Framing technology and learning towards Education 4.0: Selected readings

Part 1: Framing technology

Selection from:

Kaptelinin, V., & Nardi, B. A. (2012). Activity theory in HCI: Fundamentals and reflections. Williston, Vermont: Morgan and Claypool. Pages 14-17.

LEV VYGOTSKY AND THE SOCIAL NATURE OF HUMAN MIND

The most fundamental issue for Vygotsky was the relationship between the mind, on the one hand, and culture and society, on the other. He maintained that culture and society are not merely external factors influencing the mind but rather generative forces directly involved in the very production of mind. It was critically important, according to Vygotsky, that this fundamental idea be assimilated by psychology.

The clear implication of this postulate is that our relation to technology (which is part of culture) is a deep one; the use of technology materially shapes who we are and become. Technologies do not exist simply as neutral "helpers" "out there" that we pick and choose from according to the demands of some task. We grow and change in intimate relation to and with technology, developing as skilled persons according to how we learn and use technology. Our very personality and identity spring from connectedness to technology; for example, we become proficient software developers, competitive video gamers, famous bloggers. From this connection to technology, communities of practice and social networks are defined as we encounter others through the development of technologically based skills.

[2] Leontiev himself usually referred to his framework as "activity approach" ("dejatelnostnyj podhod"), or "activity approach in psychology," rather than "activity theory" (cf. Mescherjakov and Zinchenko, 2003).

At the same time, Vygotsky rejected a straightforward view of culture and society as directly determining or shaping the human mind. Vygotsky argued that the only way to reveal the impact of culture on the mind was to follow developmental, historical transformations of mental phenomena in the social and cultural context. This directive is enormously challenging to execute in practice but remains an important ideal as it is seemingly the only way to confront the actual complexity of mind.

A concept proposed by Vygotsky for analysis of the social determination of mind was the notion of *higher psychological functions.* Higher psychological functions can be contrasted to "natural" psychological functions, i.e., mental abilities such as memory or perception with which every animal is born. These functions can develop as a result of maturation, practice, or imitation, but their structure does not change and these functions are basically the same in similar species. Human beings have natural psychological functions, too, which are similar to those of other primates. However, human beings also develop higher psychological functions. Higher psychological functions emerge as a result of a re-structuring of natural psychological functions in a cultural environment. This re-structuring can be described as an emerging mediation of natural psychological functions.

Human beings seldom interact with the world directly. An enormous number of artifacts has been developed by humankind to mediate our relationship with the world. Using these artifacts is the hallmark of living the life of a human being. Tools or instruments—physical artifacts mediating external activities—are easy to recognize and their impact on the everyday life of every individual is obvious.

By way of analogy to conventional technical tools (like hammers), Vygotsky introduced the notion of psychological tools, such as an algebraic notation, a map, or a blueprint. Technical tools are intended to help people affect things, while psychological tools are signs intended to help people affect others or themselves (Vygotsky, 1982). Of course, "psychological tools" and tools in a more traditional sense are very different. Vygotsky warned against pushing the analogy too far (Vygotsky, 1982, 1983)[3]. However, one thing is common to instruments and signs, which is their role in human activity. Both hammers and maps are mediators. The use of mediators, whether crushing a nutshell or becoming oriented in an unfamiliar city, changes the structure of human behavior and mental processes. Psychological tools transform natural mental processes into instrumental acts (Figure 2.1), that is, mental processes mediated by culturally developed means. Vygotsky referred to mediated mental processes as higher mental functions, to separate them from unmediated natural mental functions that can be observed in other animals as well.

Initially Vygotsky (1982) did not make a distinction between psychological tools as physical artifacts (e.g., pieces of art, maps, diagrams, blueprints) and as symbolic systems (e.g., languages,

[3]This warning, in our view, should be extended to the widespread use of the distinction between technical and psychological tools, assigned to Vygotsky, in current research. This useful conceptual distinction is difficult to practically apply to concrete, real-life cases. The same object can be a technical or a psychological tool depending on the way it is used. For instance, a knife is a technical tool when it is used to slice a sausage but it is a psychological tool when it is used by a robber to frighten his victim into submission. Therefore, the border between technical and psychological tools is not clear-cut. They should rather be considered two different aspects of the same artifact, often intertwined in a complex way. For instance, a pen is a technical tool in the sense that it is used to change a thing (e.g., to write a note on a piece of paper) but at the same time it is a psychological tool, since it is used to write a message intended to affect people.

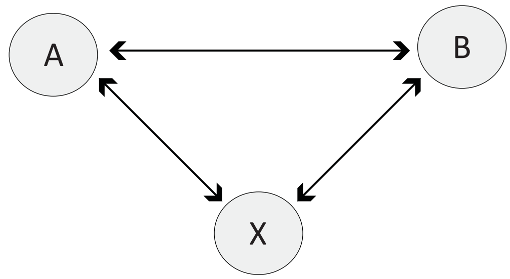

Figure 2.1: The structure of an instrumental act, based on Vygotsky (1982). "A-B" represents a simple association between two stimuli, underlying a natural mnemonic act. When memory transforms into a high-level psychological function, this association is replaced with an instrumental act comprising "A-X" and "X-B."

numeric systems, algebraic notations) that in some cases can exist only "in the head." It did not take long, however, for him to realize the importance of whether or not psychological tools are physical, external artifacts. Empirical studies of higher psychological functions showed that in many cases, subjects who used external mediational artifacts to solve a task spontaneously stopped using these artifacts and improved their performance. Vygotsky (1983) explained this phenomenon in terms of internalization (which he also referred to as "growing inside," *vraschivanie*, especially in his earlier works), that is, the "transition of an external operation into an internal one"(Vygotsky, 1983, our translation).

In the process of internalization, some of the previously external processes can take place in the internal plane, "in the head." The processes remain to be mediated, but mediated by internal signs rather than external ones. It should be emphasized that internalization is not a translation of initially external processes into a pre-existing internal plane; the internal plane itself is created through internalization (Leontiev, 1978). Internalization of mediated external processes results in mediated internal processes. Externally mediated functions become internally mediated.

Internalization is not just an elimination of external processes but rather a re-distribution of internal and external components within a function as a whole. Such a re-distribution may result in a substantial transformation of both external and internal components, such as an increased reliance on internal components at the expense of external ones, but both internal and external components are always present. The raison d'etre for internal activities is their actual or potential impact on how the individual is interacting with the world. The impact can only be made through external activities. For instance, after conducting calculations "in the head" a child may decide to buy fewer candies than she originally planned because she realizes that their total cost would exceed the amount of cash she has[4].

[4]Internalization was the object of study in an empirical investigation conducted by Leontiev under Vygotsky's supervision (Leontiev, 1981). The study employed a method called "double stimulation," created by Vygotsky specifically for studies of the development

Over the course of internalization, external processes can transform into internal ones. There is no firm boundary between the internal, the inner world of subjective phenomena, and the external, objective world. Internalization is one of the main modes of cultural determination of the mind. Internalization enables external mediation by culturally developed tools to effect internal, mental processes, which become culturally mediated, as well.

Selection from:

Gibson, J. J. (1986). The theory of affordances. In R. Shaw & J. Bransford (Eds.), Perceiving, acting and knowing. Hillsdale, NJ: Lawrence Erlbaum Associates.

Chapter 8
THE THEORY OF AFFORDANCES

I have described the environment as the surfaces that separate substances from the medium in which the animals live. But I have also described what the environment *affords* animals, mentioning the terrain, shelters, water, fire, objects, tools, other animals, and human displays. How do we go from surfaces to affordances? And if there is information in light for the perception of surfaces, is there information for the perception of what they afford? Perhaps the composition and layout of surfaces constitute what they afford. If so, to perceive them is to perceive what they afford. This is a radical hypothesis, for it implies that the "values" and "meanings" of things in the environment can be directly perceived. Moreover, it would explain the sense in which values and meanings are external to the perceiver.

The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill. The verb to *afford* is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment. The antecedents of the term and the history of the concept will be treated later; for the present, let us consider examples of an affordance.

If a terrestrial surface is nearly horizontal (instead of slanted), nearly flat (instead of convex or concave), and sufficiently extended (relative to the size of the animal) and if its substance is rigid (relative to the weight of the animal), then the surface *affords support*. It is a surface of support, and we call it a substratum, ground, or floor. It is stand-on-able, permitting an upright posture for quadrupeds and bipeds. It is therefore walk-on-able and run-over-able. It is not sink-into-able like a surface of water or a swamp, that is, not for heavy terrestrial animals. Support for water bugs is different.

Note that the four properties listed—horizontal, flat, extended, and rigid—would be *physical* properties of a surface if they were measured with the scales and standard units used in physics. As an affordance of support for a species of animal, however, they have to be measured *relative to the animal*. They are unique for that animal. They are not just abstract physical properties. They have unity relative to the posture and behavior of the animal being considered. So an affordance cannot be measured as we measure in physics.

Terrestrial surfaces, of course, are also climb-on-able or fall-off-able or get-underneath-able or bump-into-able relative to the animal. Different layouts afford different behaviors for different animals, and different mechanical encounters. The human species in some cultures has the habit of sitting as distinguished from kneeling or squatting. If a surface of support with the four properties is also knee-high above the ground, it affords sitting on.

We call it a *seat* in general, or a stool, bench, chair, and so on, in particular. It may be natural like a ledge or artificial like a couch. It may have various shapes, as long as its functional layout is that of a seat. The color and texture of the surface are irrelevant. Knee-high for a child is not the same as knee-high for an adult, so the affordance is relative to the size of the individual. But if a surface is horizontal, flat, extended, rigid, and knee-high relative to a perceiver, it can in fact be sat upon. If it can be discriminated as having just these properties, it should *look* sit-on-able. If it does, the affordance is perceived visually. If the surface properties are seen relative to the body surfaces, the self, they constitute a seat and have meaning.

There could be other examples. The different substances of the environment have different affordances for nutrition and for manufacture. The different objects of the environment have different affordances for manipulation. The other animals afford, above all, a rich and complex set of interactions, sexual, predatory, nurturing, fighting, playing, cooperating, and communicating. What other persons afford, comprises the whole realm of social significance for human beings. We pay the closest attention to the optical and acoustic information that specifies what the other person is, invites, threatens, and does.

THE NICHES OF THE ENVIRONMENT

Ecologists have the concept of a *niche*. A species of animal is said to utilize or occupy a certain niche in the environment. This is not quite the same as the *habitat* of the species; a niche refers more to *how* an animal lives than to where it lives. I suggest that a niche is a set of affordances.

The natural environment offers many ways of life, and different animals have different ways of life. The niche implies a kind of animal, and the animal implies a kind of niche. Note the complementarity of the two. But note also that the environment as a whole with its unlimited possibilities existed prior to animals. The physical, chemical, meteorological, and geological conditions of the surface of the earth and the pre-existence of plant life are what make animal life possible. They had to be invariant for animals to evolve.

There are all kinds of nutrients in the world and all sorts of ways of getting food; all sorts of shelters or hiding places, such as holes, crevices, and caves; all sorts of materials for *making* shelters, nests, mounds, huts; all kinds of locomotion that the environment makes possible, such as swimming, crawling, walking, climbing, flying. These offerings have been taken advantage of; the niches have been occupied. But, for all we know, there may be many offerings of the environment that have *not* been taken advantage of, that is, niches not yet occupied.

In architecture a niche is a place that is suitable for a piece of statuary, a place into which the object fits. In ecology a niche is a setting of environmental features that are suitable for an animal, into which it fits metaphorically.

An important fact about the affordances of the environment is that they are in a sense objective, real, and physical, unlike values and meanings, which are often supposed to be subjective, phenomenal, and mental. But, actually, an affordance is neither an objective property nor a subjective property; or it is both if you like. An affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behavior. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer.

The niche for a certain species should not be confused with what some animal psychologists have called the *phenomenal environment* of the species. This can be taken erroneously to be the “private world” in which the species is supposed to live, the “subjective world,” or the world of “consciousness.” The behavior of observers depends on their perception of the environment, surely enough, but this does not mean that their behavior depends on a so-called private or subjective or conscious environment. The organism depends on its environment for its life, but the environment does not depend on the organism for its existence.

MAN’S ALTERATION OF THE NATURAL ENVIRONMENT

In the last few thousand years, as everybody now realizes, the very face of the earth has been modified by man. The layout of surfaces has been changed, by cutting, clearing, leveling, paving, and building. Natural deserts and mountains, swamps and rivers, forests and plains still exist, but they are being encroached upon and reshaped by man-made layouts. Moreover, the *substances* of the environment have been partly converted from the natural materials of the earth into various kinds of artificial materials such as bronze iron concrete and bread. Even the *medium* of the environment—the air for us and the water for fish—is becoming slowly altered despite the restorative cycles that yielded a steady state for millions of years prior to man.

Why has man changed the shapes and substances of his environment? To change what it affords him. He has made more available what benefits him and less pressing what injures him. In making life easier for himself, of course, he has made life harder for most of the other animals. Over the millennia, he has made it easier for himself to get food, easier to keep warm, easier to see at night, easier to get about, and easier to train his offspring.

This is not a new environment—an artificial environment distinct from the natural environment—but the same old environment modified by man. It is a mistake to separate the natural from the artificial as if there were two environments; artifacts have to be manufactured from natural substances. It is also a mistake to separate the cultural environment from the natural environment, as if there were a world of mental products distinct from the world of material products. There is only one world, however diverse, and all animals live in it, although we human animals have altered it to suit ourselves. We have done so wastefully, thoughtlessly, and, if we do not mend our ways, fatally.

The fundamentals of the environment—the substances, the medium, and the surfaces—are the same for all animals. No matter how powerful men become they are not going to alter the fact of earth, air, and water—the lithosphere, the atmosphere, and the hydrosphere, together with the interfaces that separate them. For terrestrial animals like us, the earth and the sky are a basic structure on which all lesser structures depend. We cannot change it. We all fit into the substructures of the environment in our various ways, for we were all, in fact, formed by them. We were created by the world we live in.

Selections from:

Shaffer, D. W., & Clinton, K. A. (2006). Toolforthoughts: Reexamining thinking in the digital age. Mind, Culture, and Activity, 13(4), 283-300. doi:10.1207/s15327884mca1304_2

FROM TOOLS AND THOUGHTS TO TOOLFORTHOUGHTS

A Virtual Cognitive Ontology

Instead, we suggest that just as tools are externalizations of human designs, thoughts are internalizations of our actions with tools. All thoughts are connected to tools, and all tools are connected to thoughts: Every time we consider a thought (because it is an internalization of action with a tool) it is inextricably linked to a tool, and every time we consider a tool (because it is an externalization of a thought) it is inextricably connected with a thought. In this view, tools are not distinct from thoughts; rather, the reciprocal relation between tool and thought exists in both. Every tool contains thoughts, and every thought contains tools. Neither exists without the other. We thus suggest that rather than seeing tools as static thoughts—objects distinct from human participants—we grant tools and thoughts the same ontological status. That is, we follow Dewey and posit explicitly that tools and thoughts are fundamentally the same kind of thing (Hickman, 1991). Vygotsky (1978) drew a distinction between sign and tool, arguing that both are mediators of activity, but because signs orient internally and tools orient externally, "the nature of the means they use cannot be the same" (p. 55). Positing symmetry between persons and artifacts means arguing that all activity is simultaneously internal and external, and that the processes involved are therefore not ontologically distinct—different in specific properties, perhaps, but not in their fundamental nature.[4]

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[4]Using the terms *tool* and *artifact* suggests that tools are made by humans and thus conceptually distinct from elements of nature. Although it is beyond the scope of the discussion here, we argue that natural objects are similarly actants. Consider, for example, gazing at the moon. It may be true that one can gaze at the moon and have a thought without using a physical artifact—although even then one is gazing at the moon in a particular place, wearing particular clothes, and in a particular context that is heavily determined by material artifacts. But because language itself is a tool, marking particular sensations of light as the moon is using a tool. Even the moon itself—meaning the light we see in the sky and not the word—is a cultural construct: It is an artifact (a "made thing"), and therefore a tool.

Toolforthoughts Defined

In this ontology, then, there are no tools without thinking, and there is no thinking without tools. There are only toolforthoughts, which represent the reciprocal relation between tools and thoughts—between persons and objects, whether natural or constructed—that exists in both.[5] When we say that something is a tool for thought (as separate words), this might suggest that thought is the broader category and that tools are something that help people think. Or it might imply that tool is the broader framework and persons are agents who use both thoughts and physical artifacts as tools. To avoid these difficulties, we connect the nouns *tool* and *thought* to suggest that toolforthoughts are the outcome of a process of tools' existing in a reciprocal relation with thoughts. In so doing, we acknowledge the awkwardness of the term. However, we believe that the linguistic unease that it creates is useful. We are long accustomed to seeing tools and thoughts as distinct. The term *toolforthought* marks both the difficult ontological shift and the resulting ontological dissonance that may characterize the advent of virtual culture.

Donald (1997) described the process through which technology and human cognition have coevolved as a "tight iterative loop" (p. 737). At times, we focus on how tools are shaped by thoughts. For example, Petroski (1992) argued that new tools are invented in response to the failures of old tools. At other times, we focus on how thoughts are shaped by tools. For example, Postman (1993) warned that "new technologies change what we mean by 'knowing' and 'truth'" and thus change our sense of "what is reasonable, of what is necessary, of what is inevitable, of what is real" (p. 12). Toolforthoughts bring together these two perspectives. A toolforthought can be analyzed as a tool or a thought, but a toolforthought is always more than the sum of "what a tool is" added to "what a thought is." It is the reflexive coconstruction of both concepts.

Whether they are internalizations of social interaction (Vygotsky, 1978) or externalizations of cognitive processes (Shaffer & Kaput, 1999), toolforthoughts are templates for action: Reifications of patterns of social action that arise from an ongoing historical dialectic between tools and thoughts. We refer to these reifications as templates because they have a particularity to their form. This particularity does not ensure that toolforthoughts enact the social organizations that their inventors intend—a toolforthought is a social pattern, and no one would expect that intent is equivalent to outcome in a social setting. The particularity of a toolforthought does imply, however, that when a toolforthought participates in action, the action is inflected by the pattern of the template: Some actions, although perhaps still possible, are less likely to emerge than others; other actions, although perhaps not inevitable, are more likely to emerge. Any toolforthought collaborates in some ways better than others, which is to say that any toolforthought has a set of constraints and affordances (Gibson, 1986; Norman, 1993). Any action that unfolds with a tool/forthought unfolds in some particular way, rather than in another way; thus all toolforthoughts are inherently ideological. As Postman (1993) argued, every tool implies "a predisposition to construct the world as one thing rather than another, to value one thing over another" (p. 13).

[5]For a similar reason, we reject Dewey's categorization of tools and thoughts as both being technological (Hickman, 1991). The term would be appropriate in this context, but it emphasizes the instrumental quality of both—which is Dewey's intention, of course—rather than their status as mutual actants through which action emerges.

Toolforthoughts as Objects of Study

In a theoretic culture, a tool shapes the actions of others but does not act itself. A person has thoughts, but those thoughts do not shape the actions of others unless they are instantiated using some tool. The construct of toolforthought, in contrast, preserves the unity of action and mediation. Toolforthoughts are the cognitive instantiation of Latour's mutually mediating mediators. They neither act nor are acted upon; rather, they interact to produce a model of thinking in which biological cognition has the same ontological status as that of other elements in the system, and thinking, in the words of Latour (1996c), involves "constantly shifting from one medium to the other," with work divided between "actors in the setting, either humans or nonhumans" (p. 57).

We refer to this as a theory of distributed mind and suggest that although extant theories—such as ecological theories of mind, actor-network theory, activity theory, and theories of mediational means and distributed cognition—contain elements of this stance, a theory of distributed mind is distinct in its explicit emphasis on the impact of individual toolforthoughts. A theory of distributed mind posits that the fundamental unit of analysis for cognition is not a system composed of human beings and tools but is rather the systemic effects of individual toolforthoughts and the particular forms of social interaction they foster. For each toolforthought, the task is to understand its particular constraints and affordances—and thus how it participates in particular kinds of social interactions at the expense of others.

Toolforthoughts and the Principle of Progress

If tools mediate human action, then humans are agents, and the person using a tool bears responsibility for the consequences of his or her action. From this perspective, to cite an old saw, guns do not kill people, people kill people—or as our friend and colleague Kurt Squire says, tongue-in-cheek, "A bag of potato chips in the middle of the table doesn't force you to eat." If, on the other hand, the bag of chips creates particular patterns of action and social interaction, then it is perfectly sensible to make judgments about those patterns. The concept of toolforthoughts thus provides a level of analysis for examining tools in the context of their social consequences.

One possible objection to such a perspective is that it appears to suggest a moral equivalence between persons and things. However, the fact that we attribute responsibility to both bags of chips and their consumers for the patterns of action they afford does not mean that we necessarily hold them accountable in the same way. Human beings bear the moral weight of freedom to choose that even a theory of distributed mind does not ascribe to tools.[6] But we can ask how a particular toolforthought functions in relation to others. That is, we can ask what it means for a toolforthought to be good or bad. If toolforthoughts afford particular patterns of interaction, then the question of the value of toolforthoughts is ultimately a question about the relative value of these different patterns of interaction. Norman (1993) suggested that tools do not make people more efficient: A system composed of a person and tool is more effective at doing some things and less effective at others. More generally, any set of interacting toolforthoughts will be more likely

[6]Burke's bias is not necessarily universal but rather is tied to Western views of agency and morality. Legal systems inscribe the moral view of humans as accountable for "their" actions and for the actions of "their" property (machines, but in many cases children as well, remarkably). Latour (1993) examined the consequences of moral and legal equivalence of humans and artifacts as the politics of a parliament of things.

to engage in some kinds of activity, but this will always be at the cost of being less likely to accomplish some other task. Ballpoint pens are more efficient for writing than quill pens and inkwells—unless, as is the case for many calligraphers, the process of grinding ink matters, either to control the qualities of the medium or to foster mindfulness. The question is thus not whether one toolforthought is better than another in any objective sense, but whether one set of social patterns is better than another—which depends, ultimately, on how we view the nature of human happiness and thus of progress.

If there exist ideal modes of human social interaction, then clearly some toolforthoughts are better than others. Illich (1973), for example, argued that human nature is fundamentally convivial, and thus we should engage in counterfoil research to develop tools that support communitarian interdependency rather than industrial alienation. On the other hand, if we refuse to privilege one way of life over others and instead adopt a stance of cultural relativism, then toolforthoughts are neither good nor bad: Different toolforthoughts lead to different social patterns, which have different advantages and disadvantages. Yet another possibility is to look at the local coevolution of technologies and mores. Theories of neural Darwinism suggest that brain development is an ongoing process by which we organize and reorganize the configuration of our neural pathways to deal with incoming stimuli (Clark, 2003; Donald, 1991). Our bodies literally configure themselves to accommodate particular kinds of interactions rather than others. If the pace of change of toolforthoughts rises too quickly, it is inherently disruptive to this process of local adaptation.

Our view of the value of toolforthoughts is thus shaped by whether we see the human condition as striving toward some universal ideal, as sets of social circumstances that can only be evaluated relative to a particular culture, or as a process of accommodation with and adaptation to a changing environment. We might call this a principle of progress: What we think about toolforthoughts depends fundamentally on how we view the nature of human happiness. Whichever standard we adopt, the analysis of a toolforthought depends on understanding the social patterns it creates: What opportunities for action are made available, to whom, and under what circumstances? A theory of distributed mind emphasizes that any toolforthought creates and reinforces certain social worlds at the expense of others—and that we understand toolforthoughts by examining the relative advantages and disadvantages of the worlds they help create.

DISCUSSION: LEARNING IN A VIRTUAL CULTURE

We began this article by arguing that current thinking and theorizing about tools are based on a particular assumption about agency: that humans have it and tools don't. Indeed, the notion of causality is at the center of Western philosophy: There is always someone or something that is responsible for making things happen. But ecological theories of mind—including cybernetics, actor-network theory, ecology of mind, conversation theory, and pragmatic tools—all suggest instead that thinking may emerge from complex interactions among tools and persons. In complex systems (ecosocial and otherwise), the behavior of the system is emergent: It cannot—in theory or in practice—be described as the result of the actions of any single force, within or outside the system (Lemke, 2005). We thus took from Latour as an alternative postulate[9] that neither tools nor humans have agency in the traditional sense; rather action emerges from the interaction of mutually mediating actants, which can be human or nonhuman. We posited an ontological equivalence between interactivity and intraactivity in thinking. Positing such equivalence, we argue, requires creating a new analytic category that we call toolforthoughts: a view from virtual culture of the relationship between technology and cognitive activity. For rhetorical purposes we describe this as a theory of distributed mind. However, we want to emphasize that our goal is neither to supplant existing sociocultural theories of cognition nor to re-create actor network theory. In consolidating this challenge to the notion of human beings as the locus of cognitive causality in a theory of distributed mind, we suggest that such a view of thinking may be useful in analyzing cognitive activity—and thus educational issues—in an era of computational tools. Put another way, we suggest that the development of interactive computational systems may require a reexamination of the concept of agency, and with it a reevaluation of the relationship between persons and objects (whether natural or constructed) in cognitive activity more generally.

Looking at toolforthoughts in mathematics and literacy education highlights how different toolforthoughts offer different possibilities for action. From the perspective of distributed mind, the fundamental unit of analysis for such toolforthoughts is the social patterns they afford. Thus, the question we ask is not, Will students learn traditional math and print literacy? Rather, we ask, Who will be able to work with these toolforthoughts, and what will they be able to accomplish?

[9]Our approach is similar in spirit to the development of non-Euclidean geometries in the 19th century. Euclidean geometry is based on five postulates. The fifth—"given a Line A and a Point B not on A, there exists one and only one line through B parallel to A"—was widely considered unintuitive and problematic in the mathematical community. A number of mathematicians—including Gauss, Riemann, Bolyai, and Lobachevsky—tried to test the postulate by assuming an opposite position: Either that there are no parallel lines or that there are more than one. They were hoping to find a contradiction and thus prove the validity of Euclid's original. The result, instead, was new geometries that apply to spheres (no parallel lines) and hyperbolic spaces (multiple parallel lines).

Under what conditions? And how important are those activities in the school curriculum and in the broader curriculum of students' lives?

Our current educational system is based on the assumption that thinking happens in the head of a person using tools, and that what matters, in the end, is the thinking and not the using of the tools. This view privileges abstract formalisms and the problems those formalisms were developed to solve—neither of which has been empowering historically for students from less advantaged backgrounds. If tools and persons are equivalent actants, however, then thinking and acting mean learning to coordinate and be coordinated by valued toolforthoughts. In a time of rapid and fundamental technological change it is easier to see that which toolforthoughts are valued in this sense is inherently ideological: Toolforthoughts support particular social patterns that, depending on the social forms we value, may be more or less desirable. By conceptualizing tools as participants in, rather than merely mediators of, cognition, a theory of distributed mind addresses the inevitable pedagogical panic that arises in our theoretic frame of mind when young people begin using new and powerful toolforthoughts: the panic that our children are no longer learning how to think. A theory of distributed mind suggests that what matters instead is what students will be able to accomplish in collaboration with toolforthoughts. Without such a perspective, we may inadvertently privilege particular representational forms—and in so doing, privilege the students who benefit from the institutionalization of those forms and the things that can be done with those forms. The theory of distributed mind thus dispels the naturalistic fallacy of mistaking what is for what ought to be. The technologies we have inherited do not define a fixed realm of what is cognitively possible or desirable. Learning always means doing particular kinds of things in collaboration with particular kinds of toolforthoughts. What matters are the actions we value—and the new possibilities for action that new toolforthoughts make possible.

We suggest, in other words, that Burke's argument needs to be revisited. In an era of powerful computational toolforthoughts, we need to justify the "distinction between things moving and persons acting" by more than just our discomfort at being removed from the analytical center of cognition. Or, we need to accept the disconcerting proposal that both tools and thoughts are merely reflections of the toolforthoughts that shape the cognitive and social worlds in which we live. Current anthropocentric sociocultural theories may be sufficient to understand cognitive activity relative to potato chips and the theoretic culture that produces them. But we may need to develop the concept of toolforthoughts to account for cognitive activity relative to microchips and the virtual culture they are creating.[10]

[10]In a similar vein, Newtonian mechanics is a powerful toolforthought for analyzing force and motion at industrial and preindustrial scales of time and space—the scales at which we experience most of our everyday lives. But quantum mechanics and the equations of relativity theory—both of which contradict Newton's laws—are useful, even essential, to understand the universe at the micro and macro scales that new technologies make accessible.

Selection from:

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3 Human-Automation Symbiosis: Intelligent Hybrid Agents

In this section, the strategy to attain *human-automation symbiosis* in manufacturing work systems is explored through a discourse of 'adaptive automation' and 'intelligent multi-agent systems' as the bases for a sharing and trading of control strategy [14].

An *intelligent agent* is an entity (human, artificial or hybrid) with the following characteristics [16]: (a) *purposeful* - displays goal-seeking behaviour, (b) *perceptive* - can observe information about the surrounding world and filter it according to relevance for orientation, (c) *aware* - can develop situational awareness that is relevant for the agent's purpose, (d) *autonomous* - can decide a course of action (plan) to achieve the goal, (e) *able to act* - can mobilise its resources to act on its plan; these resources may include parts of the self or tools at the autonomous disposal of the agent, and resources for physical action or information gathering/processing, (f) *reflective* - can represent and reason about the abilities and goals of self and those of other agents, (g) *adaptable* and *learning* - can recognise inadequacy of its plan and modify it, or change its goal, and (h) *conversational* and *cooperative* - can negotiate with other agents to enhance perception, develop common orientation, decide on joint goals, plans, and action; essentially participate in maintaining the 'emergent agent' created through joint actions of agents. Note that this classification of agent functions may be interpreted as the ability to perform the Observe, Orient, Decide and Act (OODA) Loop of Boyd [17] [18], developed as a theory to explain the conditions and functions of successful operation, and therefore this classification may be used to direct the engineering and development of intelligent agents [16], which, as we shall see below, are expected to be 'adaptive' and 'hybrid' in nature.

Human agents, under certain circumstances, and in defined domains of activity, are able to act as intelligent agents (e.g. able to perform complex assembly sequences and operations in a flexible production line). However, once the assumptions are no longer true (e.g. due to a heavy physical, sensorial and/or cognitive workload), the quality of *agenthood* deteriorates; thus the human does no longer have the ability to perform one or several functions that are normally attributed to an intelligent agent. Consequently, the question is: how to restitute human agenthood by extending human capabilities (physical, sensorial and/or cognitive) through automation-aided means?

Similarly, *artificial (machine) agents,* under certain circumstances and in defined domains of activity can act as intelligent agents (e.g. they are able to perform repetitive and routine tasks in a high volume production line, make decisions based on learnt patterns, etc.). Nevertheless, once the assumptions are no longer true (e.g. the need (ability) to improvise and use flexible processes to reduce production downtime due to an error), the quality of *agenthood* deteriorates; thus the machine does no longer have the ability to perform one or several functions that are normally attributed to an intelligent agent. Therefore, the question is: how to restore machine agenthood by extending the machine's capabilities through human-aided means?

Hybrid agents are intelligent agents established as a symbiotic relationship (human-automation symbiosis) between the human and the machine, so that in situations where neither would display agenthood in isolation, the symbiotic hybrid agent does. In this research, the vision is that at any time a human (the 'Operator 4.0') lacks some of these *agenthood* abilities, such as due to heavy physical, sensorial and/or cognitive workload, automation will extend the human's abilities as much as necessary to help the operator to perform the tasks at hand, according to the expected quality of performance criteria. Thus, it is proposed to implement *hybrid agents,* as a form of 'adaptive automation', in order to sustain *agenthood* by determining whenever and wherever the operator requires augmentation (e.g. using *advanced trained classifiers* to recognise this need [19]), and prompting the appropriate type and level of automation to facilitate optimal operator performance. An important objective is that the level of this extension need not be a 'design time' decision, but should be able to be dynamically configured as needed. Furthermore, the 'hybrid agents' view of the Operator 4.0 is a component of the solution to preserve the operator's *situation awareness* [20], as the status, experience and information processing capability of the operator can cause loss of agenthood and consequent decision-making errors, thus the need for 'symbiotic technical support'. Work on *affective computing* [21] showed that the task allocation and adaptation between humans and machines/computers supporting them is not a trivial task and should involve sensory assessments of humans' physical and cognitive states in order to be efficient.

For the purpose of comparison, in the case of an Operator 3.0 (*cf.* human-robot collaboration), the design time decision would be determined by the required capability of the manufacturing or assembly operation (e.g. speed, accuracy, capacity, reliability, etc.), which then would decide (based on technical, economic, social and human benefits) the level of automation of the process, as well as the accompanying skills and abilities required by the human role. In contrast, in the case of an Operator 4.0, automation level would be determined in less detail at design time, allowing an initial detailed procedure and much automated support (e.g. in case of a novice or new-to-the-task operator), while providing 'on the fly' solutions that develop together with the individual operator's skills. Apart from achieving job satisfaction and a variety of desired process 'ilities' [22], such dynamic allocation of different levels/extent of automation fosters the use of human skills and abilities. This includes the creation of favourable conditions for workforce development and learning, the improvement of human-robot collaboration and tacit knowledge development, as it is well known that in many (although not all) tasks acting based on tacit knowledge are much more efficient and effective than following predetermined procedures.

Emergent agents are virtual entities, who exist as a cooperative and negotiated arrangement between multiple agents of either kind above (sometimes on multiple levels of static or dynamic aggregation), whereupon two human agents, or a human and a machine/robot, or two machine/robot agents, or more than two agents of any of these types, form a 'join entity agent' that from the external observer's viewpoint acts as a single intelligent agent. It is expected that an Operator 4.0 will have the ability to be part of an intelligent group of agents with appropriate functionality for the formation, operation, transformation and dissolution of these groups. Note that it is not necessary for every agent to have the same level of contribution to such self-organising ability; agents may specialise in certain tasks and assume different roles in the lifecycle of the emergent agent.

4 The Operator 4.0: Aiding for Enhanced Workers Capabilities

A *capability* is the "measure of the ability of an entity (e.g. department, organisation, person, system) to achieve its objectives, especially in relation to its overall mission" [23]. In the case of human beings, this involves having the resources and the ability to deploy their capabilities for a purpose.

4.1 Automation Aiding for Enhanced Physical Capabilities

A *physical activity* is any bodily movement produced by skeletal muscles that requires energy expenditure. We define *physical capability* as the operator's capacity and ability to undertake physical activities needed for daily work, and can be characterised by multiple attributes, including the description of the physical function (e.g. ability to lift, walk, manipulate and assemble) together with its non-functional properties (e.g. speed, strength, precision and dexterity), as well as the description of the ability in terms of maturity- and expertise- level. The agent's activity supported is that of (physically) acting, i.e. the 'A' in the OODA loop.

For example, the operator may be: (a) ‘procedure following - novice’ with no autonomy over the details of the operation and under supervision along the whole procedure, (b) ‘procedure following - advanced’ with limited operational autonomy and less supervision across the procedure, or (c) ‘expert’ - featuring internalised tacit knowledge (know-how) and autonomy towards improving the operation, where only the operation’s outcome is supervised. The vision of Operator 4.0 acknowledges that capabilities are not static, but they evolve over time, as well as change depending on context (e.g. the operator may be tired or rested, new- or accustomed- to-the-task), therefore physically aiding an Operator 4.0 assumes that one can assess the physical capabilities in a dynamic and timely fashion, preferably in real-time. Some assessment tools for testing an operator’s physical capabilities may include: (a) *Physical Abilities Tests (PATs)* [24] [25] capable of matching the physical abilities of an operator with the physical demands of a job (or operation) up-front to its allocation (e.g. such methods are getting increased attention in the defence community); and (b) *Advanced Trained Classifiers (ATCs)* [26], based on a variety of machine learning techniques, to measure (test) in real-time the operator’s physical performance and dynamically identify when an assisted/enhanced operation is necessary in an unobtrusive manner, relying on physiological measures (*cf.* ergonomics [27]). This is done in order to actively determine when an operator actually requires assistance and subsequently prompt the appropriate type and level of physical (aided) capability to facilitate optimal physical performance by the operator. Moreover, PATs may be useful for job role allocation and/or for determining training needs (e.g. how to handle lifting, posture correction, etc.), while ATCs may be advantageous for reducing the chances of accidents due to tiredness or of injuries due to repetitive strain, or to improve product quality by reducing errors and re-work.

4.2 Automation Aiding for Enhanced Sensing Capabilities

A *sensorial* capability is the operator’s capacity and ability to acquire data from the environment, as a first step towards creating information necessary for orientation and decision-making in the operator’s daily work [28]. There are two components to sensing: (a) the physical ability to collect data from the environment (by vision, smell, sound, touch, vibration), and (b) the ability to selectively perceive it (as we know that a very low percentage of the data generated by the physical sense of an operator enters the short-term memory and is made available for processing). It is known that an operator is selectively filtering out what he/she does not consider important: “of the entire amount of new information generated by our environment, our senses filter out >99% of signals before they reach our consciousness” [29]. It is also known that this filtering is not a conscious process. Therefore, OODA is not a simple loop; there is information that flows to make an operator perceive selectively what his/her brain considers important (i.e. what data are useful for analysis and decision-making). This selectivity is acquired by the operator through learning. As a consequence, there are two points where the operator’s sensing abilities are subject to assessment and where these abilities may need improvement, as further described.

The first potential sensory improvement is the creation of new- or augmentation- of existing senses (e.g. by way of using sensor devices to collect, convert, aggregate signals that would not be accessible for the operator, either due to physical accessibility of the data source, general human limitations, or due to individual personal limitations). Also, due to the different levels of sensitivity of humans across senses, transforming one signal to another form may increase the ability of the human to identify information within the data (e.g. transforming temperature to visible colour, vibration to audible spectrum sound, or using data aggregation, can enable the human to make use of otherwise inaccessible data). The second type of sensory limitation is more difficult to overcome if it is to be done exclusively at sensor level. This is because information feedback produced by analysis (orientation) and decision-making must be used to filter out unwanted data (i.e. containing irrelevant information) and to sensitise selective perception to smaller signals, which may carry relevant information.

Some assessment tools for testing an operator's sensorial capabilities may include: (a) *Sensorial Abilities Tests (SATs)* [30] capable of matching the sensorial abilities of an operator with the sensorial demands of a job (or operation) up-front to its allocation. This is not a trivial tasks, because even though the sensorial abilities of an operator can be tested (such as by using simple vision and hearing tests), sensing successfully in the situation (i.e. registering/perceiving signals necessary for analysis and orientation) is also dependent on the nature and level of prior experience of the operator as previously explained.

It is therefore expected that the solution to selective perception deficits is not simply providing operators with 'bionic ears and eyes' (even though in some situations that may be sufficient), but in using the 'emergent agent' model, where the machine agent has its own intelligence in terms of analysis and orientation, and the ability to reason about the human agent's needs and decision what data to present for the human's needs and when.

The traditional limitation for decision-making has been scarcity of information, requiring human (and machine) agents to make decisions in light of insufficient data about the operations. With the proliferation of sensor devices (the so-called 'Internet of Things') this situation could change, but only if sensor agents are made intelligent in terms of what data to register and transmit to other agents.

New algorithms are needed for cooperative and collaborative learning of situations for collective sense-making and decision-making by sensor agents (including agent networks). This is so that the situational knowledge base of participating agents can be utilised to adaptively filter unwanted data and to 'zoom-in' to enhance faint but relevant signals, as well as negotiate signal bandwidth for priority communication. Part of this situation recognition may be implemented by machine learning techniques, such as (b) *Advanced Trained Classifiers (ATCs)* [26], where part of an intelligent sensor agent may use machine learning to support human-automation symbiosis and to learn about the individual operator and that operator's behaviour in action, to actively determine when an operator actually requires assistance, and to subsequently prompt the appropriate type and level of sensing (aided) capabilities to facilitate optimal sensing performance by the operator.

4.3 Automation Aiding for Enhanced Cognitive Capabilities

A *cognitive capability* is the operator's capacity and ability to undertake the mental tasks (e.g. perception, memory, reasoning, decision, motor response, etc.) needed for the job and under certain operational settings [31]. In the OODA model, these cognitive tasks are to 'Orient' and to 'Decide', together amounting to a mental workload, decision-making, skilled performance, human-computer interaction, maintaining reliability in performance, dealing with work stress whether in training or in the job.

As the Factories of the Future become increasingly dynamic working environments (*cf.* Industry 4.0) due to the upsurge in the need for flexibility and adaptability of production systems, the upgraded shop-floors (*cf.* Factory 4.0) call for *cognitive aids* that help the operator perform these mental tasks, such as those provided by augmented reality (AR) technologies or 'intelligent' Human-Machine Interfaces (HMI) to support the new/increased cognitive workload (e.g. diagnosis, situational awareness, decision-making, planning, etc.) of the *Operator 4.0.* It can be expected that this aid would increase human reliability in the job, considering both the operator's well-being and the production system's performance.

Some assessment tools for testing an operator's cognitive capabilities may include: (a) *Cognitive Abilities Tests (CATs)* [32] capable of matching the cognitive abilities of an operator with the mental demands and cognitive skills needed for performing a job (or operation) up-front to its allocation; and (b) *Advanced Trained Classifiers (ATCs)* [26] based on various machine learning techniques, to measure (test) in real-time the operator's cognitive performance and dynamically identify when an assisted/enhanced action is necessary, and do so in an unobtrusive manner, relying on cognitive load measurements (*cf.* cognitive ergonomics [33]).

Part 2: Framing learning

Selection from:

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Expansive learning – a new approach

Standard theories of learning are focused on processes where a subject (traditionally an individual, more recently possibly also an organization) acquires some identifiable knowledge or skills in such a way that a corresponding, relatively lasting change in the behavior of the subject may be observed. It is a self-evident presupposition that the knowledge or skill to be acquired is itself stable and reasonably well defined. There is a competent "teacher" who knows what is to be learned.

The problem is that much of the most intriguing kinds of learning in work organizations violates this presupposition. People and organizations are all the time learning something that is not stable, not even defined or understood ahead of time. In important transformations of our personal lives and organizational practices, we must learn new forms of activity which are not yet there. They are literally learned as they are being created. There is no competent teacher. Standard learning theories have little to offer if one wants to understand these processes.

Gregory Bateson's (1972) theory of learning is one of the few approaches helpful for tackling this challenge. Bateson distinguished between three levels of learning. Learning I refers to conditioning, acquisition of the responses deemed correct in the given context – for instance, the learning of correct answers in a classroom. Bateson points out that wherever we observe Learning I, Learning II is also going on: people acquire the deep-seated rules and patterns of behavior characteristic to the context itself. Thus, in classrooms, students learn the "hidden curriculum" of what it means to be a student: how to please the teachers, how to pass exams, how to belong to groups, etc. Sometimes the context bombards participants with contradictory demands: Learning II creates a double bind. Such pressures can lead to Learning III, where a person or a group begins to radically question the sense and meaning of the context and to construct a wider alternative context. Learning III is essentially a collective endeavor. As Bateson points out, processes of Learning III are rare and dangerous:

> Even the attempt at Level III can be dangerous, and some fall by the wayside. These are often labeled by psychiatry as psychotic, and many of them find themselves inhibited from using the first person pronoun.
>
> (Bateson, 1972, pp. 305–306)

Bateson's conceptualization of Learning III was a provocative proposal, not an elaborated theory. The theory of expansive learning develops Bateson's idea into a systematic framework. Learning III is seen as learning activity which has its own typical actions and tools (these will be discussed later in this chapter). The object of expansive learning activity is the entire activity system in which the learners are engaged. Expansive learning activity produces culturally new patterns of activity.