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ARTICLES

Toolforthoughts: Reexamining Thinking in the Digital Age

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In this article we argue that new computational tools problematize the concept of thought within current sociocultural theories of technology and cognition by challenging the traditional position of privilege that humans occupy in sociocultural analyses. We draw on work by Shaffer and Kaput (1999) and Latour (1996a, 1996b, 1996c) to extend the analytical reach of *activity theory* (Engeström, Miettinen, & Punamaki, 1999; Nardi, 1996b), *mediated action* (Wertsch, 1998) and *distributed cognition* (Hutchins, 1995; Pea, 1993; Salomon, 1993) by adopting a stronger form of the concepts of distribution and mediation in the context of cognitive activity. For rhetorical purposes, we posit this stronger form of the distribution of intelligence across persons and objects as a theory of distributed mind. Previous theories of cognition and technology show that persons and artifacts both contribute to meaningful activity. Here we explore how understanding the pedagogical implications of new media may require creating a new analytic category of *toolforthoughts*. The result of such a shift in thinking provides a view of the relationship between technology and cognitive activity appropriate to the emerging virtual culture of the digital age. We suggest that this may provide a useful perspective from which to analyze pedagogical choices in the context of rapid expansion of powerful cognitive technologies. Theorizing the cognitive agency of tools provides a means to evaluate (in the fullest sense of the word) the educational consequences of new technologies.

INTRODUCTION

New technologies pose a challenge for educators. Theorists argue that personal computers, personal digital assistants, Game Boys, and the Internet may displace formal schooling as the primary means of developing thinking skills (Gee, 2003; Papert, 1996; Shaffer, 2004). Computational media may create new skills and habits of mind, such as programming and algorithmic thinking, that students need to master (diSessa, 2000; Papert, 1980). Spreadsheets and statistical analysis tools may shift emphasis in mathematics from algorithmic fluency to mathematical modeling (Kaput, 1996a; Lehrer & Romberg, 1996; Papert, 1980; Shaffer & Kaput, 1999). Video games and word processors may move the focus of language arts from reading and writing the printed word to par-

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ticipation in multimodal literacy spaces (Bolter, 1991; Gee, 2003; Kress, 2003; Murray, 1999). But perhaps the most profound educational challenge posed by new technologies is to how we think about thinking itself.

This would not be the first time that a technological shift has changed our understanding of thinking. The field of cognitive science was based on the advent of computers, when theorists such as Newell and Simon (1956, 1972) and Anderson (1980, 1993) described human cognitive activity in terms of computational processes (see also Pinker, 1997). These models challenged the behaviorist paradigm by providing testable assertions about otherwise implicit cognitive activity within the mind of an individual. More recently, sociocultural theories—including activity theory (Engeström, 1999; Tikhomirov, 1999), mediational means (Wertsch, 1998) and distributed cognition (Hutchins, 1995; Norman, 1993; Pea, 1993)—have argued that mind does not exist solely within an individual but arises in activity. Intelligence, these theories suggest, is an attribute of a system involving multiple individuals and the tools they use in a larger social context. In this article we ask, do computational media again provide a means and a motivation to push beyond current theories of cognition—in this case, to extend and perhaps reframe sociocultural theories of cognition?

We approach this question by starting with the theory of virtual culture, an extension of ecological theories of cognitive coevolution of humans and artifacts (Clark, 2003; Donald, 1991, 2001) that suggests that computational media are creating new forms of cognitive activity and with them a new cognitive culture (Shaffer & Kaput, 1999). We then discuss the concept of agent-acting-with-mediational-means (Wertsch, 1998) as the fundamental analytical unit for sociocultural analyses. We focus in particular on how theories of mediated action, activity theory, and distributed cognition enable us to view thinking as an interaction between person and cultural tools. We argue that in the context of virtual culture, the conception of objects in these theories is too limited in scope: Focus shifts from studying the agent in isolation to studying the individual acting with tools, yet the agent still retains analytic primacy. To address this issue, we draw from the work of Latour (1996a, 1996b, 1996c) and from actor-network theory more generally (Law & Hassard, 1999; Suchman, 2000) an understanding of action that views objects as agents in their own right—in which both humans and objects are actants that simultaneously act and mediate the actions of others. In this view, we cannot talk about tools (physical or symbolic) as mediators of thought, because to do so reestablishes a distinction between persons and artifacts. Instead, we argue, the status of human beings and objects as analytically equivalent actants requires creating a new category of *toolforthoughts*—a concatenated creature representing a view of the relationship between artifact and cognition from the perspective of virtual culture.

Our approach is thus to assume the strong form of the concept of mediation developed in actor-network theory. Starting with this assumption, we explore how new computational tools problematize the concept of thought within current sociocultural approaches to the study of cognition by challenging the traditional position of privilege that humans occupy in such analyses. The result is a stronger form of the distribution of intelligence across persons and objects. For rhetorical purposes we describe this as a theory of distributed mind, but our intent is not primarily to develop a new cognitive theory. Rather, we hope to begin a conversation between the sociological perspective of actor-network theory and psychological theories of sociocultural cognition. In particular, we hope to suggest that a consolidation of these complementary theories may provide a useful perspective for thinking about pedagogical choices in an age marked by rapid expansion of powerful cognitive technologies. The idea that humans do not occupy a privileged position in psychological analyses is clearly unsettling. In this exploration, we hope to articulate how and why we might choose to make such a conceptual leap—or if not, to help clarify the reasons for and consequences of continuing to position humans uniquely at the center of the cognitive universe.

BACKGROUND

The Dilemma of Action

We begin with a dilemma. Wertsch (1998) described a moment in Kenneth Burke's thinking about the nature of human activity when Burke contrasted the actions of persons with the "sheer 'motions' of 'things'" (p. 12). Burke claimed that he was "not pronouncing on the metaphysics of this controversy," for "the distinction between things moving and persons acting is but an illusion." However, Burke added, "Illusion or not, the human race cannot possibly get along with itself on the basis of any other intuition" (p. 13). For Burke, humans need to remain at the center of activity, because it is too disconcerting to think otherwise.

Computational media problematizes this basic intuition. Modern computers—and equipment controlled by computers—act independently in ways that traditional "things" do not. Computer-controlled robots work in factories. Computers fly airplanes. Computers give directions based on a car's location, search for information on the Internet, and bid for merchandise on our behalf. Computers generate anatomical models from X-rays, perform statistical analyses, and test complex mathematical models in ways that human beings alone cannot. Thought and action are no longer the sole property of humans, and in what follows, we argue that although existing sociocultural theories of cognition assign an essential role to objects in their frameworks for studying action, Burke's center still holds. Computational media thus provide both a means and a motive to push beyond current theory.

Ecological Theories of Mind

A number of theorists describe the mind as an ecological system, in which individuals interact with cultural tools to produce thought and action. In his theory of instrumentalism, for example, Dewey argued that knowing is not something that takes place in the brain or in some inner consciousness; rather it is a form of activity in the world involving the entire body and the cultural tools at hand (Hickman, 1991). Dewey (1953) wrote, "Hands and feet, apparatus and appliances of all kinds are as much a part of [thinking] as changes in the brain" (p. 328). Bateson (1972) argued that the human mind is a cybernetic system "whose boundaries do not coincide with the boundaries either of the body or of what is popularly called the 'self' or 'consciousness'" (p. 319). This cybernetic view of intelligence was described more explicitly in Pask's (1975) conversation theory, in which thinking is a discussion among conceptual procedures (which he called P-individuals) that may or may not be part of the same persons or machines (or M-individuals). Similarly, in Minsky's (1985) society of mind, intelligence emerges from the interactions of many small computational processes, which he referred to as agents. Clark (2003) described human beings as cyborgs who use speech, text and other tools "to go beyond the bounds of our animal natures" (p. 81). Donald (1991) suggested, "the individual mind has long since ceased to be definable in any meaningful way within its confining biological membrane" (p. 359).

These theories collectively describe a cognitive ecology in which thinking emerges from the interaction of persons and technologies, blurring the distinction between the two. Dewey, in particular, suggested that there is not a conceptual difference between internal thoughts and external tools; both are forms of technology through which individuals conduct "competent and controlled inquiry" (Hickman, 1991, p. 38). In what follows, we argue that a strong view of thinking as an ecological process is essential to understanding the virtual cognitive culture made possible by computational media.

Virtual Culture

Donald (1991) argued that this distinctly human cognitive ecology developed through an iterative process. At each stage, a critical cognitive advance was externalized in a cultural tool, leading to a new form of paradigmatic thought and with it a new cognitive culture—which in turn laid the groundwork for a new cognitive advance and the next cycle of development. In Donald's account, the first protohumans supplemented event-based primate cognition with the ability to represent events in physical gestures, leading to a mimetic culture of gesture-based social interaction and communication. Donald argued that standardized or ritualized gestures, in turn, became the basis of symbolic reference. Once symbolic competence had been developed, language emerged—from rudimentary vocalization to complex articulation—as an efficient system for creating and communicating abstract symbols about the world. Once developed, linguistic symbols (i.e., words) made possible rapid and precise communication, leading to elaborate recounting of events and ultimately to the stories that help define the norms of preliterate cultures. The development of language thus led, Donald argued, to the creation of a mythic culture based on narrative transmission of cultural understandings (see also Bruner, 1986, 1976; Nelson, 1996). The record-keeping needs of commerce and astronomy in the extended societies of mythic culture led to the creation of external symbol systems, of which mathematical notations were probably the first (Kaput & Roschelle, 1998; Schmandt-Besserat, 1978, 1992, 1994). Donald argued that these external records led to the development a theoretic culture based on written symbols and paradigmatic thought characteristic of scientific disciplines. In a theoretic culture, such tools play a leading role in cognitive activity, and formal education focuses on learning to create and interpret written language and mathematical notations (diSessa, 2000; Donald, 1991).

Writing and mathematical notations are, of course, static representational systems. Once marks are made on a writing surface, they do not change unless they are reinscribed. When you write an equation with a pencil on paper, it remains there until someone erases, changes, or adds to it. Thinking in a theoretic culture can therefore be reasonably characterized as the result of human agency mediated by cultural tools. Theoretic culture depends on large-scale storage of information as a database for analytic thinking, and on a set of external tools that help us control the flow of this information to our biological processors—that is, to our brains, which evaluate and transform that information (Donald, 1991). In a theoretic culture, what matters is not what the unaided mind can accomplish, but rather, as Clark (2003) suggested, "how information is poised for retrieval and for immediate use as and when required" (p. 69). In such a culture, tools and thoughts are equivalent, as Dewey suggested, in the sense that both are used by individuals (or groups of individuals) in activity (Hickman, 1991).

Computational media, however, offer inherently dynamic representations: The power of a computer lies in its ability to change its state in the world without the ongoing action of a programmer or user (Kaput, 1986; Shaffer & Kaput, 1999). When you ask a graphing calculator to solve a system of simultaneous equations, it calculates a long series of approximate solutions until it converges on an answer without further action on the part of any human being.[1] Computational media thus pose a different relationship between tool and person. Building on Donald's framework, Shaffer and Kaput described computational media as a new transformative tool, one in the process of creating a new cognitive culture. They suggested that just as the theoretic inscription systems of writing and mathematical notation externalize human memory, computational media make it possible to externalize a particular form of thinking—namely, understanding that can be expressed as a well-formed finite-state algorithm. A procedure that can be described to a computer can be carried out independent of any person. Shaffer and Kaput argued that just as the ability to represent events in physical gestures created a mimetic culture, the ability to exchange narrative stories using spoken language made possible a mythic culture, and the ability to store symbolic information with written symbols led to a theoretic culture, the externalization of symbolic processing in computational media is in the process of creating a new virtual cognitive culture.

Epistemological Pluralism in a Virtual Culture

The basis of this virtual culture is the process of simulation (Turkle, 1995). In a virtual culture, computational media provide a broad range of interactive simulation systems, such as dynamic geometry environments, spreadsheets, modeling languages, and interactive games. These representational tools open new fields of inquiry, such as the study of complex systems (Bassingthwaighte, 1985; Resnick, 1991) and longitudinal data (Singer & Willett, 2003). They make possible new forms of expression, such as multimedia, video, and computer games (Gee, 2003; Murray, 1999). New tools let people work in domains once reserved for specialists—such as developing mathematical proofs (Lichtfield, Goldenheim, & Dietrich, 1997) or collecting and analyzing scientific data (Evans, Abrams, & Rock, 2001) —that make it easier to learn about the world through participation in meaningful activities (Shaffer, 2000, 2004). New tools let students manipulate virtual representations (Noss, Healy, & Hoyles, 1996; Papert, 1980), allowing them to develop abstract understanding through a web of connections among embodied experiences (Gee, 2004; Wilensky, 1991). Simulations let people use inductive and concrete techniques to address issues that once required abstract formal models. Questions that once required differential equations, for example, can be answered using a spreadsheet or a *body syntonic*[2] LOGO microworld (Papert, 1980).

This representational pluralism makes possible epistemological pluralism (Shaffer & Resnick, 1999; Turkle & Papert, 1990). In a theoretic culture, writing and mathematical notation—and the

[1]In some complex statistical models, it can take hours or days of independent activity on the part of the computer to produce a result.

[2]Papert (1980) used the term *body syntonic* to refer to the way programming with the LOGO Turtle lets children develop computational models that are connected to their "sense and knowledge about their own body" (p. 63) because they can "play" at being a Turtle (p. 58).

abstract modes of thinking such tools require—are the most effective means to solve complex problems. In a virtual culture, a range of powerful representational tools support multiple pathways to understanding. The cognitive world of games and simulations is (potentially) broader, more embodied, and more epistemologically inclusive than a theoretic culture of static inscriptions. In the next section, we look at three leading sociocultural theories of cognition and technology and suggest that such theories may not—in their current articulations—be adequate for analyzing cognitive activity in such a virtual culture.

Theories of Mediational Means, Activity Theory, and Distributed Cognition

A broad range of recent work in psychology supports the basic contention that the relationships among thought, action, and technology are essential in understanding learning. Although by no means a definitive or exhaustive set (see Preston, 1998; Wilson, 2002), sociocultural theories of mediational means, activity theory, and distributed cognition are widely used tools for understanding the cognitive and pedagogical role of technology in educational settings. Each of these theories begins by positing that activity necessarily takes place in the context of mediating tools. Wertsch (1998) argued that thinking always emerges through action with mediational means—that is, with tools—and thus learning is mastery and appropriation of cultural tools. In activity theory, Vygotsky's (1978) model of mediated action relates subject, object, and mediating artifact (Engeström, 1999). In distributed cognition, systems of activity are composed of persons and artifacts (Norman, 1993). In each case, the unit of analysis is the interaction of people and tools in social context, rather than either persons or tools in isolation. Activity theory, for example, links individual actors, tools, confederates, and the norms of action within a social context into a descriptive framework in which consciousness is located in practice, which is, in turn, embedded in a historically developed social matrix of people and artifacts (Engeström, 1999). Distributed cognition proposes that knowledge resides in people, in tools, and in cultural settings in which people interact with tools; it is not locatable exclusively in the heads of individual persons or in the design of specific artifacts. The system as a whole is more knowledgeable than the sum of its parts (Hutchins, 1995).

All of these theories, however, posit an asymmetrical relationship between persons and artifacts. This distinction is explicit in the case of activity theory, which identifies three levels of means as operation, action, and activity, with the corresponding ends of instrumental conditions, goal, and motive (Engeström, 1999). The last (motive) is ascribed only to human beings (Kaptelinin, 1996; Nardi, 1996a), and thus the structure of the highest level in the operation/action/activity framework is by definition determined by the humans in the system. In distributed cognition, the asymmetry is less explicitly drawn. Both humans and artifacts are referred to as agents in the system. However, Pea (1993) suggested that "the primary sense of distributed intelligence arises from thinking of people in action" and argues "for the centrality of people-in-action … as units of analysis for deepening our understanding of thinking" (p. 49). Elsewhere he explained, "I use the phrase 'distributed intelligence' rather than 'distributed cognition,' because people, not designed objects, 'do' cognition" (p. 50). Wertsch's (1998) conception of persons and objects was implied in his construal of mediated action as meaning agent-acting-with-mediational-means, as when he suggests that "the task of a sociocultural approach is to explicate the relationships between human action, on one hand, and the cultural, institutional, and historical contexts in which this action occurs, on the other" (p. 24).

These frameworks, in other words, reinscribe Burke's center: It is people who are doing the acting. This may not be a problem in a theoretic culture of static inscriptional systems. In a virtual culture based on the offloading of symbolic processing, however, using human action to analyze activity obscures the active role tools play. We may need to reexamine the analytic privilege we accord humans in thought and action.

Latour's Translation Model of Action

Latour (1996b, 2000) described how objects, by virtue of their being in the world in some form, push back in their interactions with humans. A thought, once instantiated, is no longer exactly that thought, for it now has an independent existence in the world. We can fold ourselves into an object, but the object always expresses our thoughts, values, intentions, and norms with its own "timings, tempos, and properties" (1996a, p. 268) —that is, in its own particular form. Latour gave the example of delegating to a wooden fence the task of containing sheep. He asked, "Are the sheep interacting with me when they bump their muzzles against the rough pine planks?" and answered, "Yes, but they are interacting with a me that is, thanks to the fence, disengaged, delegated, translated, and multiplied. There is indeed a complete actor who is henceforth added to the social world of sheep, although it is one that has characteristics totally different from those of [human] bodies" (1996a, p. 239). The fence enacts Latour's intention to keep the sheep all together in one place to make sure that none wander off. His action is folded into the nature of the fence; but if one looks for a "mind" in this situation, it is as much in the head of Latour, who is now freed up to read a book, as it is in the fence that enacts a particular way of thinking (keep the sheep together), a way of valuing (although the sheep might not like it much, it is more important for them to be penned up than for them to roam free), and a way of interacting (now the sheep interact with the fence rather than with Latour). The relation between humans and technology is thus best conceived not as humans using objects, but rather as humans interacting with and through objects.

From this perspective, action has no point of origin; rather action is distributed between actants (things and people). Latour (1996a) argued that "to act is to mediate another's action" (p. 237). The properties of particular humans and objects shape the way action unfolds—that is, humans and objects are mediators—and all action arises from a process of mutual mediation. This conception of action does not grant analytic priority to humans, because action is a moment of mutual mediation between actants, "no one of which," Latour (1996a) explained, "ever, is exactly the cause or the consequence of its associates" (p. 237).

In what follows, we take as a premise that persons and artifacts are equivalent actants in this sense: Persons and artifacts engage in mutual mediation, and the actions that result are not ascribable more to one than the other. We extend the logic of this premise, suggesting that it implies a theory of distributed mind in which mediation is the fundamental ontological unit of activity. We examine the pedagogical and cognitive consequences of such a position, asking, what is thinking if human action is not the focus of activity? And what are the pedagogical implications of such a view? That is, we assess the value of addressing Burke's metaphysical controversy in developing our conception of thinking and learning in a virtual culture.

FROM TOOLS AND THOUGHTS TO TOOLFORTHOUGHTS

A Virtual Cognitive Ontology

Latour's translation model challenges the idea that humans have a privileged position in action. Seeing action as an association of mediating actants pushes us out of the Western anthropological schema that, Latour (1996a) suggested, "always forces the recognition of a subject and an object, a competence and a performance, a potentiality and an actuality" (p. 237). If objects were only the reified intents or concretized designs of their makers, it would make sense to orient to them, as Pea (1993) suggested, as things that have intelligence but cannot do cognition. The structuring effects of objects designed to shape action (and thus also thought) would be principally relevant to our understandings of activity. Yet, as is often noted, objects have a way of exceeding or changing the designs of their makers (Postman, 1993; Tenner, 1997). The characteristics and properties of a tool shapes action in ways that are influenced by, but not reducible to, the initial inputs of its designers and users.[3]

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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[3]It remains true, of course, that humans and human motives play a large role in determining the development and deployment of tools. But we argue that understanding a tool and the social patterns it creates is not possible solely through an analysis of the human contributions. The tool is greater than the sum of its parts: It has its own rhythms, tempos, and properties that are influenced by, but not reducible to, the initial inputs and their interactions. That is the point (or one of the points) of Latour's fence: The sheep experience the fence as an actant in their world that expresses desires, values, and ways of being that are related to (but not exclusively derived from) Latour's intentions and actions. A weak form of the claim would be that as a practical matter, the actions of tools are not explainable by an analysis of inputs because of the immense complexity of those inputs and their interactions over cultural-historical time. The stronger form is that tools are not reducible to their inputs even in principle.

[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.

EXAMPLES: TOOLFORTHOUGHTS IN MATHEMATICS AND LITERACY

A theory of distributed mind thus proposes that the fundamental unit of analysis for cognition is the systemic effects of individual toolforthoughts—that is, the particular forms of social interaction they foster. Our interest in developing the concept of toolforthoughts here is as a tool for understanding the cognitive and educational implications of computational media. We therefore examine the utility of the concept by looking at the pedagogical consequences of computational toolforthoughts in two areas of virtual culture: mathematics and literacy.

Toolforthoughts in Mathematics

In a theoretic culture of static inscriptions, students learn to solve complex mathematical problems by representing them in algebraic notation. For example, the motion of a ball after it is thrown is determined by representing the motion with two equations—one for horizontal position and one for vertical position—and solving the resulting system of equations. In a virtual culture of computational media, the same problem can be solved with a variety of toolforthoughts: difference models in a spreadsheet, dynamic systems or linear models in iterative modeling environments, programmable simulations, or even dynamic geometry models. A student can diagram the factors that influence the position of the ball (such as its location, its speed, the direction in which it is moving, and the effects of gravity and friction), and then manipulate the assumptions of the model to understand Newtonian mechanics without first having to learn algebra (Papert, 1980). Such methods let young students solve problems that in the traditional mathematics curriculum require the use of calculus and other advanced techniques: launching a rocket to Mars, for example, or modeling how a bicycle stays upright.[7]

One might defend the primacy of algebra in the curriculum by arguing that only when using algebra are students really doing, and thus really understanding, mathematics; when a student uses a computer, the spreadsheet or modeling environment is solving the problem. But this argument is only sustainable from a particular view of cognition—in this case, as something happening in the head that is only manifest in symbolic manipulation. If we define mathematics as computation using particular techniques then, indeed, when these become externalized in a new tool, the original endpoint of instruction has been taken over by the tool.

The theory of distributed mind, however, focuses on the outcomes of interacting toolforthoughts. It emphasizes how new tools lead to new kinds of actions, and thus to new modes of thought. In this view, the reason for introducing new technologies into the classroom is not to recreate existing activities, but rather to allow more compelling possibilities that new toolforthoughts provide. Because there are no thoughts independent of tools (or tools devoid of thought), intelligence is always the collaboration of toolforthoughts. Pedagogy does sacrifice understanding when a toolforthought is used to accomplish the thinking that is already folded into it. However, the understanding being sacrificed is not what has been folded into the toolforthought. That understanding is still present but has been relocated. The understanding being sacrificed is that which comes from actions that are only possible with the aid of the toolforthought. Using a calculator to add 2 + 2 does not sacrifice the ability to add. That capacity is still present in the person–calculator system. What is sacrificed is the understanding that would come from working with the calculator to do something we cannot do with pencil and paper alone.

In other words, it is not new toolforthoughts that potentially diminish understanding, but rather curricula—or, more precisely, a poor match between toolforthought and activity. Thus, Pea's (1993) argument that a trade-off exists between "deeper understanding" and "engaging in meaningful whole-task problem solving" (p. 74) is only sustainable for a particular way of thinking about technology, cognition, and learning. In the theory of distributed mind, all thinking is a tool-thought combination. From this perspective, algebra is not inherently more powerful than other mathematical modeling systems, except perhaps by virtue of its place in the historical development of mathematics. It is not enough that algebra has traditionally been a dominant toolforthought, however, because the social pattern that algebra creates as a toolforthought has also traditionally disempowered a wide range of students—and pushed important problems be-

[7]Others have similarly suggested that new tools open new avenues for solving problems (see, e.g., Kaput, 1986, 1992; Papert, 1980; Shaffer & Kaput, 1999; Shaffer & Resnick, 1999). The concept of toolforthoughts expands the implications of this change.

yond the reach of all students. New mathematical toolforthoughts potentially let more students work with more complex mathematical ideas than the curriculum of theoretic culture (Kaput & Shaffer, 2002; Papert, 1980). These new possibilities for mathematical understanding depend on learning to interact with a range of mathematical toolforthoughts to achieve meaningful ends.

Toolforthoughts in Literacy

Bolter (1991) described a writing space as the interplay of writing materials and techniques of inscription used to produce literacy objects. Not surprisingly, theoretic writing spaces emphasize print literacy, and theoretic schooling emphasizes the production and consumption of symbolic text as a primary literacy activity. That is, school focuses on learning to read and write words on paper. In a virtual culture, however, writing increasingly means interacting with a range of inscriptional toolforthoughts: artifacts that expand traditional forms of writing (such as the Web), but also modes of communication that were not previously available (such as interactive multimedia), or were available but not in the form of writing technologies (such as immersive role-playing simulations). The basic cognitive engine of virtual culture is the externalization of symbolic processing. Simulations function as virtual worlds in which students can "read" concepts experientially (Gee, 2004; Norman, 1993). In a theoretic culture it is possible to conceive of literacy as an interaction between tool and person: between the text and the reader or writer. However, new forms of reading and writing such as we find in videogames and other simulations require a degree of projection (or inhabitance) that makes it increasingly difficult to analytically separate person from tool. Indeed, what is the ubiquitous avatar if not a representation of the tight coupling between computationally literate person and computational literacy object?

The potential consequences of this increased embodiment are profound. In theoretic culture, writing creates a world on paper (Olson, 1994). Understanding a world on paper requires experience of the real-world contexts to which the text refers (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004). In virtual culture, writing creates a world on the computer—a world that provides both a "text" and the experiences needed to understand it. Simulations give students the potential to learn through a new form of direct experience, and lengthy cognitive apprenticeship in the dominant symbolic systems of theoretic culture may not be needed to understand complex cognitive domains. Papert (1980) famously suggested that computers make it possible to learn mathematics by living in Mathland as one can learn French by moving to France. Similarly, students can learn French by playing a massively multiplayer online computer game conducted in French.[8] Students can come to know *Hamlet* through multimedia projects (Murray, 1999)—or perhaps some day through a Prince of Denmark video game. These students may not be facile at translating words reprinted from Shakespeare's folio or quarto into a personally relevant interpretation of the dilemmas that face the troubled prince. But doing so was not, after all, Shakespeare's intent in writing the play. *Hamlet* was written to be seen, not read. More to the point: From experiencing the play through a range of literacy toolforthoughts, more students may be able to interact with the themes of *Hamlet,* the nuances of Shakespeare's dramatic skill, and the relationship between performance

[8]Black (2004), for example, suggested that participation in online fan fiction communities is a powerful tool for students learning English as a second language.

and interpretation that the play represents. Digital worlds make it easier to learn by having meaningful experiences and accomplishing meaningful ends. Such experiences depend on learning to "read" and "write" in collaboration with toolforthoughts that develop understanding of the world from the inside, through students' own actions—and we evaluate such experiences by the communicative, interpretive, and expressive ends they make possible.

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]

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[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.

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