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Social Situatedness of Natural and Artificial Intelligence: Vygotsky and Beyond

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The concept of "social situatedness," that is, the idea that the development of individual intelligence requires a social (and cultural) embedding, has recently received much attention in cognitive science and artificial intelligence research, in particular work on social or epigenetic robotics. The work of Lev Vygotsky, who put forward this view as early as the 1920s, has influenced the discussion to some degree but still remains far from well known. This article therefore is aimed at giving an overview of his cognitive development theory and a discussion of its relation to more recent work in primatology and socially situated artificial intelligence, in particular humanoid robotics.

Keywords social situatedness · Vygotsky · cognitive development · primate cognition · epigenetic robotics · humanoid robots

1 Introduction

The concept of situatedness has since the mid-1980s been used extensively in the cognitive science and artificial intelligence (AI) literature, in terms such as "situated action" (Suchman, 1987), "situated learning" (e.g., Lave, 1991), "situated AI" (e.g., Husbands, Harvey, & Cliff, 1993), "situated robotics" (e.g., Hallam & Malcolm, 1994), "situated activity" (e.g., Hendriks-Jansen, 1996), "situated cognition" (Clancey, 1997; Clark, 1999), and "situated translation" (Risku, 2002). Roughly speaking, the characterization of an agent as "situated" is usually intended to mean that its behavior and cognitive processes first and foremost are the outcome of a close coupling between agent and environment. Hence, situatedness is nowadays by many cognitive scientists and AI researchers considered a *conditio sine qua non* for any form of "true" intelligence, natural or artificial.

As some of the above phrases indicate, the term "situated" is indeed commonly applied to both natural and artificial systems. The differences between the two types of systems may also help to clarify what is meant by "social situatedness." Brooks (1991), one of the main proponents of the situated approach within AI, formulated a number of shortcomings of traditional AI and initially particularly focused on the challenges of getting robots to act in the real world. This shift toward a situated approach within AI, nowadays referred to as "New AI," initially resulted in embodied mobile robots, which closely interacted with the *physical* environment and therefore could be considered to

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be *physically situated* in that sense. Although these situated robots typically had a close coupling with their physical environment, still something significant might be argued to be lacking. Such robots can be considered to have some degree of *physical* situatedness, but it has been argued that humans are also *socially* and *culturally situated*, resulting in an increased interest within cognitive science and AI in taking the social and cultural environment into account (cf. e.g., Brooks & Stein, 1993; Brooks, Breazeal, Marjanović, Scassellati, & Williamson, 1998; Clark, 1997; Dautenhahn, 1995; Edmonds, 1998; Hutchins, 1995; Kozima & Yano, 2001; Tomasello, 1999).

According to Dautenhahn and colleagues (Dautenhahn, Ogden, & Quick, 2002), the concept of situatedness can be transferred to the social field, by broadening the physical environment to the social environment as follows: "a *socially situated* agent acquires information about the social as well as the physical domain through its surrounding environment, and its interactions with the environment may include the physical as well as the social world" (p. 410). Social aspects of situatedness will be the major focus in this article. Hence, the main question addressed here is: What are the role and relevance of social situatedness in natural and artificial intelligent systems, and to what extent can recent work in socially situated AI be used to model and understand the mechanisms of (natural) social situatedness?

Traditionally, the study of the social environment, such as social, cultural, and historical aspects, has been ignored and factored out in mainstream cognitive science and AI. Gardner (1985), for example, argued that context and cultural factors, which he referred to as "murky concepts," would only cause problems in trying to find the "essence" of individual cognition. However, Hutchins (1995), for example, claimed that there are some unnoticed costs if we initially take no concern of the social and cultural nature of cognition. He argued that cognition is a result of sociocultural processes and that we cannot ignore culture, context, and history, which he considered as primary factors of the development of individual intelligence. Similarly, Tomasello (2000) claimed that if a human infant grew up from birth with no contacts with human culture, and without exposure to human artifacts, it would not develop the cognitive abilities that are the hallmarks of human intelligence. Interestingly, some researchers in socially situated AI (cf. Brooks et al., 1998; Zlatev, 2001) presented a closely related argument: If a humanoid (i.e., physically human-like) robot "grew up" in close social contact with human caregivers then it might develop similar cognitive skills to those of human beings.

Whereas interest in social situatedness is relatively new in cognitive science and AI, the Russian scholar Lev Vygotsky pointed out the importance of social interactions for the development of individual intelligence in humans as early as during the 1920s and 1930s. Vygotsky's theory of cognitive development particularly stresses that individual intelligence emerges as a result of biological factors (embodiment, one might say in today's terms) that interact with a physical and especially a social environment (in today's terms: situatedness) through a developmental process. Unfortunately, his work was not spread to the Western world before the 1960s, when the first public translation to English appeared in 1962. One cause for this delay is probably the fact that Vygotsky's work was actually banned in the Soviet Union from the mid-1930s to the mid-1950s. More recently, Vygotsky's work has influenced theories of (socially) situated cognition to some degree (e.g., Clark, 1997; Hutchins, 1995; Kirshner & Whitson, 1997), but it still seems to be far from well known. Hendriks-Jansen (1996), Brooks et al. (1998), and Sinha (2001), for example, discuss many ideas closely related to Vygotsky's work without actually referring to it at all. Parts of this article are therefore dedicated to presenting his ideas in detail (Section 2), and evaluating them in the light of contemporary work in primatology (Section 3) and socially situated AI (Section 4).

Primatology is another field that stresses the importance of social interactions for individual intelligence. Tomasello (2000), for example, pointed out that human cognition is a special case of primate cognition, and many structures of human cognition are identical with those of other primates. He therefore argued that the study of nonhuman (in particular primate) cognition should play a more important role within cognitive science than it has so far. In Section 3, therefore, we discuss the relation between Vygotsky's cognitive development theory and recent work on primate cognition, in particular the "enculturation" of apes.

As Scassellati (2001) pointed out, research in (human) cognitive development and work in situated AI and robotics can and should be complementary, but unfortunately comparative analysis of ideas and theories from different disciplines is still largely lacking. This article is aimed at providing exactly this kind of comparative analysis. On the one side, socially situated natural intelligence is addressed in an overview of Vygotsky's cognitive developmental theory and examples of interesting findings in nonhuman primate intelligence. On the other side, socially situated artificial intelligence is represented by studies of robot–human interaction (e.g., Billard, Dautenhahn, & Hayes, 1998; Brooks et al., 1998; Kozima & Yano, 2001), and robot–robot interaction (e.g., Billard & Dautenhahn, 1997, 1998, 1999).

2 Vygotsky

Although interest in the social embedding of individual intelligence has increased rapidly within contemporary cognitive science and AI, and much of the literature is directly, or more often indirectly, influenced by Vygotsky, there are surprisingly very few researchers who mention his work as a source of inspiration. Moreover, some of those who do seem not to have a full understanding of Vygotsky's theory and basic ideas, but instead only pick out selected parts to fit their own purposes. Section 2.1 therefore presents an overview of Vygotsky's theory of cognitive development and elaborates in particular those aspects most relevant to the discussion in this article. This is followed by Section 2.2 which covers contemporary views of Vygotsky's work.

2.1 Vygotsky's Cognitive Development Theory

The Russian scholar Lev Vygotsky viewed individual cognition and intelligence as culturally based, grounding his theory in the cultural history of the human species and the child's interactions with other people in its particular culture. According to Kozulin (1986), Vygotsky was initially active during an era when Russian psychology was dominated by behavioristic reflex theories, proposed by, for example, Pavlov and Bekhterev. Besides contemporary Russian psychology, Vygotsky was familiar, for example, with Gestalt psychologists such as Koffka, Buhler, and Köhler, and also the early work of Piaget. Vygotsky himself was critical of both behaviorism and Gestalt psychology; he argued that these studies, in their "zoological models" removed the essential differences between human and animal intelligence. He therefore claimed that human intelligence was "more than a leather sack filled with reflexes" (1925/1979, p. 9), arguing that the existing psychological theories had failed, because they were not capable of explaining all the structures of human behavior. Instead, Vygotsky (1925/1979) requested a psychological theory that would describe the development of the abilities that are exclusively human. He claimed that this could only succeed if all dimensions of the human mind were analyzed, but not in the form of introspectionism. Vygotsky (1925/1979) was critical of this "mentalistic" convention, since it, in his opinion, confined itself through circular reasoning in which states of consciousness were "explained" by the term of consciousness. As an alternative, he argued that if consciousness is taken as the subject of study, then its explanation must be sought in some other dimension of reality. Vygotsky proposed that socially meaningful activities play this role of "producer" of consciousness, arguing that the individual mind is constructed from the outside, through interactions with other people. In his own words:

> The mechanism of social behavior and the mechanism of consciousness are the same…. We are aware of ourselves in that we are aware of others; and in an analogous manner, we are aware of others because in our relationship to ourselves we are the same as others in their relationship to us. (Vygotsky, 1925/1979, p. 29)

This means that the nature of individual human intelligence is, according to Vygotsky, developed through interactions with the environment in general, and more precisely it is the result of social interactions with other human beings.

Vygotsky (1934/1978) distinguished between *elementary* and *higher* mental functions. He argued that our elementary mental functions had to be those functions that were genetically innate and existed both in humans and (other) animals. These elementary or natural mental functions are, for example, simple memory, perception, and attention. These mental functions are controlled by the recognition of co-occurring stimuli in the environment, which Vygotsky (1934/1978) referred to as *signalization.* The higher or cultural mental functions are, according to Vygotsky, *exclu-*

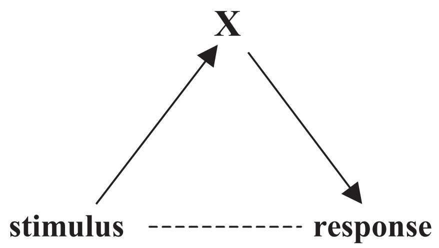

Figure 1 The organization of higher behavior via a mediated act involving a "psychological tool" (X). Adapted from Vygotsky (1934/1978, p. 40).

sively human and emerge dynamically through radical transformations of the lower ones. In elementary functions there is a direct link between a stimulus in the environment and a response from the creature, which Vygotsky (1934/1978) expressed by a stimuli → response formula. However, for a higher mental function the structure differs significantly, because it involves an *intermediate link* between the stimulus and the response, as illustrated in Figure 1.

Vygotsky (1934/1978) pointed out that this type of organization is fundamental to all higher cognitive processes, although typically in a much more complicated structure than shown above. The intermediate link involves the psychological tool that is "drawn into" the cognitive operation to fulfill a special function, namely creating an altered relation between stimulus and response. The higher mental functions lie *outside* the individual, in the form of psychological tools and interpersonal relations. The lower functions do not disappear in the "developed" or "enculturated" mind, but they undergo some reorganizations according to particular forms of human cultural activity (Kozulin, 1986).

Vygotsky particularly focused on the factors that distinguish between elementary and higher mental functions. Primarily he mentioned the shift of control from the environment (*signalization*) to the individual's voluntary regulation of his/her behavior. Next, he claimed that social origins and nature are the driving forces of higher mental abilities, as well as the use of *psychological tools* that mediate higher mental functions. For example, Vygotsky (1929/1977; 1934/1978) argued that such a simple operation as tying a knot in a handkerchief to function as a memory cue altered the psychological construction of remembering. As a result, the memory process was extended beyond the biological inherited factors; the incorporation of artificial or self-generated stimuli in the form of *psychological tools* was the key difference between animal and human behavior. He argued that previously in human evolution, humanlike ancestors developed simple tools, and this invention led to a shift of behavior, resulting in an important change in the pattern of thinking. Vygotsky (1929/1977, 1934/1978) called this process of conveying meaning to arbitrary stimuli *signification.* He argued that (other) animals were not capable of performing such operations, which demarcate the starting point of human intelligence.

The invention and use of arbitrary stimuli as psychological tools to perform advanced cognitive "tasks" like remembering, decision-making, and so forth, is according to Vygotsky (1934/1978; 1981), analogous to the human invention and use of technical tools such as hammers, saws, spades, and ploughs. However, this analogy has significant differences, because the two separate activities have crucial distinctions according to Vygotsky. The basic foundation in the analogy between a psychological tool and a technical tool lies in their *mediating function*, which characterizes both of them. Consequently, they can be included under the same category, from a psychological standpoint. Vygotsky (1934/1978) argued that the essence of the use of psychological tools for mediated activity is that they influence and have an effect on human behavior; since actions conducted with these psychological tools create thoughts. In 1933 he stated that "the central fact about our psychology is the fact of mediation" (quoted from Wertsch, 1985, p. 15).

The most important distinction between a technical tool and a psychological tool lies in how they affect human behavior. The technical tool is *externally* oriented, toward changing objects, whereas psychological tools are *internally* oriented, changing ways of thinking, controlling, regulating, and organizing behavior. As a consequence, both technical and psychological tools transform cognition. The psychological tools bridge the gap between elementary and higher mental functions, and they include "various systems for counting; mnemonic techniques; algebraic symbol systems; works of art; writing; diagrams; maps, and technical drawings; all sort of conventional signs, and so on" (Vygotsky, 1981, p. 137). Of the psychological tools, mediating our thoughts, feelings and behavior, he considered language the most significant.

Vygotsky (1934/1978, 1934/1986) stressed that the primary function of language, in the form of speech, is a device for social contact, and interpersonal communication, influencing other people. Later, this social speech transforms and becomes *egocentric speech,* which internalizes social speech for the child's own ends. Vygotsky (1934/1986) argued that this egocentric speech is a shift from social speech (between people) to inner speech, which "goes" inward into the mind, by directing our own thinking. Consequently, the interpersonal becomes intrapersonal, and "actions" with this special psychological tool create thought; thus language liberates us from our immediate perceptual experience and allows us also to represent the past, the future, and the un-present. Thinking and language are dynamically related, because understanding and producing language are processes that transform the process of thinking.

As a result of his analysis of the differences between animal and human behavior, resulting in elementary and higher functions, Vygotsky identified two different influences on psychological development, namely *biological principles* and *sociohistorical factors* (Vygotsky, 1934/1978). According to Vygotsky, *biological* factors are part of our ontogenetic development and incorporate the development of the physiological body. These biological factors control the initial months of life in infants, responsible for the development of perception, basic memory, and spontaneous attention. Vygotsky called the emergence of these elementary mental functions *natural* (or *primitive*) *development.* The second line of development is *sociohistorical,* and it appeared with the invention and use of culturally based psychological tools (signification) in primitive humans. These tools function as "regulators" of human *social* behavior, and especially language is an important "organizer," both in the form of speech and written text. The line of sociohistorical development separated human behavior from animal behavior, and it also has a significant role in the cognitive development of the individual child, since the child literally is born into the psychological tool systems of its particular culture. Vygotsky characterized the importance of these two lines of development for individual intelligence as follows:

> The cultural development of the child is characterized first by the fact that it transpires under conditions of dynamic organic changes. Cultural development is superimposed on the process of growth, maturation, and the organic development of the child: It forms a single whole with these processes. It is only through abstraction that we can separate one set of processes from another.
>
> The growth of the normal child into civilization usually involves a fusion with the processes of organic maturation. Both planes of development—the natural and the cultural—coincide and mingle with each other. The two lines of change interpenetrate one another and essentially form a single line of sociobiological formation of the child's personality. (quoted from Wertsch, 1985, p. 41)

Hence, the cognitive abilities of an "enculturated" adult human are the product of these processes of cognitive development, in which "primitive" and "immature" humans are transformed into cultural ones. Roughly speaking, the child initially has to learn the particular psychological tools in its culture and then learn how to use them to master and control its own behavior. This transformation process, from elementary (or natural) mental functions to more complex higher functions is described (not explained) by two key principles, namely, the process of *signification* (using psychological tools*),* and a principle referred to as the *general law of cultural development* (Wertsch, 1985). The essence of the latter is as follows:

> Every function in the child's development appears twice: first, on the social level, and later, on the individual level; first, *between* people *(interpsychological),* and then *inside* the child *(intrapsychological).* … All the higher functions originate as actual relations between human individuals. … *The transformation of an interpersonal process into an intrapersonal one is the result of a long series of developmental events.* … The internalisation of socially rooted and historically developed activities is the distinguishing feature of human activity, the basis of the qualitative leap from animal to human psychology. (Vygotsky, 1934/1978, pp. 56–57, original emphasis)

Vygotsky (1934/1978) called this process of transforming an interpersonal process (human-to-human interaction) into an intrapersonal one *internalization.* To illustrate the essential role of social interactions during this transformation process Vygotsky (1934/1978) used the example of the development of pointing in the child. He claimed that initially it is only a simple and incomplete grasping movement directed toward a desired object, only represented by the child's reaching and grasping movement, and nothing more. When the caretaker comes to help the child, the meaning of the gesture situation itself changes, since it obtains another meaning, as the child's failed reaching attempt provokes a reaction, not from the desired object, but from another person. The individual movement "in itself" becomes a gesture "for-others." The caretaker in this case interprets the child's grasping/reaching movement as a kind of pointing gesture, resulting in a socially meaningful communicative act, whereas the child itself at the moment is not aware of its communication ability. However, after a while the child becomes aware of the communicative function of its movements and then begins addressing its gestures toward other people, rather than the object of interest that was its primary focus initially. Thus, "*the grasping movement changes to the act of pointing"* (Vygotsky, 1934/1978, p. 56). As Kozulin (1986) pointed out, it is essential to note that the child itself is the last person who "consciously" grasps the "new" meaning of its own pointing gesture.

Another central concept in Vygotsky's theory is the so-called *zone of proximal development*, and it is related to the process of internalization in the child, transforming interpersonal functions into intrapersonal ones. It is in the zone of proximal development that the child learns, through social interactions, how to use the tools available, especially the psychological ones. Vygotsky (1934/1978, 1934/1986) noticed that when a caretaker gives meaning to the child's interaction, when the child is unable to do so for itself, the child is working in the zone of proximal development, which Vygotsky characterized as follows:

> It is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (Vygotsky, 1934/1978, p. 86)

The caretaker realizes the child's achievement by means of hints, explanations, encouragements, regulating and controlling the child's focus of attention, and so on. Vygotsky (1934/1978) also related *imitation* and *learning* to the zone of proximal development. He argued that a child merely can imitate what is within its zone of proximal development, and if a caregiver presents a too advanced solution to a problem, the child could not grasp the solution, even if the solution was presented repeatedly. The child can therefore only "imitate" and adopt a solution to a problem or an activity if it is within the boundaries of the child's particular zone of proximal development. Moreover, Vygotsky (1934/1978) argued that only humans possess a zone of proximal development:

> A primate can learn a great deal through training by using its mechanical and mental skills, but it cannot be made more intelligent, that is, it cannot be taught to solve a variety of more advanced problems independently. For this reason animals are incapable of learning in the human sense of the term; *human learning presupposes a specific social nature and a process by which children grow into the intellectual life of those around them.* (Vygotsky, 1934/1978, p. 88, original emphasis)

Thus, according to Vygotsky, the "mind" of the chimpanzee, for example, can never be developed and extended further than their biological heritage, since they lack a zone of proximal development. However, in Section 3 we will address evidence from recent primate studies that indicates the opposite.

2.2 Contemporary Views on Vygotsky's Work

Various forms of criticism have been raised against Vygotsky's work, especially that he did not pay enough attention to biological factors, particularly in his empirical research. According to Davydov and Radzikhovskii (1985), there is a major gulf between "Vygotsky the psychologist" and "Vygotsky the methodologist." They pointed out that Vygotsky almost exclusively focused on the sociocultural forces in his empirical studies, and that he neglected the biological line of development, especially the physical maturation in the child during its first years of life. They further argued that Vygotsky tended to view biological factors as "raw materials," which then are transformed by the sociocultural forces, whereas he mentioned almost nothing about how changes in biological factors may influence sociocultural ones. Wertsch (1985), on the other hand, argued that Vygotsky himself was aware of the necessary, but not sufficient, conditions provided by biological factors, since he assumed that the natural factors play the major role in early ontogeny, and that cultural forces take the leading role later on. Hence, Wertsch argued that Vygotsky did not view advanced cognition and thinking as the outcome of social factors alone; he also stated that "culture creates nothing; it only alters natural data in conformity with human goals" (cited in Wertsch, 1985).

Another criticism is that Vygotsky only managed to accomplish a broad outline, with very few details. Lack of detail exists, for example, in the vagueness of the notion of a zone of proximal development, which lacks explanations concerning which psychological processes are involved in the transformation process of internalization, and how one might "measure" the width of the zone (e.g., Miller, 1983). Moreover, Vygotsky (1934/1978) used concepts that were not well defined; for example, he did not characterize exactly what he actually meant by "imitation." Partly these weaknesses can be explained by the fact that Vygotsky died of tuberculosis at the age of 37, before he had developed a more complete theory (Wertsch, 1985).

However, Vygotsky's initial ideas have been elaborated and developed further after his death by his colleagues and followers. Some of Vygotsky's closest colleagues were Luria, Leont'ev, and Gal'perin. Luria applied Vygotsky's ideas in his work on reasoning, speech functions, and language disorders, and he was the founder of the field of neuropsychology (Bechtel & Graham, 1999). Leont'ev elaborated Vygotsky's ideas of "mediated activity" as the basic unit of analysis and was one of the founders of *activity theory* (Engeström, 1987). Activity theory offers a theoretical framework to the study of relations between actions, individuals, artifacts, and communities as a whole. Leont'ev (in Engeström, 1987) argued that studying only individual tool-mediating activity was unsatisfactory, because human activity is always collaborative in its nature. Leont'ev's view of activity theory has been elaborated further by Engeström (1999). Gal'perin's work, on the other hand, has received much less attention in the Western world than Luria's and Leont'ev's work. Gal'perin focused on the mental processes that transform mediated actions, trying to explain *how* higher mental functions emerged (Arievitch & Stetsenko, 2000).

The work of Vygotsky's followers has mainly focused on the concept of the zone of proximal development, particularly in different cultural contexts and educational settings (cf. Brown, 1997; Bruner, 1990; Cole & Scribner, 1974; Cole, Engeström, & Vasquez, 1997; Moll, 1990; Rogoff, 1990, 2003; Rogoff & Lave, 1984; Wertsch, 1985; Wood, Bruner, & Ross, 1976). They have investigated how different cultures and educational instructions emphasize different psychological tools, and how these affect cognitive abilities. To conclude, activity theory has been used in a number of different areas since Leont'ev's initial work in the 1930s, particularly in human–computer interaction (e.g., Bødker, 1998; Kaptelinin, Nardi, & Macaulay, 1999; Nardi, 1996), and computer-supported cooperative work (e.g., Kuutti, 1996).

3 Primate Studies

The role of social interactions and their impact on individuals have lately been addressed as *the* major force for the emergence of primate intelligence. Initially this idea was addressed by researchers such as Chance and Mead (1953) and Jolly (1966), but it is nowadays often presented under the banners of the *social intelligence hypothesis* (Kummer, Daston, Gigerenzer, & Silk, 1997) or the *Machiavellian intelligence hypothesis* (Byrne & Whiten, 1988; Whiten & Byrne, 1997). Roughly speaking, these authors have proposed that the development of individual intelligence is a result of the requirements of a complex social living environment. Primates not only "search for food," they also have social strategies of their own, since they may gain adaptive advantages by co-operating with selected conspecifics as "friends" and learn important things from each other. Whiten (2000) pointed out that there are various forms of cultural transmission, and *imitation* is supposed to be the most advanced one. In "true" imitation the imitator really reproduces the behavioral strategy of the demonstrator and for the same goal as the demonstrator; that is, the imitator has to understand the *intention* behind the actions carried out by the demonstrator, not only perform the imitating act. Heyes (1993) argued that imitation could be the mechanism that mediates social transmission, which is essential for achieving a culture (Whiten, 2000).

The question of whether among primates only humans have a culture is a challenging one. Galef (1992) proposed that human culture depends on sophisticated learning processes, including learning, teaching and imitation, and stated that it is wrong to talk about "animal cultures" if they do not use these complex social learning mechanisms, which would be needed for cultural transmission to occur. Studies of social learning and evidence for wild primate "cultures" in their natural habitats have been conducted particularly on chimpanzees in Africa (cf. Boesch, 1991, 1996; Goodall, 1986: McGraw, 1992; Whiten et al., 1999). Specific comparisons have been made on activities such as cracking nuts and "ant dipping." The results indicate that there are different "cultural traditions" in separated places. However, Tomasello (2000) argued that primates do not understand others as intentional beings and therefore do not engage in cultural learning as they do not obtain a "cultural heritage" from generation to generation, since the non-human primate only is born into the particular knowledge of its generation. Moreover, Tomasello (1999) pointed out, following Vygotsky's (1934/1978) ideas, that the uniqueness of human intelligence lies in its collective nature, which is the joint product of lots of people's working over generations, combining and accumulating cognitive skills and knowledge. The mechanism needed for being able to enter this "collective knowledge" is, according to Tomasello, Kruger, & Ratner (1993), *cultural learning*. They pointed out that cultural learning depends critically on the ability to understand others' behavior as intentional. They argued that human infants start to acquire an understanding of others as intentional when they are nearly 1 year old as they begin to engage in different kinds of joint attention interactions with other human beings, especially their caretakers, using such mechanisms as gaze following, imitation, and gestural communication. However, there are some impressive similarities between how primates such as chimpanzees and humans engage in joint attention activities, for example, eye direction, gaze following, and mutual gaze, of which the latter is supposed to be necessary for mediating more complex social interactions (Povinelli, Bering, & Giambore, 2000).

Contrary to Vygotsky's view, recent findings especially in great apes indicate that humans are not the only ones performing acts of internalization. Tomasello (1999) pointed out that great apes reared by humans, so-called "enculturated apes," become to some extent situated in the human sociocultural environment. Furthermore, they have acquired some human-like social behaviors and mechanisms that they actually do not develop in the wild. However, Taylor Parker and McKinney (1999) pointed out that imitation actually occurs even in wild chimpanzees and is not only a result of "enculturation" by humans. Nevertheless, the presence of a human cultural environment makes it possible for the apes to go beyond their current level of ape performance and become more "human-like" through social interactions and scaffolding. For example, some enculturated apes are able to perform pointing gestures for requesting objects (Miles, 1990) or to indicate specific directions they want to travel to (Savage-Rumbaugh, Shanker, & Taylor, 1998). But there is no scientific evidence that chimpanzees really point in the wild (cf. Povinelli *et al.,* 2000). Instead, their pointing seems to be the outcome of close social interactions with human beings, since they probably have observed how people use the pointing gesture in interactions with each other and also toward the ape. On the other hand, the unanswered question is if "enculturated apes" really understand that they actually are pointing in the same way as humans do, or if they "only" have altered their arm extension behavior (cf. Povinelli *et al*., 2000).

According to Tomasello (2000), there are unfortunately (at the moment) no surveys of what is known about the cognitive skills of individual "enculturated apes," which have learned to use a variety of "psychological tools." However, Miles (1999) has put together a survey regarding speech and language studies in great apes that show some anecdotal evidence of more advanced social learning strategies in enculturated apes. Miles (1994), for example, described that the enculturated orang-utan *Chantek,* who has learned to use the American Sign Language (ASL), encouraged one of his caregivers to make certain signs. Moreover, another encultured ape, the gorilla *Koko,* who also is able to use ASL, shaped her doll's hand in an attempt to form a sign (cf. Patterson & Cohn, 1994). The same kind of hand-molding behavior is reported by Fouts, Fouts, & von Cantfort (1989) in their home-reared chimpanzee *Washoe*, who molded the hand of her adopted son *Loulis* in the form of a sign. Despite the numerous anecdotes about the complex social behavior of these apes there are few or even no scientific investigations carried out on these individual apes (Tomasello, 1999). However, some scientific work has been conducted on the bonobo or pygmy chimpanzee *Kanzi*, which is one of the most famous enculturated apes today. Kanzi has learned to communicate via symbols representing words and is able to use about 240 signs (Savage-Rumbaugh et al., 1998). Initially, the major goal was to teach Kanzi's mother how to use the symbols (in the form of lexigrams) to communicate her desires and needs. At the time Kanzi was so young that he did not want to be separated from his mother during her training sessions so he was present too. After a while Kanzi showed that he had acquired communication ability, without explicitly having been trained and actually performed much better than his mother. Kanzi's language comprehension has been argued to be as good as that of a two-and-a-half-year-old human child and he is also able to interpret spoken sentences, even when hearing them for the very first time (Savage-Rumbaugh et al., 1998).

Tomasello (2000) argued that being situated in human culture can be the factor that makes the difference, but for the moment it is not known exactly what the underlying mechanisms really are. It has been suggested that the intimate interactions with humans might lead to an understanding of intentionality, which free-living primates (perhaps) lack. However, Tanner and Byrne (1999) pointed out that spontaneous gestural communication is present in a group of zoo-living gorillas in San Francisco. These gorillas have developed "species-typical" gestures that are shared by all the members in the group whereas other gestures seem to be individually unique. The individual gorillas' use of the gestures varies in time and in different social environments. An amazing discovery made by Tanner, who earlier had been working with signing gorillas, was that the gestural communication in these zoo gorillas resembled untaught or even taught signing gestures in human-instructed signing gorillas. These studies might suggest that there is some sort of innate potential for using communicative gestures in great apes. Finally, Whiten (2000) pointed out that we know very little of these processes in either humans or non-human primates. One way of finding out how these transformations occur might be robotic modeling (cf. Dautenhahn & Nehaniv, 2002), examples of which we will present in the following section.

4 Socially Situated AI

The following subsections address how Vygotsky's view of intelligence relates to traditional AI and early work on "child machines" (Section 4.1), as well as contemporary work on robots developing in social interaction with robotic caretakers (Section 4.2) and human caretakers (Section 4.3), respectively.

4.1 Historical Perspective

Vygotsky's theory is in stark contrast to the way intelligence has been viewed traditionally in AI research, which from its beginning in the mid-1950s until the mid-1980s paid little attention to biological factors, learning/development, or social factors. This is not to say that these aspects were ignored completely. On the contrary, AI pioneer Alan Turing, for example, dedicated a section of his seminal 1950 paper "Computing machinery and intelligence" to the issue of "learning machines." He realized the difficulties of attempting to engineer/program an adult-like artificial mind and envisioned as a possible alternative so-called "child machines," equipped with "the best sense organs that money can buy," whose education "could follow the normal teaching of a child":

> Instead of trying to produce a program to simulate the adult mind why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain. Presumably the child-brain is something like a notebook as one buys from the stationers. Rather little mechanism, and lots of blank sheets. … Our hope is that there is so little mechanism in the child-brain that something like it can easily be programmed. The amount of work in the education we can assume, as a first approximation, to be much the same as for the human child. (Turing, 1950)

Turing himself carried out some experiments with simple "child machines," but after his death in 1954, despite some successes in early neural network research, most AI researchers focused on other approaches. However, since the mid-1980s, at least partly due to the re-emergence of connectionism and neural network research, interest in learning and development has grown tremendously. Furthermore, since approximately the mid-1990s a number of researchers in situated AI and robotics have begun to take seriously the idea that the creation of artificially intelligent systems might require not only *physical* situatedness and embodiment, but also some form of child-like development in interaction with some *social* environment. Hence, nowadays several AI researchers (cf. Brooks et al., 1998; Kozima & Yano, 2001; Zlatev, 2001) present arguments combining Vygotskyan theories with Turing's child-machine idea: If a humanoid (i.e., physically human-like) robot "grew up" in close social contact with human caregivers then it might develop similar cognitive abilities to human beings, that is, in some sense become an "enculturated" robot.

Turing (1950) himself seems to have considered neither human-like embodiment nor the full range of human social interactions as particularly crucial for the child machine's mental development. With reference to the famous case of Helen Keller (cf., e.g., Leiber, 1996), Turing argued that "we need not be too concerned about the legs, eyes, and so on," as long as "communication in both directions between teacher and pupil can take place by some means or other." Furthermore, he envisioned the machine as being tutored by humans, but also argued that "one could not send the creature to school without the other children making excessive fun of it." Today's theorists, on the other hand, tend to emphasize more strongly the relevance and richness of human/natural embodiment and social interactions. Zlatev's (2001) elaborate proposal for the development of a human-like robot mind, for example, is based on the following cornerstones:

- Sociocultural situatedness: the ability to engage in acts of communication and participate in social practices and "language games" within a community;
- Naturalistic embodiment: the possession of bodily structures giving adequate causal support for the above, e.g. organs of perception and motor activity, systems of motivation, memory and learning; …
- Epigenetic development: the development of physical, social, linguistic skills along a progression of levels so that level $n + 1$ competence results from level n competence coupled with the physical and social environment. (Zlatev, 2001, p. 161)

Zlatev and Balkenius (2001), in their introduction to the proceedings of the First International Workshop on Epigenetic Robotics, referred to the above three points as "crucial properties" for true intelligence, natural or artificial, and in their conclusions they asked: "What concepts of *embodiment*, *situatedness* and *development* are most adequate for Epigenetic Robotics and for Cognitive Science in general?" We believe that paying more attention to Vygotsky's work will help the field to make further progress toward answering that question, to which we will return in the final section.

The following two subsections illustrate in some further detail the relation between different elements of Vygotsky's theory and examples of contemporary work in *socially situated AI*. We here roughly distinguish between (a) projects investigating robot–robot interaction, for example, robots (or simulated agents) learning through imitation of other, more experienced or skilled agents, and (b) projects that investigate scenarios in which the social environment consists of humans, for example, robots socially situated through interaction with human "caregivers."

4.2 Robot–Robot Interaction

Dautenhahn and Billard (1999) contrasted Piaget's view of "the child as a solitary thinker" with Vygotsky's view of "the child in society" and argued that the latter provides a particularly promising framework for social robotics research. Drawing direct inspiration from Vygotsky's theories, they carried out a number of experiments in which a robot learned a proto-language through social interactions with a teacher that could be either another robot (e.g., Billard & Dautenhahn, 1999) or a human being (e.g., Billard et al., 1998). Hence, these experiments "followed Vygotsky's approach … by providing the robot with a primary ability to socially interact with a teacher, by imitating the teacher's movements" (Dautenhahn & Billard, 1999).

In the experimental setup illustrated in Figure 2, for example, a learner ("child") robot follows a teacher ("mother") robot, implicitly imitating its movements. Both were equipped with radio transceivers and emitters, inclination and light sensors. A simple vocabulary was transmitted from the teacher, who labeled current perceptions in certain standard situations and transmitted these labels as "words." The learner could associate these communicated "words" to similar perceptions that it made on its own. In a second stage, teacher and learner were separated, and the latter had to use its acquired knowledge of the teacher's vocabu-

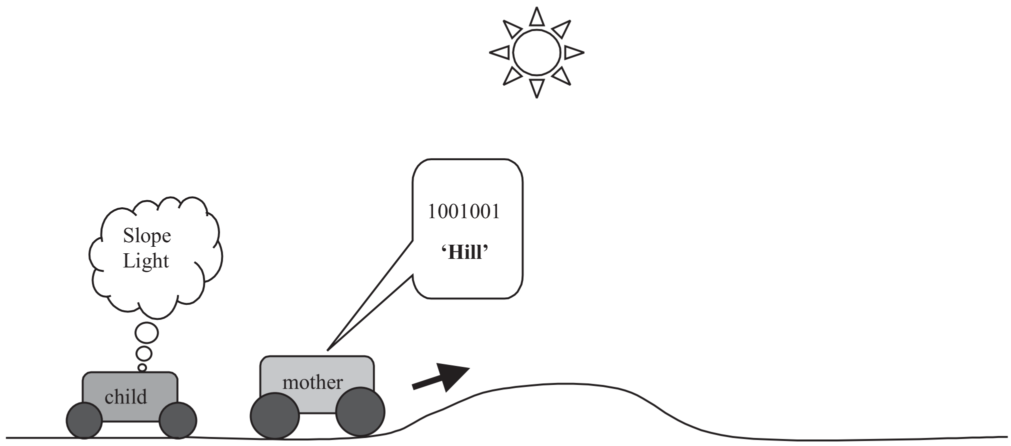

Figure 2 The experimental setup. The teacher/mother robot goes over the hill first, transferring signals that the following learner/child robot receives. Adapted from Billard and Dautenhahn (1997).

lary to discover her location by following a "verbal" description. Later experiments in simulation (Billard & Dautenhahn, 1999) showed that the learner–teacher scenario successfully scaled up to the transmission of a vocabulary among a group of nine robotic agents.

4.3 Human–Robot Interaction

One of the insights (re-) gained by recent research in embodied cognition (e.g., Lakoff & Johnson, 1980, 1999; Varela, Thompson, & Rosch, 1991; Clark, 1997; Pfeifer & Scheier, 1999) is that the mind is not, in fact, largely independent of the body, but rather strongly determined by it. For AI research striving to model human intelligence this has radical consequences. Clearly, if cognition is dependent on body and sensorimotor capacities, then the only way to achieve or model truly human-level or human-like intelligence in artifacts is to equip them with human-like bodies and sensorimotor capacities, that is, to build *humanoid robot*s.

There are by now a number of projects that have taken this approach, such as Brooks' well-known Cog project (Brooks et al., 1998) or Kozima's Infanoid project (e.g., Kozima & Yano, 2001). Both Cog and the Infanoid are upper-torso humanoids, that is, roughly human-size robotic torsos equipped with stereo-vision heads, arms and hands with degrees of freedom roughly similar to those of human bodies. However, this obviously only solves part of the problem. Even if a human-like body nowadays is considered by many a *necessary* condition for a human-like mind, it could hardly be a *sufficient* one. The remaining question is, roughly speaking, how to get a mind "into" the body. Both of the above projects, inspired to some degree by Vygotsky's theories, aim to let their robots undergo some kind of *artificial ontogenesis* in physical and social interaction with their environment. Both also particularly emphasize the interaction with human caregivers, based on theories of social learning in infants. This means that Cog and Infanoid are supposed to acquire or develop sensorimotor and cognitive capacities, and ultimately a mind, in some kind of long-term interaction similar to the ontogenesis of human children (note, however, that it is only the software, not the hardware/body, that develops).

Taking this approach to the extreme, one might argue like Zlatev (2001, p. 155) that such "robotogenesis could possibly recapitulate [human] ontogenesis, leading to the emergence of intentionality, consciousness and meaning" in robots. He further argued that there is "no good reason to assume that intentionality is an exclusively biological property … and thus a robot with bodily structures, interaction patterns and development similar to those of human beings would constitute a system possibly capable of meaning" (ibid).

This view is closely related to Harnad's (1989, 1990) formulation of a *robotic functionalism*, partly a response to Searle's (1980) famous *Chinese room argument* (CRA). The CRA was directed against what Searle referred to as "strong AI," that is, roughly speaking, the view that computer programs could be (or have) actual minds rather than just being useful tools for the modeling of mind (the latter position he referred to as "weak AI"). In particular Searle argued that computer programs simply lacked a number of "causal powers," including perception, action, and learning, which, according to him, would be necessary for intentionality [or intrinsic meaning, in Harnad's (1990) terms]. Hence, one might argue, as Zlatev (2001) did, that a sufficiently human-like robot, equipped with some artificial equivalents of those causal powers (perception, action, and learning), could very well have or develop intentionality in the same sense as humans.

It should be noted that both the Cog and the Infanoid project are far from having fully implemented visions as ambitious as the above. The Cog project has started by implementing the following basic social behaviors: pointing to a visual target, recognizing a beginning to joint attention through face and eye finding, imitation of head nods and regulating interaction of expressive feedback (Brooks et al., 1998). Furthermore, the vision and emotive response platform Kismet can engage in various forms of basic interaction behaviors, grounded in a "drive system" *(fatigue, social*, and *stimulation*). The platform's "mood" becomes replicated as emotional and facial expressions *(anger, calm, disgust, happiness, interest, sadness*, and *surprise).* As a consequence of not being stimulated the system "expresses" *boredom*; when overstimulated it "expresses" *fear.* Otherwise Kismet "is" *interested* (Breazeal & Scassellati, 2000). Finally, in Infanoid, so far the initiation of a shared attention ability has been implemented, namely, the capability of detecting human faces and finding their eyes, then catching the gaze direction to find the object of interest (Kozima & Yano, 2001).

5 Discussion and Conclusions

As mentioned in the Introduction, this article was intended to overview and integrate different perspectives on the role of social situatedness in the development of (individual) intelligence. We started off by providing a summary of Vygotsky's cognitive development theory, which, directly or indirectly, has had a very strong impact on today's research. Many aspects of Vygotsky's work have been criticized and some positions have turned out to be wrong. However, considering its age, many elements of Vygotsky's theory are surprisingly up-to-date and in line with contemporary research. In particular the central points of his theory, the view of social scaffolding as a necessary requirement for the development of individual intelligence, and more specifically the observation that "every function in the child's development appears twice: first, on the social level, and later, on the individual level," are still cornerstones of current theories, and not least also of current work on socially situated AI.

Vygotsky himself considered socially situated development of intelligence as limited to human beings. In particular he did not believe that any other animals had what he referred to as the zone of proximal development. Recent work in primatology certainly can be considered to prove him wrong in this particular point. Kanzi could be considered a good example of Vygotsky's "general law of cultural development." For instance, his "cognitive" development appeared twice, first between agents (his mother and her trainers) and then on the individual level (in Kanzi himself). His training began when he was a youngster, and not a grown-up, resulting in an ontogenetic development that was a combination between biological and social factors that Vygotsky argued would be significant for the development of individual intelligence. This is quite interesting, since Vygotsky initially tried to identify the difference in the intelligence of humans and other animals, arguing that the latter could not be "taught" to be more intelligent. Thus, instead of characterizing the uniqueness of human intelligence, the "Vygotskyan" approach actually blurs the line between animal and human intelligence.

Studies of socially situated animal intelligence in general may contribute much more to cognitive science and AI than they have done so far. There are many possible candidates for (socially) intelligent animals besides primates, such as parrots and cetaceans, for example (cf. Bekoff, Allen, & Burghardt, 2002; Dautenhahn & Nehaniv, 2002). Despite much research on human infants, there is not yet any clear understanding of how the developmental process emerges, partly because it progresses so quickly in human beings, with the result that it is very difficult to observe what exactly happens. In nonhuman species, however, these processes develop more slowly and therefore are easier to study (on the other hand, they might be more difficult to interpret and observe, at least in the wild).

It should also be noted that there are some tentative risks in combining different research areas. One risk might be misinterpretations of other fields, and another lies in significantly different definitions of the same concepts. One example is the use of the concept of *imitation*. AI researchers (cf. Brooks et al., 1998; Billard and Dautenhahn, 1997, 1998) tend to interpret the term imitation in a relatively wide sense, whereas primatologists are much more restrictive, arguing that imitation is *the* most advanced social learning mechanism (e.g., Tomasello, 1999, 2000; Whiten, 2000). However, if we weigh the pros and cons of combining these research fields, we are still convinced that the benefits are much greater than the disadvantages.

Given that apes apparently can be enculturated through social interactions with humans, at least to some degree, one might ask to what degree this might also apply to robots. Obviously, the experimental work on Cog and Infanoid is still in its beginning stages, that is, they simply have not yet gone through any prolonged epigenetic development. Nevertheless, one might already want to address the question of exactly what could be expected to be the outcome of such a process. Will social situatedness and interaction with human caregivers lead to internalization in Vygotsky's sense? Consequently, will it lead to the "emergence of intentionality, consciousness and meaning" in humanoid robots, as Zlatev (2001) envisioned? We have argued in detail elsewhere (Sharkey & Ziemke, 2001; Ziemke, 2001, 2002) that this would not be the case. It should be noted that this would not imply any "failure" of humanoid robotics. It might very well turn out to be extremely useful from a weak-AI or cognitive modeling perspective, or from an engineering or human–machine interaction perspective, but we doubt that it could lead to the development of phenomenal robot minds or intrinsic meaning in Searle's "strong" sense.

This means, we believe, that even if robots like Cog or Infanoid or their successors did develop human-like behavior, it would still only be human observers interpreting this behavior as meaningful. One of the reasons is that the behaviors currently exhibited by Cog and Infanoid, and the mechanisms underlying them, have not emerged ontogenetically as in humans or other primates, but rather they have been "built in" to the robots. For example, the implemented ability to point to a visual target in Cog, is just a built-in behavior, derived from a computational mapping between hand and eye coordination, and is not actually a result of shared attention as in human beings. Instead, the robot actually simply points toward the object at the center of its visual field, without actually sharing attention toward a target of mutual interest with a human collaborator. Similarly, Infanoid can seemingly accomplish joint attention to some extent with a person, focusing on an object of shared interest, but actually the creators have been forced to build in some tricks to implement this behavior. In this case, there is a "color preference" for red so that the robot can distinguish and locate the object of shared interest, a red or pink toy (Kozima, personal communication). No doubt, it is certainly not impossible to implement such behaviors without any "tricks," but would that make the behavior intrinsically meaningful to the robot itself?

To assess the remaining differences between humans and today's robots it might be useful to return to the three crucial properties of true intelligence (sociocultural situatedness, naturalistic embodiment, epigenetic development) that Zlatev (2001) and Zlatev and Balkenius (2001) addressed (cf. above). When it comes to sociocultural situatedness, research in social/epigenetic robotics has certainly come a long way in taking into account the Vygotskyan assumption that "sociality lies at the heart of cognitive development," as Dautenhahn and Billard (1999) formulated it. In particular work in humanoid robotics, despite obvious remaining technical difficulties, has come to a stage where it seems possible to envision human-like robots developing in relatively "natural" social interaction with humans, that is, a much richer type of interaction than what Turing envisioned for his child machines. When it comes to epigenetic development, on the other hand, robotics research has not yet fully realized its own visions and ambitions. Much initial effort in humanoid robotics projects has been invested into equipping robots like Cog and Infanoid with the basic behavioral capacities, such as joint attention, that could bootstrap social interaction with human caretakers. As a consequence, there are very few examples, if any, of robots that have actually gone through several stages of epigenetic development, although there seems to be no reason to believe that this would be impossible in principle.

When it comes to naturalistic embodiment, finally, it seems obvious to us that the bodies of today's robot's are "naturalistic" only in the eyes of human observers. We have elsewhere argued in detail (e.g., Sharkey & Ziemke, 2001; Ziemke, 2001; Ziemke &

Sharkey, 2001) that a crucial difference between living bodies and their robotic counterparts might be the autopoietic, that is, self-creating and self-maintaining, organization of living systems (Maturana & Varela, 1980), and Zlatev (in press) agrees. We believe that many robotics researchers are to some degree repeating the "mistake" of Turing who believed that "there is so little mechanism in the child-brain that something like it can easily be programmed." Consequently, he conceived of his child machines as going through two separate stages: an initial design of the machine's relatively simple hardware and adaptive software followed by a possibly complex, prolonged course of education. In terms of Vygotsky's theory, this separation might be justified with reference to the distinction between biological factors, which determine the first months of life, and sociohistorical factors, which dominate later stages of development. However, Vygotsky also pointed out the inseparability of these two processes: "*Cultural development is superimposed on the process of growth, maturation, and the organic development of the child: It forms a single whole with these processes. It is only through abstraction that we can separate one set of processes from another*" (cf. Section 2.1). Although we are aware of robotic work taking into account computational abstractions of bodily maturation (e.g., Lungarella & Berthouze, 2002), we would like to argue that developing robots such as Cog and Infanoid might very well be exposed to the right sociohistorical factors, but they simply lack the necessary biological factors, which in our opinion cannot be reduced to computational mechanisms.

It might be worth pointing out that we are well aware that this line of argument is not unproblematic. First, admittedly, we do not know exactly what these biological factors are (although we believe, as suggested above, that autopoiesis is one strong candidate). Second, we have argued ourselves in this article that Vygotsky severely underestimated animals when considering them as essentially different from humans and characterizing them (indirectly) as "leather sack[s] filled with reflexes" (cf. Section 2.1). Similarly, one might argue that we are making the same type of mistake thinking of robots as "dead metal shells filled with computer programs." Against that, however, it can be pointed out that Vygotsky misjudged animals because in his time relatively little was known about the richness of their social interactions and, perhaps even more importantly, the similarities of the biological mechanisms underlying human behavior and that of other animals. Our argument, on the other hand, is that it is exactly the biological mechanisms underlying cognition in living systems that make a crucial difference between animal cognizers and robots. In sum, somewhat simplified, we believe that social situatedness and interaction with (human) caregivers will not suffice to facilitate the development of true intelligence and intentionality in robots, as long as they are built from "dead" material and computer programs (cf. Sharkey & Ziemke, 2001; Ziemke, 2001). In a similar vein Trevarthen (2002) wrote:

> I am sure robots will never live as we do. I believe that the idea of simulating psychology with computational machines is thinkable for our culture only because of a tautology. We have created a mechanistic psychology that forgets, or misrepresents, the natural intentionality and emotionality that makes cognition useful. (p. 142)

However, putting aside the question of whether current approaches to humanoid robotics will lead to phenomenal robot minds in the sense of strong AI, we would like to point out that the issue more relevant in practice might be the other side of the social-situatedness coin anyway. Regardless of whether a humanoid robot could be socially situated in the human world and truly intelligent in a strong sense itself, it is simply a fact that this type of technology allows humans to be or become more socially situated in the world of artifacts. This means the real strength of social/humanoid robotics, or developing artifacts in general, in our opinion, is not its role as a strong robotic AI, but rather its potential to facilitate more "natural" human–machine interaction, allowing humans to interact with artifacts in the way they are used to interacting with each other.

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