side* [long pause]*. Umm... well, all the different elements connect and work in the phone so enable you to … make the phone call. I don't know how, but yeah ... I don't know. It's a mystery. It's magical* [laughs]*. I have no understanding of how it works. So it really is magical.* (Participant 3, EQ = 55)

> [Interviewer] What happens if you enter your PIN code incorrectly?
> *Three times? It locks me out.*
> [interviewer] And what does it mean?
> *It means I can't use it and I cry quite a lot.* (Participant 8, EQ = 56)

For Participant 3, who shows above average empathizing propensity, the language is quite different from that of the other extracts. This participant ascribed agency to her phone ("It comes to life") and often referred to her phone as being magical.

Space prevents a fuller account of these interviews but what is clear is that there is a relationship (but not a simple one) between the systemizing quotients and the nature of the answers people gave. People with high SQs appear to have complex, well populated mental models of their phones; people with lower SQs less so. For those with high EQs, the picture is less clear. There is some evidence of anthropomorphism, but we suspect the demand characteristics of the situation may have obscured this. The balanced individuals are best characterized as being disinterested, with no real evidence of either systemizing or empathizing propensities.

DISCUSSION

As we have seen, there is a considerable body of evidence regarding how people reason about and conceptualize everyday interactive technology. We have argued that Baron-Cohen's

(1995, 2002, 2004) distinction between systemizing and empathizing cognition is used here differentially to create either mental model or anthropomorphic descriptions, as required. The data we have presented from the study of how people think about their mobile phones indicate that

- people who demonstrate high SQs tend to produce detailed, technical accounts of technology. This finding is consistent with the mental models hypothesis.
- people who demonstrate high EQs correspondingly show little technical knowledge and are given to describing the workings of technology in terms of magic and anthropocentricism.
- people who demonstrate a balanced EQ and SQ appear to offer explanations on how technology works that are neither overly technical nor anthropomorphic.

However a powerful factor in an experimental setting such as this is the way in which we posed the questions. Cognition cannot be observed directly, but the very ways in which we study it necessarily affect the results. Orne (1962) and Orne and Whitehouse (2000) have identified what they describe as demand characteristics that can be encountered in psychological studies. They found that people, understandably, attempt to make sense of what the experimenter is trying to achieve. So as soon as we ask questions about how people think about something, we are (a) necessarily asking biased questions, and (b) effectively prompting them to answer in a particular way. Demand characteristics, more formally, refer to the totality of cues and role expectations that are inhered within all social contexts, including a study such as this. The consequences or effect of demand characteristics in this situation will vary with the extent to which they are perceived, as well as with the motivation and ability of the person to comply. Demand characteristics are very difficult to control for and, in asking people about the operation of mobile phones, we can recognize that some questions will tend to elicit or prompt a technical answer while other questions will tend to prompt more discursive nontechnical answers. This then is consistent with Norman's (1993) and Clancey's (1997) observations concerning situated cognition. As Norman (1993, p. 4) observes, situated cognition places an emphasis on

> the structures of the world and how they constrain and guide behavior…. Human knowledge and interaction cannot be divorced from the world. To do so is to study a disembodied intelligence, one that is artificial, unreal, and uncharacteristic of actual behavior. What really matters is the situation and the parts that people play. One cannot look at just the situation, or just the environment, or just the person. To do so is to destroy the very phenomenon of interest. After all, it is the mutual accommodation of people and the environment that matters, so to focus upon only aspects in isolation is to destroy the interaction, to eliminate the role of the situation upon cognition and action.

Therefore, we must be aware that all of the responses we received were, in part, a function of the demand characteristics of the study condition; in short, technical questions elicit technical replies and everyday questions elicit everyday answers. Given this, we conclude that the explanations people gave as to how technology works was a function of their ability to adopt the appropriate cognitive style and to manage the situation demanding this cognition. So how people think about interactive technology may be thought of as an interaction between their cognitive propensities and the situation in which their cognition is exercised.

FURTHER WORK

So what are the practical applications of these findings? While it is difficult to imagine how cognitive style might be used to guide the design of, say, custom-made interactive technology (e.g., a mobile phone for above-average empathizers, although its usefulness in marketing is quite clear), it may have consequences for the evaluation of interactive technology.

Evaluation is the cornerstone of HCI; it lies at the heart of the user-centered approach to the development of interactive systems (e.g., the star lifecycle model; Hartson & Hix, 1993). It is the means by which the user experience of the system is fed back to the designer; it is the obverse of design. Many different evaluation techniques are available to the HCI practitioner, but they can be reasonably categorized into four basic themes:

1. Expert evaluation is characterized by the absence of the intended end user of the system but the presence of an expert (e.g., Smith & Mosier, 1986). The expert makes judgments about the design of the interactive technology against a set of guidelines.
2. Model-based evaluation is based on predictions about user behavior made using a psychologically plausible or ergonomic model (e.g., Card et al., 1980; John & Kieras, 1996).
3. Scenario-based, task-based, and cooperative forms of evaluation involve one or more representative users. A typical scenario or task is created with the users working through it, during which problems are identified (e.g., Carey & Rusli, 1995).
4. Finally, there are evaluation techniques that simulate the presence or behavior of a user, such as the cognitive walkthrough (e.g., Poulson, Bovair, & Kieras, 1982; Spencer, 2000).

It is important not to overstate any criticism of these approaches, as they have significantly contributed to the creation of very many usable systems. However all four styles of evaluation treat users like experimental subjects, just as in the classic psychological experiments that (a) sought to make statements about the general population, rather than individuals; and (b) tested hypotheses of the form, interface/artifact A is “better” than interface/artifact B. In all, there typically is no treatment of individual differences beyond a gross categorization, such as novice and expert, or frequent and infrequent users. It may be that this fairly simple systemizer–empathizer–balanced categorization may prove to be both a useful and, just as importantly, a practical means of saying something about individual differences in the experience of end users of a given interactive technology.

ENDNOTES

1. See http://store.irobot.com for more information.
2. Baron-Cohen (2004, pp. 135–136) describes Asperger syndrome (AS) as a variant of autism. He writes, “A child with AS has the same difficulties in social and communication skills and has the same obsessional interests. However, such children not only have normal or high IQ (unlike those with high-functioning autism) but they also start speaking on time.
3. Balanced scores can be so at all three levels of SQ and EQ: high, medium, and low.

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Author's Note

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All correspondence should be addressed to:
Phil Turner
School of Computing
Edinburgh Napier University
Edinburgh, UK
EH 10 5DT
p.turner@napier.ac.uk

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APPENDIX A: THE EQ QUESTIONNAIRE

The Empathy Quotient is intended to measure how easily you pick up on other people's feelings and how strongly you are affected by other people's feelings. Please read each of the 60 following statements very carefully and rate how strongly you agree or disagree with them by circling your answer. There are no right or wrong answers, or trick questions.

1. I can easily tell if someone else wants to enter a conversation.	strongly agree	slightly agree	slightly disagree	strongly disagree
2. I prefer animals to humans.	strongly agree	slightly agree	slightly disagree	strongly disagree
3. I try to keep up with the current trends and fashions.	strongly agree	slightly agree	slightly disagree	strongly disagree
4. I find it difficult to explain to others things that I understand easily, when they don't understand it first time.	strongly agree	slightly agree	slightly disagree	strongly disagree
5. I dream most nights.	strongly agree	slightly agree	slightly disagree	strongly disagree
6. I really enjoy caring for other people.	strongly agree	slightly agree	slightly disagree	strongly disagree
7. I try to solve my own problems rather than discussing them with others.	strongly agree	slightly agree	slightly disagree	strongly disagree
8. I find it hard to know what to do in a social situation.	strongly agree	slightly agree	slightly disagree	strongly disagree
9. I am at my best first thing in the morning.	strongly agree	slightly agree	slightly disagree	strongly disagree
10. People often tell me that I went too far in driving my point home in a discussion.	strongly agree	slightly agree	slightly disagree	strongly disagree
11. It doesn't bother me too much if I am late meeting a friend.	strongly agree	slightly agree	slightly disagree	strongly disagree
12. Friendships and relationships are just too difficult, so I tend not to bother with them.	strongly agree	slightly agree	slightly disagree	strongly disagree
13. I would never break a law, no matter how minor.	strongly agree	slightly agree	slightly disagree	strongly disagree
14. I often find it difficult to judge if something is rude or polite.	strongly agree	slightly agree	slightly disagree	strongly disagree
15. In a conversation, I tend to focus on my own thoughts rather than on what my listener might be thinking.	strongly agree	slightly agree	slightly disagree	strongly disagree
16. I prefer practical jokes to verbal humour.	strongly agree	slightly agree	slightly disagree	strongly disagree

17. I live life for today rather than the future.	strongly agree	slightly agree	slightly disagree	strongly disagree
18. When I was a child, I enjoyed cutting up worms to see what would happen.	strongly agree	slightly agree	slightly disagree	strongly disagree
19. I can pick up quickly if someone says one thing but means another.	strongly agree	slightly agree	slightly disagree	strongly disagree
20. I tend to have very strong opinions about morality.	strongly agree	slightly agree	slightly disagree	strongly disagree
21. It is hard for me to see why some things upset people so much.	strongly agree	slightly agree	slightly disagree	strongly disagree
22. I find it easy to put myself in somebody else's shoes.	strongly agree	slightly agree	slightly disagree	strongly disagree
23. I think that good manners are the most important thing a parent can teach their child.	strongly agree	slightly agree	slightly disagree	strongly disagree
24. I like to do things on the spur of the moment.	strongly agree	slightly agree	slightly disagree	strongly disagree
25. I am good at predicting how someone will feel.	strongly agree	slightly agree	slightly disagree	strongly disagree
26. I am quick to spot when someone in a group is feeling awkward or uncomfortable.	strongly agree	slightly agree	slightly disagree	strongly disagree
27. If I say something that someone else is offended by, I think that that's their problem, not mine.	strongly agree	slightly agree	slightly disagree	strongly disagree
28. If anyone asked me if I liked their haircut, I would reply truthfully, even if I didn't like it.	strongly agree	slightly agree	slightly disagree	strongly disagree
29. I can't always see why someone should have felt offended by a remark.	strongly agree	slightly agree	slightly disagree	strongly disagree
30. People often tell me that I am very unpredictable.	strongly agree	slightly agree	slightly disagree	strongly disagree
31. I enjoy being the centre of attention at any social gathering.	strongly agree	slightly agree	slightly disagree	strongly disagree
32. Seeing people cry doesn't really upset me.	strongly agree	slightly agree	slightly disagree	strongly disagree
33. I enjoy having discussions about politics.	strongly agree	slightly agree	slightly disagree	strongly disagree
34. I am very blunt, which some people take to be rudeness, even though this is unintentional.	strongly agree	slightly agree	slightly disagree	strongly disagree
35. I don’t tend to find social situations confusing.	strongly agree	slightly agree	slightly disagree	strongly disagree

36. Other people tell me I am good at understanding how they are feeling and what they are thinking.	strongly agree	slightly agree	slightly disagree	strongly disagree
37. When I talk to people, I tend to talk about their experiences rather than my own.	strongly agree	slightly agree	slightly disagree	strongly disagree
38. It upsets me to see an animal in pain.	strongly agree	slightly agree	slightly disagree	strongly disagree
39. I am able to make decisions without being influenced by people's feelings.	strongly agree	slightly agree	slightly disagree	strongly disagree
40. I can't relax until I have done everything I had planned to do that day.	strongly agree	slightly agree	slightly disagree	strongly disagree
41. I can easily tell if someone else is interested or bored with what I am saying.	strongly agree	slightly agree	slightly disagree	strongly disagree
42. I get upset if I see people suffering on news programmes.	strongly agree	slightly agree	slightly disagree	strongly disagree
43. Friends usually talk to me about their problems as they say that I am very understanding.	strongly agree	slightly agree	slightly disagree	strongly disagree
44. I can sense if I am intruding, even if the other person doesn't tell me.	strongly agree	slightly agree	slightly disagree	strongly disagree
45. I often start new hobbies but quickly become bored with them and move on to something else.	strongly agree	slightly agree	slightly disagree	strongly disagree
46. People sometimes tell me that I have gone too far with teasing.	strongly agree	slightly agree	slightly disagree	strongly disagree
47. I would be too nervous to go on a big rollercoaster.	strongly agree	slightly agree	slightly disagree	strongly disagree
48. Other people often say that I am insensitive, though I don’t always see why.	strongly agree	slightly agree	slightly disagree	strongly disagree
49. If I see a stranger in a group, I think that it is up to them to make an effort to join in.	strongly agree	slightly agree	slightly disagree	strongly disagree
50. I usually stay emotionally detached when watching a film.	strongly agree	slightly agree	slightly disagree	strongly disagree
51. I like to be very organised in day to day life and often make lists of the chores I have to do.	strongly agree	slightly agree	slightly disagree	strongly disagree
52. I can tune into how someone else feels rapidly and intuitively.	strongly agree	slightly agree	slightly disagree	strongly disagree

53. I don't like to take risks.	strongly agree	slightly agree	slightly disagree	strongly disagree
54. I can easily work out what another person might want to talk about.	strongly agree	slightly agree	slightly disagree	strongly disagree
55. I can tell if someone is masking their true emotion.	strongly agree	slightly agree	slightly disagree	strongly disagree
56. Before making a decision I always weigh up the pros and cons.	strongly agree	slightly agree	slightly disagree	strongly disagree
57. I don't consciously work out the rules of social situations.	strongly agree	slightly agree	slightly disagree	strongly disagree
58. I am good at predicting what someone will do.	strongly agree	slightly agree	slightly disagree	strongly disagree
59. I tend to get emotionally involved with a friend's problems.	strongly agree	slightly agree	slightly disagree	strongly disagree
60. I can usually appreciate the other person's viewpoint, even if I don't agree with it.	strongly agree	slightly agree	slightly disagree	strongly disagree

APPENDIX B: THE SQ QUESTIONNAIRE

The Systemizing Quotient gives a score based on how interested you assess yourself to be in each of the following forms of systemizing. Systemizing is the drive to analyse and explore a system, to extract underlying rules that govern the behaviour of a system; and the drive to construct systems. Please read each of the following 60 statements very carefully and rate how strongly you agree or disagree with them by circling your answer. There are no right or wrong answers, or trick questions.

1. When I listen to a piece of music, I always notice the way it's structured.	strongly agree	slightly agree	slightly disagree	strongly disagree
2. I adhere to common superstitions.	strongly agree	slightly agree	slightly disagree	strongly disagree
3. I often make resolutions, but find it hard to stick to them.	strongly agree	slightly agree	slightly disagree	strongly disagree
4. I prefer to read non-fiction than fiction.	strongly agree	slightly agree	slightly disagree	strongly disagree
5. If I were buying a car, I would want to obtain specific information about its engine capacity.	strongly agree	slightly agree	slightly disagree	strongly disagree
6. When I look at a painting, I do not usually think about the technique involved in making it.	strongly agree	slightly agree	slightly disagree	strongly disagree
7. If there was a problem with the electrical wiring in my home, I'd be able to fix it myself.	strongly agree	slightly agree	slightly disagree	strongly disagree
8. When I have a dream, I find it difficult to remember precise details about the dream the next day.	strongly agree	slightly agree	slightly disagree	strongly disagree
9. When I watch a film, I prefer to be with a group of friends, rather than alone.	strongly agree	slightly agree	slightly disagree	strongly disagree
10. I am interested in learning about different religions.	strongly agree	slightly agree	slightly disagree	strongly disagree
11. I rarely read articles or webpages about new technology.	strongly agree	slightly agree	slightly disagree	strongly disagree
12. I do not enjoy games that involve a high degree of strategy.	strongly agree	slightly agree	slightly disagree	strongly disagree
13. I am fascinated by how machines work.	strongly agree	slightly agree	slightly disagree	strongly disagree
14. I make it a point of listening to the news each morning.	strongly agree	slightly agree	slightly disagree	strongly disagree

15. In maths, I am intrigued by the rules and patterns governing numbers.	strongly agree	slightly agree	slightly disagree	strongly disagree
16. I am bad about keeping in touch with old friends.	strongly agree	slightly agree	slightly disagree	strongly disagree
17. When I am relating a story, I often leave out details and just give the gist of what happened.	strongly agree	slightly agree	slightly disagree	strongly disagree
18. I find it difficult to understand instruction manuals for putting appliances together.	strongly agree	slightly agree	slightly disagree	strongly disagree
19. When I look at an animal, I like to know the precise species it belongs to.	strongly agree	slightly agree	slightly disagree	strongly disagree
20. If I were buying a computer, I would want to know exact details about its hard drive capacity and processor speed.	strongly agree	slightly agree	slightly disagree	strongly disagree
21. I enjoy participating in sport.	strongly agree	slightly agree	slightly disagree	strongly disagree
22. I try to avoid doing household chores if I can.	strongly agree	slightly agree	slightly disagree	strongly disagree
23. When I cook, I do not think about exactly how different methods and ingredients contribute to the final product.	strongly agree	slightly agree	slightly disagree	strongly disagree
24. I find it difficult to read and understand maps.	strongly agree	slightly agree	slightly disagree	strongly disagree
25. If I had a collection (e.g. CDs, coins, stamps), it would be highly organised.	strongly agree	slightly agree	slightly disagree	strongly disagree
26. When I look at a piece of furniture, I do not notice the details of how it was constructed.	strongly agree	slightly agree	slightly disagree	strongly disagree
27. The idea of engaging in "risk-taking" activities appeals to me.	strongly agree	slightly agree	slightly disagree	strongly disagree
28. When I learn about historical events, I do not focus on exact dates.	strongly agree	slightly agree	slightly disagree	strongly disagree
29. When I read the newspaper, I am drawn to tables of information, such as football league scores or stock market indices.	strongly agree	slightly agree	slightly disagree	strongly disagree
30. When I learn a language, I become intrigued by its grammatical rules.	strongly agree	slightly agree	slightly disagree	strongly disagree
31. I find it difficult to learn my way around a new city.	strongly agree	slightly agree	slightly disagree	strongly disagree

32. I do not tend to watch science documentaries on television or read articles about science and nature.	strongly agree	slightly agree	slightly disagree	strongly disagree
33. If I were buying a stereo, I would want to know about its precise technical features.	strongly agree	slightly agree	slightly disagree	strongly disagree
34. I find it easy to grasp exactly how odds work in betting.	strongly agree	slightly agree	slightly disagree	strongly disagree
35. I am not very meticulous when I carry out D.I.Y.	strongly agree	slightly agree	slightly disagree	strongly disagree
36. I find it easy to carry on a conversation with someone I've just met.	strongly agree	slightly agree	slightly disagree	strongly disagree
37. When I look at a building, I am curious about the precise way it was constructed.	strongly agree	slightly agree	slightly disagree	strongly disagree
38. When an election is being held, I am not interested in the results for each constituency.	strongly agree	slightly agree	slightly disagree	strongly disagree
39. When I lend someone money, I expect them to pay me back exactly what they owe me.	strongly agree	slightly agree	slightly disagree	strongly disagree
40. I find it difficult to understand information the bank sends me on different investment and saving systems.	strongly agree	slightly agree	slightly disagree	strongly disagree
41. When travelling by train, I often wonder exactly how the rail networks are coordinated.	strongly agree	slightly agree	slightly disagree	strongly disagree
42. When I buy a new appliance, I do not read the instruction manual very thoroughly.	strongly agree	slightly agree	slightly disagree	strongly disagree
43. If I were buying a camera, I would not look carefully into the quality of the lens.	strongly agree	slightly agree	slightly disagree	strongly disagree
44. When I read something, I always notice whether it is grammatically correct.	strongly agree	slightly agree	slightly disagree	strongly disagree
45. When I hear the weather forecast, I am not very interested in the meteorological patterns.	strongly agree	slightly agree	slightly disagree	strongly disagree
46. I often wonder what it would be like to be someone else.	strongly agree	slightly agree	slightly disagree	strongly disagree
47. I find it difficult to do two things at once.	strongly agree	slightly agree	slightly disagree	strongly disagree
48. When I look at a mountain, I think about how precisely it was formed.	strongly agree	slightly agree	slightly disagree	strongly disagree

49. I can easily visualise how the motorways in my region link up.	strongly agree	slightly agree	slightly disagree	strongly disagree
50. When I'm in a restaurant, I often have a hard time deciding what to order	strongly agree	slightly agree	slightly disagree	strongly disagree
51. When I'm in a plane, I do not think about the aerodynamics	strongly agree	slightly agree	slightly disagree	strongly disagree
52. I often forget the precise details of conversations I've had	strongly agree	slightly agree	slightly disagree	strongly disagree
53. When I am walking in the country, I am curious about how the various kinds of trees differ	strongly agree	slightly agree	slightly disagree	strongly disagree
54. After meeting someone just once or twice, I find it difficult to remember precisely what they look like	strongly agree	slightly agree	slightly disagree	strongly disagree
55. I am interested in knowing the path a river takes from its source to the sea	strongly agree	slightly agree	slightly disagree	strongly disagree
56. I do not read legal documents very carefully	strongly agree	slightly agree	slightly disagree	strongly disagree
57. I am not interested in understanding how wireless communication works	strongly agree	slightly agree	slightly disagree	strongly disagree
58. I am curious about life on other planets	strongly agree	slightly agree	slightly disagree	strongly disagree
59. When I travel, I like to learn specific details about the culture of the place I am visiting	strongly agree	slightly agree	slightly disagree	strongly disagree
60. I do not care to know the names of the plants I see	strongly agree	slightly agree	slightly disagree	strongly disagree

APPENDIX C: THE QUESTIONS ASKED OF THE PARTICIPANTS

What kind of phone do you have and how often do you use it?
What do you use the phone for other than calling?
What happens if you enter the wrong pin number to switch on the phone?
What is in the telephone?
What is in the SIM card?
How is the information used?
Do you know what the PIN code does?
How do you think the telephone works?
Is there a difference between messaging & email?
What happens to the ‘phone during the connection?
Why does the battery go flat when you don't use the phone?
What does the signal availability mean?
What does it mean when the network is busy?
What makes the battery life go down fastest?
What do the bars on the phone mean?

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Scott W. Ambler, IBM, Canada
Anthony D. Andre, San Jose State University, USA
Sandrine Balbo, Deakin University, Australia
Pieter Ballon, IBBT-SMIT, Vrije Universiteit Brussels, Belgium
David Benyon, Edinburgh Napier University, UK
Eleni Berki, University of Tampere, Finland
Andy Bissett, Sheffield Hallam University, UK
Ann Blandford, University College London, UK
Kirsimarja Blomqvist, Lappeenranta University of Technology, Finland
Stina Boedeker, University of Tampere, Finland
Kirsten Boehner, Cornell University, USA
Jim Buckley, CSIS and Lero, University of Limerick, Ireland
Kathy Buckner, Edinburgh Napier University, UK
Stéphanie Buisine, Arts et Métiers ParisTech, France
Marilyn Campbell, Queensland University of Technology, Australia
José C. Campos, University of Minho, Portugal
Gilbert Cockton, University of Sunderland, UK
Andy Crabtree, University of Nottingham, UK
Andy Dearden, Sheffield Hallam University, UK
Françoise Détienne, CNRS - Telecom ParisTech, France
Keith Devlin, Stanford University, USA
Alan Dix, Lancaster University, UK
Benedict du Boulay, University of Sussex, UK
Chris Exton, University of Limerick, Ireland
Bjørn Furuholt, University of Agder, Norway
Azucena Garcia-Palacios, Universidad Jaume I, Spain
Darren Gergle, Northwestern University, USA
Narciso Gonzalez Vega, University of Jyväskylä, Finland
Judith Good, University of Sussex, UK
Misty Gripper, Wright State University, USA
Ingunn Hagen, Norwegian University of Science and Technology, Norway
Lynne Hall, University of Sunderland, UK
Sung H. Han, Pohang University of Science & Technology, South Korea
Seamus Hickey, University of Oulu, Finland
Eva Hudlicka, Psychometrix Associates, USA
M. Gordon Hunter, University of Lethbridge, Canada
Sampsa Hyysalo, University of Helsinki, Finland
Stephen Intille, Massachusetts Institute of Technology, USA
Marja Järvelä, University of Jyväskylä, Finland
Gareth Jones, Dublin City University, Ireland
Matt Jones, Swansea University, UK
Eija Kaasinen, VTT Technical Research Centre of Finland
Erkki Karvonen, University of Tampere, Finland
Harri Ketamo, Satakunta University of Applied Sciences, Finland
Kristian Kiili, Tampere University of Technology, Finland
Leena Korpinen, Tampere University of Technology, Finland
Marja Kuittinen, University of Joensuu, Finland
Maria Kutar, University of Salford, UK
Tommi Laukkanen, University of Joensuu, Finland
Mauri Leppänen, University of Jyväskylä, Finland
Louis W. Leung, The Chinese University of Hong Kong
Juha Lindfors, University of Lapland, Finland
Heikki Lyytinen, University of Jyväskylä, Finland
Yannis Markoulidakis, Vodafone, Greece
Lindsay Marshall, Newcastle University, UK
Deborah J. Mayhew, Deborah J. Mayhew & Associates, USA

Oli Mival, Edinburgh Napier University, UK
John Mueller, University of Calgary, Canada
Craig D. Murray, Lancaster University, UK
Bogdan Nadolu, West University of Timisoara, Romania
Veli-Pekka Niitamo, Center for Knowledge and Innovation Research, Helsinki School of Economics, Finland
Jan Noyes, University of Bristol, UK
Brian O'Keefe, Edinburgh Napier University, UK
Wendy Olphert, Loughborough University, UK
Hanna Parkkola, Hanna Park Oy, Finland
Markku Penttonen, University of Jyväskylä, Finland
Jo Pierson, IBBT-SMIT, Vrije Universiteit Brussels, Belgium
Seppo Puuronen, University of Jyväskylä, Finland
Reetta Raitoharju, Turku School of Economics, Finland
Karen Renaud, University of Glasgow, UK
Ronald Rice, University of California, Santa Barbara, USA
Ingrid Richardson, Murdoch University, Australia
Francisco Rebelo, Technical University of Lisbon, Portugal
Hans Rystedt, University of Gothenburg, Sweden
Jorma Sajaniemi, University of Joensuu, Finland
Maria V. Sanchez-Vives, Institute of Biomedical Research Augusto Pi y Suñer, Spain
Simon Schütte, Linköping University, Sweden
Ahmed Seffah, University of Concordia, Canada
Chuan-Fong (Eric) Shih, Sungkyunkwan University, South Korea
Emilia Sobolewska, Edinburgh Napier University, UK
Grace P. Y. Szeto, Hong Kong Polytechnic University, Hong Kong
Matti Tedre, University of Joensuu, Finland
Bjørnar Tessem, University of Bergen, Norway
Stephen Timmons, Nottingham University, UK
Bettina Törpel, Technical University of Denmark
Simon Tucker, University of Sheffield, UK
Phil Turner, Edinburgh Napier University, UK
Susan Turner, Edinburgh Napier University, UK
Michael B. Twidale, University of Illinois at Urbana-Champaign, USA
Seppo Väyrynen, University of Oulu, Finland
Stephen Viller, University of Queensland, Australia
Steve Walker, Open University, UK
Peter J. Wild, Cambridge University, UK
Susan Wiedenbeck, Drexel University, USA
Nancy Willard, Center for Safe and Responsible Internet Use, USA
Peter Wright, Sheffield Hallam University, UK

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