Effects of Technology on Verbal and Visual-Spatial Abilities

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We argue that, although human intelligence has an innate component, artifact-free abilities do not exist. To advance this argument, we draw attention to the two main features of technologies: Their role as amplifiers of human abilities and their mixed nature as both material and conceptual entities. To illustrate the impact of cognitive technologies, we discuss how they influence verbal skills via notational technologies and fluid skills via visual–spatial technologies. We then approach computerization from the advantaged view of its impact on both visual–spatial and conventional literacy skills. We conclude by underlining the dynamic and context-dependent nature of human ability. To successfully adapt to its cultural niche, human intelligence engages with different cognitive tools and gains a complexity larger than the one it supposedly reaches in its development according to *g*-factor theories.

Although human intelligence has an innate component, artifact-free abilities do not exist. To advance this argument, we discuss how technologies interact with two paradigmatic human abilities: verbal and visual–spatial. We focus on these two kinds of abilities because they are commonly measured by tests of human intelligence (Mackintosh, 1998; Sternberg, 1990) and because a relevant number of influential scholars emphasize the innate aspect of these abilities over their cultural determinants (e.g., Herrnstein & Murray, 1994; Pinker & Bloom, 1990). By discussing technological influences on these abilities, we wish to call the attention of researchers to the complex and intimate relationship that exists between human intelligence and its cultural niche, with the technologies there available and, in particular, with those technologies that have intellectual consequences. In our culture, those technologies may be paper, a calculating machine or a computer, or the signs we manipulate by means of these artifacts, such as alphabets and numeric systems. In other cultures, such aids may be of quite a different nature. For instance, in the pre-Columbian Inca culture of the South American Andes, one ubiquitous technology was a complex set of ties called *quipu*, from the *Quechua* language, meaning "knot." It consisted of a long rope from which sets of cords hung; knots were made in these cords to represent numerical values (Urton, 2003). As illustrated by the Inca use of the *quipu* in the facilitation of counting tasks and imperial accounting, it is not only simple cognitive tasks that are influenced by the use of technologies, but also very complex ones.

We have organized the essay into three main sections. In the first section, we draw attention to the two main features of technologies as sketched by researchers in the field of intelligence and technology: their role as amplifiers of human abilities and their mixed nature as both material and conceptual entities. Second, we comment on what we call the notational impacts of technology on human abilities, in particular, the issue of literacy. Third, we discuss non-notational technologies. In particular, we address the development of visual–spatial abilities from the vantage point of the Flynn effect, the increase of standard IQ test scores of cohorts of adults from 20 different nations across the twentieth century. We then comment on how computerization technologies have not only advanced the skills underlying the Flynn effect, but also revalued conventional literacy skills. The construct of computer literacy is accordingly reviewed. We conclude by underlining the dynamic and context-dependent nature of human ability.

Technologies as Amplifiers and Affordances

Technologies are marked by two main features. A distinguishing trait of technologies is that they are created to amplify all kinds of human capabilities. The kind of skills amplified by tools is varied. For instance, Nickerson (2005) indicates that technologies may amplify motor, sensory, or cognitive skills. Whereas tools such as hammers amplify motor capabilities and devices such as eyeglasses amplify sensory capabilities, systems of representation such as written scripts (e.g., the alphabetic system), and mathematical scripts (e.g. the Arabic numerals) amplify *cognitive* capabilities. Here we have a particular interest in technologies that amplify cognitive capabilities, which we and other researchers name *cognitive tools* (see essays in Sternberg & Preiss, 2005). We argue that, as a result of their potential to amplify human cognitive capabilities, cognitive tools transform not only the physical environment but also the nature of human cognitive skills, an assertion compatible with the ideas advanced by numerous scholars in the field (Bruner, 1973; Cole, 1996; Olson, 1974, 1994; Olson & Cole, 2005; Olson & Torrance, 1991; Salomon, 1993; Scribner & Cole, 1981; Sternberg & Preiss, 2005; Tomasello, 1999a, 1999b, 2000; Tomasello, Kruger, & Ratner, 1993; Vygotsky, 1978).

The second distinguishing feature of technologies is that they have a dual nature: As noted by Cole (1996; Cole & Derry, 2005), they are both psychological and material. Certainly, technologies are material, because the elaboration of even the most basic tool involves the modification of physical materials. However, tools are made to sustain and aid goal-oriented human activities. In consequence, they have a conceptual dimension; their materiality is organized according to the anticipated intentions of prospective users. For instance, a hammer needs a dimension that suits the size and force of the human hand.

The material and conceptual dimensions of technologies meet in their particular *affordances*. For James Gibson (1977), who coined the term, the *affordances* of an object describe the reciprocal relationship between the world and a living organism. They are resources the environment offers the organism as opportunities for different kinds of action; for instance, surfaces provide support to move and walk, that is, they afford walking (Gibson, 1977). Capitalizing on Gibson's work, Norman (1988; 2002) applies the term to technologies' design and notes that they afford users the ability to execute certain behaviors to achieve their practical goals. Therefore, good design involves creating so-called user-friendly tools, that is, technologies whose conceptual dimension materializes in affordances that are easy to perceive and understand. Whereas sensory and motor tools predominantly afford transformations of the material aspects of cultural life, cognitive tools predominantly afford transformations on the symbolic aspects of cultural life and, eventually, transformations of the users of those technologies. In so doing, cognitive tools, as systems of representation, play a central role in both cultural evolution and cognitive development (Tomasello, 1999a).

Notational Impacts of Technology on Human Intelligence

Let us illustrate with a basic cognitive tool: writing scripts. As Nickerson notes: "The development of symbol systems and written language was certainly among the most noteworthy technological achievements of prehistory; there is no other technological advance whose effects on human history rival those of this one" (Nickerson, 2005, p. 25). With the advent of secular modern schooling, notational sophistication became one of the main assignments of schools (Gardner, 1991). As schooling reached a larger portion of the population, these amplifiers acquired a growing socioeconomic relevance, and their promotion, as illustrated by UNESCO's push for universal literacy, became a priority for both economic and social growth. These initiatives implemented the assumptions of the strong version of the literacy hypothesis, which, simply stated, considers that the cultural implications related to the diffusion of writing—such as the accumulation of knowledge—are instrumental to the development of logic and abstract thought (Goody, 1987; Olson, 1994). There is only one analogue to the relevance reached by writing systems and that is the relevance of numerical systems, in particular, the Arabic system. As noted by Zhang and Norman (1994), written numerals make mathematical performance easier because they allow for the distribution of the operation of mathematical calculations between external representations and internal representations. In short, external representations activate perceptual processes that complement the mnemonic processes triggered by internal representations. In consequence, different representations of numbers allow different kinds of mathematical performance. Although the Arabic system is not necessarily the most efficient, it became the dominant system of representation for numerical calculations for a number of reasons: "It integrates representation and calculation into a single system, in addition to its other nice features of efficient information encoding, compactness, extendibility, spatial representation, small base, effectiveness of calculation and, especially important, ease of writing" (Zhang & Norman, 1994, p. 293). Today, the value society places on these literacy and numeracy skills is evident: Dexterity with the script of a native language and proficiency with mathematical symbols are the canonical components of different systems of measurement of educational achievement across the world (Grigorenko, Jarvin, Niu, & Preiss, in press).

For the sake of straightforwardness, let us focus here on writing systems. Whereas the economic implications of literacy are easily apparent, its cognitive implications have remained an open question to which different scholars offer different responses. As mentioned, the strong literacy hypothesis states that knowledge of a script, in particular, the alphabet, is the principal basis for the development of abstract thinking, that is to say, of part of the core abilities measured by conventional tests of intelligence (Olson, 2005). However, empirical psychological work has weakened these claims. Scribner and Cole (1981), in a famous study developed among the Vai people in Liberia, which compared people literate in English, Arabic, and/or Vai, showed that the impact of literacy can be equated with the impact of schooling only in cases that involve the widespread use of a script, which explains why in industrialized societies the impact of literacy is so pervasive. As Cole summarized recently, “in any society where literacy practices are ubiquitous and complexly interrelated, the associated cognitive skills will also become more widespread and complexly related” (Cole, 1996, p. 235). Therefore, the cognitive implications of literacy are not a direct consequence of knowledge of a script (for instance, of learning the alphabet), but rather are mediated by the practical use that people make of the script. For instance, people knowledgeable of Arabic were especially good at tasks involving incremental memory because they trained this ability in the context of their Qura’nic classes, where they had to learn the Qur’an in an incremental fashion. On the other hand, those that made practical use of the Vai script in writing letters showed more abilities in the organization of information than those that did not use the script in that way. “If the uses of writing are few, the skill development they foster will also be limited to a narrow range of tasks in a correspondingly narrow range of activities and content domains” (Cole, 1996, p. 235). Only the participants exposed to a certain level of schooling and to a continuous engagement with school-like activities as adults created discourse that the researchers considered literate; for instance, their justifications were more task-oriented and informative than those of others or they more frequently engaged in developing what Olson (1994) calls metarepresentational concepts.

Taking into consideration the intertwinement of schooling and literacy, some scholars have revisited the strong version of the literacy hypothesis and proposed that the institutionalization of schools in Western societies is a byproduct of the development of a literate culture, and, consequently, the cognitive consequences of schooling are the result of the kind of documentary practices trained there (Goody, 1987; Olson, 1994, 1996; Olson & Torrance, 1991). What, then, are the specific cognitive skills promoted at school and what is their relation with human ability? According to Olson (1996), in learning to read and write, children acquire a new way to think about language and mind. In so doing, they are developing ontogenetically what their society, after a long historical evolution, achieved and institutionalized as a privileged way of thinking: metacognitive thought. Indeed, in their invention and subsequent historical evolution, written scripts became models of speech and created a new set of concepts for thinking. Once a script crystallizes as an accomplished system of representation, “a script provides the model, a set of distinctive but related concepts and categories however distorted and fragmentary, in terms of which one can analyze and so become aware of certain basic properties of one’s speech” (Olson, 1996, p. 86). Therefore, living in a literate world involves seeing and interpreting the world in terms of the categories employed in writing and using those categories to think about thinking, language, and the mind. For that reason, learning a script, particularly an alphabetic one, generates a new kind of metalinguistic awareness that provides “intelligence” with its basic character. In fact, IQ tests include items, among others, that deal with vocabulary and the relationship between words, testing our capacity to participate in a literate environment (Olson, 2005). Then, given the affinity between literate modes of thinking and the mode of reasoning tested by intelligence tests, it should not come as a surprise that schooling is one of the main factors boosting IQ scores (Ceci, 1991). What school does is shape human intelligence in a way that fits the way IQ tests see intelligence.

The intellectual impact of literacy is not limited to the configuration of abstract thought; it also permeates the documentary practices that are born from its development, such as the archival use of the alphabet. As noted by Nickerson (2005), it is not clear how the order of the letters of the alphabet was established, but a fixed order was instituted, which made the alphabet an invaluable tool for information organizing. Indeed, as Nickerson makes evident, the alphabetical organization of information is superior to alternative arrangements of information, such as a solely visual–spatial one: “Compare the problem of finding a bird in a bird book if one knows its name with that of finding the bird if one knows only what it looks like. The first task is easy because of the alphabetic organization of the book’s index; the second is difficult because there is no comparably simple way of organizing information on the basis of visual features” (Nickerson, 2005, p. 4).

Non-notational Impacts of Technology on Intelligence

Language has recently been distinguished by evolutionary psychologists (Pinker, 1994; Pinker & Bloom, 1990) as one of the most relevant instincts possessed by the human mind. Notational sophistication plays a relevant role in the enhancement of human language well beyond the limits of its natural configuration. Intelligence theorists acknowledge this influence when they place verbal skills among those abilities that are more susceptible to cultural influence, which they name crystallized abilities (Mackintosh, 1998). There is also evidence, however, that technologies influence other abilities that assumedly have an entirely innate component. We are speaking here of visual–spatial abilities. Intelligence theorists place visual–spatial abilities among those abilities less susceptible to cultural influence, so-called fluid abilities; tests measuring these abilities, such as the Raven tests, are deemed, incorrectly, as culture-reduced tests of intelligence (Mackintosh, 1998). The standard scores on intelligence tests such as the Raven have consistently augmented over the past decades—in 20 different nations—a phenomenon known as the Flynn effect, after its discoverer, James Flynn (Dickens & Flynn, 2001; Flynn, 1987, 1999, 2000). The Flynn effect is a telling rebuttal to the predictions made by early-twentieth-century eugenicists, who predicted a decrease of the "intelligence of the nations" caused by the immigration and hybridization processes in modern societies (Neisser, 1998). Countering these negative expectations, the Flynn effect not only revealed that the intelligence of nations did not shrink (at least, in those countries where systematic measurement of intelligence was available), it also exposed an opposite trend: IQ scores increased—and in what is supposedly the more genetically driven area of IQ: abstract-thinking and visual-thinking skills.

The real meaning of the Flynn effect has been subject to some debate (see essays in Neisser, 1998). Flynn has been reluctant to attribute such changes to a real change in human intelligence. Indeed, as he notes, although IQ standard scores were increasing in the Netherlands, the number of inventions patented showed a decline (Flynn, 1998)! Greenfield (1998) has provided convergent evidence favoring the hypothesis that the diffusion of visual–spatial technologies such as video games is one of the main forces behind the Flynn effect. Indeed, there is evidence that there exists a causal relation between amount of practice with video games such as Tetris and higher levels of performance in spatial and visual tasks such as those measured by the Raven Matrices. In particular, evidence shows that expertise in computer applications is related to improvements in attention, the development of iconic and spatial representations, and improved performance on tasks involving mental transformations (Greenfield, 1998; Maynard, Subrahmanyam, & Greenfield, 2005; Okagaki & Frensch, 1994).

An alternative hypothesis proposes that, at least in the United States, the cognitive changes related to the Flynn effect originated as a result of, first, the growing access of the population to schooling during the beginning of the twentieth century, and, second, the increasing demands of the mathematical curriculum (Blair, Gamson, Thorne, & Baker, 2005). Whereas in the first three decades of the twentieth century a large part of IQ tests takers in the United States had little or no formal schooling, over the middle decades of the century the percentage of the population with exposure to some schooling had grown significantly, as did the number of years people spent in school. After the 1950s, the impact of schooling was intensified by the changes made in the elementary school mathematics curriculum. Paradoxically, these modifications did not cause a change in the mathematical reasoning component of IQ, but rather in the visual–spatial component. As an explanation of this paradox, Blair and collaborators (2005) propose that changes to the math curricula across the twentieth century focused on the development of visual–spatial relations and the visual representation of mathematical problems instead of the execution of algorithms and basic mathematical problems. The visual–spatial nature of the mathematics taught in elementary school, according to the authors, would have favored the enhancement of skills associated with the activity of the prefrontal cortex, skills involved in fluid intelligence tests and working memory tasks. This hypothesis is compatible not only with the literacy hypothesis but with the aforementioned evidence that links schooling to an increase in IQ scores (Ceci, 1991).

Dickens and Flynn (2001) have recently proposed that there is not a unique force behind the Flynn effect. Quite on the contrary, they propose that, thanks to industrialization, there are many environmental changes that might have contributed to the rise of cognitive ability during the twentieth century. Changes include more cognitively demanding jobs and leisure activities, new technologies, and a shift to smaller families, which affords more intellectual stimulation. Once these social changes start the process, powerful individual and social multipliers escalate it. The same social trends capitalize on genetic dispositions: "A gene-caused ability advantage upgrades the school environment by more homework being done, which upgrades the environment by entry into a top academic track, which upgrades ability further. Each feedback loop acts as a potent multiplier" (Flynn, 2003, p. 98). The successive feedbacks might have all triggered a final result: In short, "the current generation may take abstract problem solving far more seriously than preceding generations did" (Dickens & Flynn, 2001, p. 352). In the end, however these multipliers interact, the Flynn effect is a clear-cut example of the way cultural tools influence basic cognitive processing (Cole, in press).

As more powerful graphic tools and machines such as calculators and computers enter the classroom, their positive impact on fluid abilities should continue. However, from the current evidence it is not clear how to disentangle the specific impact of each one of the components that might contribute to this trend: technology, curriculum, and instruction. We know, for instance, that teachers have been reluctant to include computers in their instructional routines. For instance, in a study in the United States on 4,083 teachers of grade 4 and higher in 1,150 schools, 71 percent of teachers studied assigned computer work to students “occasionally,” and only a third of them did so “on a regular basis.” Moreover, just 1 in 6 science teachers and 1 in 8 math teachers use computers for instruction (Becker, Ravitz, & Wong, 1999). The authors underscore that, although 30 percent of the teachers have their students search the World Wide Web, few teachers make use of project-oriented software: For instance, only 5% of science teachers use simulation software frequently. When authors categorized teachers according to the software they used, they found that only a small percentage of teachers were involved in significant use of diverse software, roughly 10% to 15% in total, and that teachers that made extensive use of different software were mainly computer and business education teachers. The question then is how these technologies affect human intelligence, given that mediation by teachers is not the predominant method. Notwithstanding teachers’ initial reaction to computers, intentional and incidental impacts of these technologies might be imminent. Some scholars notice that advances in instructional technology user-friendliness and students’ and teachers’ computer literacy seem to make teachers not only more receptive to implementing instructional technologies within the classroom but to do so more successfully (Kulik, 2003).

Finally, it is unclear what role in the Flynn effect is played by individual differences. We know that individual differences in exposure to print are related to differences in crystallized knowledge (Stanovich, Cunningham, & West, 1998). Can we identify a similar phenomenon in fluid abilities? In fact, although the aforementioned evidence suggests that there is a main effect of the exposure to visual–spatial technologies on fluid abilities, we still do not have enough evidence to understand how much exposure to computer media is needed to achieve substantive impact. Is deliberate practice with computer media needed to reach significant improvements in visual–spatial skills, or is incidental exposure sufficient to benefit from computer technology’s potential intellectual benefits?

From Paper to Screen

The growing diffusion of visual–spatial technologies is anchored in the larger phenomenon of the diffusion of computer technologies. Computerization has come rapidly. In the U.S., the incorporation of computer technology into schools has taken place in two stages. The first stage was the large influx of computers into school systems during the 1980s and early ’90s. The second stage was the large increase in the number of computers connected to the Internet. At the end of the 1990s, a large-scale survey of U.S. teachers reported that 93% of the teachers in grades 4–12 engaged in computer use during their professional work (Becker et al., 1999). Similarly, the National Center for Education Statistics (2000) reported that 99% of full-time public school teachers had access to computers or the Internet somewhere in their schools (although, as noted above, they were reluctant to expose their students to the new technologies in the context of instruction). And computerization has not only affected school settings; technological changes in work settings have been extensive as well. For instance, data from large-scale surveys in Britain, Germany, and the United States estimated the percentage of workers using computers on the job at 69.2, 56.2 and 52.5% respectively (Borghans & ter Weel, 2005).

It is indeed clear that the diffusion of computers fosters a different set of cognitive skills than did earlier technologies. The Flynn effect is merely an illustration of how computer-like technologies are reshaping the skill base of contemporary society. But the impact of computers goes well beyond the increase of visual–spatial skills. To illustrate, the use of word processors today is so prevalent that writing relates progressively less to the cultivation of expression on paper and more to effective computer use. There is evidence that this change restructures the entire writing process, as planning and reviewing with word processors involves more cognitive effort than does working in longhand (Kellogg & Mueller, 1993). Moreover, it is possible to correct errors and to restructure material in ways that were impossible without computer technology. Thus, writing, reading, and the teaching of reading have been affected by new digital technologies, in particular, by the diffusion of hypertext (Reinking, 1998).

The workplace has also undergone dramatic changes because of technology. A large number of tasks that were once performed with paper-based means have been altered by the introduction of computers. Moreover, as computers are not static tools, work activities change at a rapid pace. On the other hand, the Internet has dramatically changed the way organizations access information and environments. Because of the possibility of instantaneous connection around the globe, both the spatial configurations of workplaces and the management of working hours have been transformed. For instance, e-mail has reduced response times and prompted the development of new rules of communicative etiquette, which promote an instantaneous and continuous rhythm of response via straightforward communication. As a general phenomenon, people spend less time in person-to-person meetings and more time emailing. To pace these changes, there is a growing demand for flexibility in the workforce, and work-related skills are more perishable than before. Although resembling the old fears of deskilling, this new phenomenon is quite different in nature, since, instead of driving cognitive skills out of the job, the new work environment requires more and more intellectually skillful operators. For instance, it has been suggested that advanced manufacturing in newly industrializing countries such as Mexico depends "on the effectiveness with which workers could acquire new skills, especially the ability to maintain and quickly repair complex equipment" (Shaiken, 1998, p. 279). As most of the workers in newly emerging economies are not suitably trained, they have to rapidly develop an appropriate level of expertise. According to Shaiken, the most efficient way to do so is through teamwork. Thus, although complex cognitive skills have in fact been quite resilient in the face of technological substitution, contemporary technologies might actually foster their development.

The malleable nature of information technology has made it more difficult to delimit a definite notion of computer literacy. In consequence, if the definition of literacy has been highly contested by scholars, the notion of computer literacy is still more ambiguous. More than 20 years ago, Norman (1984) commented that there is no a straightforward notion of what computer literacy involves. At the time he proposed four levels of computer literacy: first, understanding the general principles and concepts of computation; second, understanding how to use computers; third, understanding how to program computers and, four, understanding the science of computation. According to him, the average person would only need to manage the first two levels, whereas the other two would probably be a specific domain of expertise. In addition, to eliminate the knowledge and power gaps between builders, designers, and users, Norman emphasized that a basic understanding of the principles and the use of computers should be part of the computer literacy of the average person. He also proposed that a specific area of research on the human–computer interface should be developed to adjust computers to users' needs. Today, great improvements have been made in computer user-friendliness. Notwithstanding these improvements, the notion of computer literacy continues to be a fuzzy and a debatable one.

Today, the term "computer literacy" is commonly used to draw attention to the fact that paper-related skills such as writing and reading are not enough to be a "productive citizen" in the information society (Reinking, 1998; Tuman, 1992). In fact, to define who is computer literate is more difficult than to define who is literate because there are no paradigmatic skills, such as reading and writing, in the arena of computers. However, a look at some new evidence should help us reassess the role of these paradigmatic skills in the computerized society. Economists recently asked the question of whether a higher level of computer literacy indeed involved higher market returns, and compared the market returns of computer skills with those of mathematical and writing skills. They inspected data taken in 1997 from the British workforce and showed that it is not computer skills that are valuable, but rather the ability to carry out mathematical analysis and to write documents that yields significant economic results (Borghans & ter Weel, 2004). Although computer users earn higher salaries than do nonusers (a result that the authors note has been replicated in several studies), what determines those higher earnings is an ability to write and to carry out mathematical operations, that is, we imagine, to make use of computers to profit from the old notational skills discussed earlier. Thus, what matters to be a productive citizen is not the specific set of technologically contingent skills, but rather the ability to use paradigmatic skills such as reading and writing on computers. In sum, what is required in this new context is not a restricted and narrow set of computer-specific abilities but a higher level of sophistication in those abilities that are particular to advanced professions. After reviewing the evidence for the ways computerization has changed the labor market, Borghans and ter Weel (2005) showed that the adoption of computer technologies changed the relative economic value of different skills on the job: In short, the skills that promote productivity increased their value, whereas those skills that were easily automated reduced their value. In consequence, computerization involves an increase in the educational requirements to fulfill some positions and a larger opportunity of educated workers to focus on those activities that constitute the core of their profession. This prediction is compatible with one of the explanations of the Flynn effect, which included higher cognitive complexity at the job as one of its main driving factors (Dickens & Flynn, 2001).

Thus, new computer technologies are making people smarter not only because of their specific impact on visual–spatial abilities, but also because they free cognitive resources so people can focus on more relevant things. This change should imply a change in the way intelligence is measured, because some of the skills measured by conventional tests of intelligence have become less important because of technological change. For instance, in times past, the number factor in Thurstone's (1938) theory was measured in large part by tests of arithmetic computation (Thurstone & Thurstone, 1941), and achievement tests, such as the

Iowa Tests of Basic Skills, also emphasized arithmetic computation as one of two or three basic skills. Today, such tests represent an anachronism, as handheld calculators and computers have rendered arithmetical-computation skills much less important than they were in the past. Thus, successful performance of the job is no longer mediated by those abilities, but rather by other abilities not measured by conventional tests of intelligence, such as practical or creative abilities (Grigorenko, Jarvin, & Sternberg, 2002; Preiss & Sternberg, 2003; Sternberg, 1985; Sternberg et al., 2000; Sternberg & Horvath, 1999; Wagner & Sternberg, 1985). Sternberg and his collaborators' push for the development of measures of creativity and practical intelligence is very compatible with the growing demand for these abilities in an environment whose technological complexity grows day after day.

Conclusion

It has been proposed elsewhere that culture-free artifacts do not exist (Cole, 1996). Artifact-free abilities do not exist either. As Olson and Bruner nicely summarize: "Each form of experience, including the various symbolic systems tied to the media, produces a unique pattern of skills for dealing with or thinking about the world. It is the skills in these systems that we call intelligence" (1974 p. 149). What they named symbolic systems, we have here named technologies. We believe that a consideration of technology as patterning human skills transcends theories of intelligence based on the *g*-factor—that is, transcends the idea that a single factor of intelligence accounts for intelligent behavior in everyday life. In opposition to *g*-factor theories, our consideration of technology portrays human intelligence as dynamic and context dependent.

Intelligence is dynamic because cognitive tools are not static. They are historical inventions that evolve through a process of selection acting at a cultural level. Their intellectual effects are, in consequence, relative to this process. Changes in computer literacy are illustrative of this process. On the one hand, the skills comprising "computer literacy" have changed as computer technology has evolved (Lin, 2000). For instance, programming was considered an important skill in the early 1980s, but not today, when Internet-related skills seem to be more important. On the other hand, the diffusion of computers is making more important those nonroutine abilities that cannot easily be automated and that engage "the ability to use problem-solving intellectual capabilities in an information technology context" (Lin, 2000, p. 69). Thus, computer literacy involves more than the mastering of a few computer applications. The technological-literacy arena is also consistent with the evidence suggesting that human skills are adaptive and, to a large extent, context dependent (Ceci, 1996; Sternberg, 1985, 1990; Sternberg et al., 2000). There are many other cases that illustrate this context dependency: As we mentioned, the use of Arabic for learning the Qu'ran incrementally was related to improvements in incremental memory, practice in visual–spatial games was related to an improvement in visual–spatial skills, and the use of Arabic numerals allowed the development of more complex mathematical operations.

Thus, the study of technology puts a real face on what psychology usually treats as an undifferentiated variable: environment (Kirlik, 2005). In doing so, it shows that culture is not a blank slate. Tools are invented and stocked historically, transmitted from one generation to the next, and acquired ontogenetically. Tools that are commonplace to one generation were created only through a great intellectual struggle by the previous generation. For instance, as Pea notes, "the inventions of Leibniz's calculus and Descartes's coordinate graphs were startling achievements; today they are routine content for high school mathematics" (1993, p. 53). As these technologies—calculus, coordinate graphs, the alphabet, computers, and many others—become commonplace and shared by a larger group of people, human intelligence must gain in complexity to successfully adapt to its cultural niche.

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