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Technology and the Development of Intelligence: From the Loom to the Computer

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The nature of a culture's tools at a particular time influences that culture's operational definition of intelligence. That is, the cognitive skills required to develop and utilize a culture's tool set become an important component of a group's implicit definition of intelligence. The major thesis of this chapter is that using a particular tool set develops the cognitive skills that are part of a group's implicit definition of intelligence. Just as we embed cognitive skills that are important in utilizing our own culture's tools in our own intelligence tests, so too we can imagine that the intelligence tests of other cultures might reflect their own cultural tools (Greenfield, 1998). This chapter will show that different tools in different cultures not only utilize, but also develop, particular sets of cognitive skills. Tools themselves evolve through historical time and thus reflect the social and cognitive developments at a particular point in history in a particular place, and at the same time they influence these developments. Therefore, when cultural tools change, it follows that cognitive skills and valued forms of intelligence should change as well; and such cultural change will be one focus of this chapter.

Humans, and primates more generally, are considered a tool-using species. The tool-making and tool-using capacities of humans are skills/abilities that have developed over the course of human evolution and continue to evolve (Boyd & Silk, 2000). If we define intelligence as successful behavioral adaptation to an ecological niche (see Scheibel, 1996), tools are an essential component of the human adaptation to a variety of different niches. Just as tools adapt to ecological niches, cognitive skills adapt to tools and to the social practices in which they are embedded (Saxe, 1994).

Let us stop a moment to define some terms. How do tools relate, definitionally, to technologies, the topic of this book? Tools are the byproduct of technologies, that is, of an underlying knowledge base. For example, the technology of literacy creates the book as a specific tool. The technology of electronics creates the computer as a specific tool. In this chapter, our particular focus is on the ways in which a culture's technologies, and the tools that are components of these technologies, both influence and reflect the forms of intelligence that are developed and valued in that culture.

Bruner (1966), along with Cole and Griffin (1980), believes that the development of intelligence is to a great extent the internalization of the tools of the cultural niche in which the child or person operates. Vygotsky (1962, 1978) makes a comparison between symbolic tools and physical tools that highlights the theoretical position of the tool in cognition. Lave (1977), Nunes, Schliemann, and Carraher (1993), Saxe (1999), and Guberman (1996) emphasize the role of tool-based activities in the development of cognitive representations and operations. This perspective on tools is based on a fundamental idea in Vygotskian psychology, well expressed by the Russian psychologist O. K. Tikhomirov: "Tools are not just added to human activity; they transform it" (1974, p. 374). In this view, tools can be either concrete or symbolic. Most tools are a mixture of the two, in that even a seemingly concrete tool like a loom requires symbolic operations.

Technology develops intelligence through the internalization of cognitive skills required by various tool systems. In some cases, physical skills carried out with the aid of a tool become mental skills. Often seemingly physical skills require particular cognitive operations of varying levels of complexity. In other cases, mental skills carried out with the aid of a tool can later be performed independently (Salomon, 1988). In other words, technology operates in what Vygotsky (1962, 1978) called the "zone of proximal development": the area between aided and independent cognitive achievement. In summary, technologies develop and lead to the internalization of the mental skills that they require for their utilization, and these skills are then embedded in a culture's implicit definition of intelligence.

At this point we must digress to mention that there are, in fact, two major categories of intelligence that exist around the world: social intelligence and technological intelligence (Mundy-Castle, 1974). Tool systems have their primary impact on one of these: technological intelligence, or cognitive skills relating to the world of things. We must recognize that although both exist in every society, they receive differential emphasis; some cultures emphasize social intelligence more, whereas others put greater emphasis on technological intelligence (Greenfield, Keller, Fuligni, & Maynard, 2003; Mundy-Castle, 1974). Our point is that the skills required for a culture's tool systems become that culture's implicit definition of technological intelligence, whether or not technological intelligence is the most important type of intelligence in a particular culture. In the Vygotskian approach, technological intelligence is implicitly assumed to be the only category of intelligence. With the aid of Mundy-Castle (1974), Wober (1974), Sternberg, Conway, Ketron, & Bernstein (1981), and Dasen (1984), we have come to realize that this is not the case. We will return to this point later.

Learning to use a particular technology both utilizes and develops mental skills on different levels of cognition. The three levels on which we focus in this chapter are attention, representation, and mental transformation (based on Piaget's notion of concrete operational intelligence). These levels go from the lower, more automatic levels to the higher, more intentional levels of cognition. We explore how these three cognitive levels of intelligence are influenced and used by different types of technology. Based on our own empirical research programs, we have chosen to focus on two types of technology in two different parts of the world: computer technology in the United States and weaving in Maya Mexico. Whereas computer technology is an invention of the 20th century, the backstrap loom used by the Maya has a history that goes back more than 4,000 years in the Americas (Greenfield, 2004). Both weaving and the computer constitute examples of technologies that not only reflect but also develop a culture's valued forms of intelligence. Each profile of highly developed cognitive skills illustrates the close connection between a tool system and the development of technological intelligence on all three levels of cognition.

COMPUTER TECHNOLOGY AND COGNITIVE SKILLS

Media are symbolic tools that vary from culture to culture and from one historical period to the next. Olson and Bruner write that "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).

One symbolic tool that began to change the landscape of home, education, and workplace in the United States and other parts of the world at the end of the 20th century is the interactive technology of the computer. How has computer technology affected the cognitive skills that we call intelligence? In this section, we consider two of the most popular of the computer applications, games and the Internet, in order to address this question.

Greenfield argued that computer applications such as action games require and develop a different profile of cognitive processes compared to earlier modes of communication, such as print (e.g., Greenfield, 1984a, 1985). Indeed there seem to be a whole set of literacy skills associated with computers and the video screen that are quite distinct from the traditional literacy skills required for print (see, e.g., Greenfield, 1984a, 1987, 1990a, 1998). Most computer applications have design features that shift the balance of required information processing from verbal to visual (Subrahmanyam, Greenfield, Kraut, & Gross, 2001). For instance, action video games, which are spatial, iconic, and dynamic, have multiple, often simultaneous, things happening at different locations and the ability to "read" and utilize the information on computer screens may therefore require a variety of attentional, spatial, and iconic skills.

The suite of skills children develop by playing such games can provide them with the training wheels for computer literacy and can help prepare them for science and technology, where more and more activity depends on manipulating images on a screen. Research has provided evidence for the thesis that computer game playing can have an impact on specific cognitive skills. Although the term *cognitive skills* encompasses a broad array of competencies, most of this research has focused on components of visual intelligence, such as perception and attention, representation (iconic and spatial), and mental transformations. These skills are crucial to most video and computer games, as well as to the Internet and many other computer applications (Greenfield, 1984a).

Attention

We begin our survey with the attentional level of cognition. On this level, one important skill involved in playing computer and video games is divided visual attention, sometimes called parallel visual processing. This is the skill of keeping track of multiple things happening simultaneously. In almost all action games, more than one entity is present and acting on the screen at the same time. This characteristic goes back at least 2 decades to the maze game of Pac-Man, one of the first popular action video games. Skilled play at Pac-Man requires simultaneously keeping track of the Pac-Man character, four monsters, your location in the maze, and four energizers. Many other more complex games, past and present, have even more information sources that must be dealt with simultaneously (Greenfield, 1984a). In order to be a successful player, one must monitor more than one location on the screen. Would this technology-based game requirement translate into skill in parallel visual processing? Would practice in the software tool of action games produce skill in dividing visual attention?

Greenfield, deWinstanley, Kilpatrick, & Kaye (1994) explored the effect of video game expertise and experience on strategies for dividing visual attention among college students enrolled in introductory psychology. Divided attention was assessed by measuring participants' response time to two

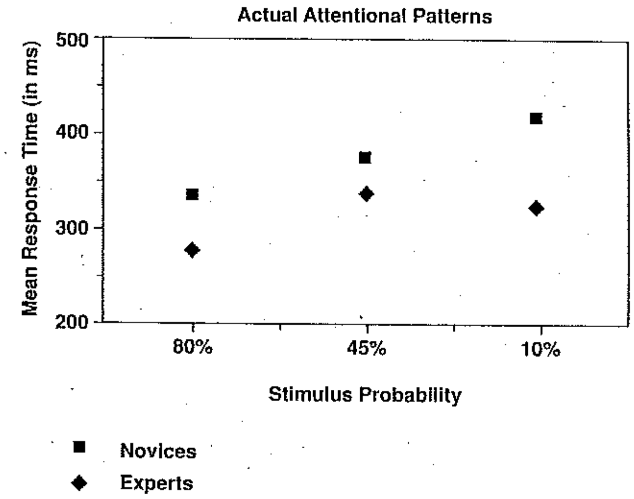

Fig 2.1. Actual relationship between video game expertise and strategies for dividing attention (Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994).

events of varying probabilities at two locations on a computer screen. In one condition, a target appeared more often at one location than another. In another condition, a target appeared with equal probability at both locations. For each condition, participants were told in advance what the probabilities were. Translating these known probabilities into monitoring strategies is analogous to what one must do after inducing the differential probabilities of various events at various locations in an action video or game.

Participants who were expert game players (those who scored higher than 200,000 on the game Robot Battle) had faster response times than novices (those who scored below 20,000 on the game Robot Battle) at both high- and low-probability positions of the icon (see Fig. 2.1). (Note that these groups represent only the extremes of game expertise.) The strategic nature of the expert players' attentional skill (versus a simple improvement in eye–hand coordination) was shown in the patterning of their performance. Prior research showed that, in comparison to equiprobable targets, people generally allocate more attention (and respond faster) to a high-probability target, whereas they allocate less attention (and respond slower) to a low-probability target (Posner, Snyder, & Davidson, 1980). Correlatively, expert players were faster only in response to the high- and low-probability targets; there was no difference between the groups in the equiprobable condition, which presumably does not require strategic deployment of attentional resources. Second, relative to the condition with two equally probable targets, expert players showed no decrement in skill in the low-probability condition; novice players, in contrast, did.

Even more important, the researchers were able to establish a causal relationship between playing an action game and improving strategies for monitoring events at multiple locations. In a second experiment, introductory psychology students (unselected for video game skill) were randomly assigned to play the action arcade game Robotron or to be in a no-play control group. Robotron, like Robot Battle, involves multiple entities acting simultaneously. The attentional task remained the same and was administered as both pretest and posttest. In the pretest, more- and less-experienced players (not as extremely different as the novices and experts in the first study) differed only at the high-probability target, where the more-experienced players again had significantly faster response times; there was no difference at the low-probability target. After 5 hours of playing Robotron, members of the experimental group responded significantly faster to the target at the low-probability position on the screen; in contrast, members of the control group, who also took the attentional posttest, did not show this improvement. Practice on the test by itself (the control condition) yielded selective improvement with the equiprobable targets, which require less strategic skill and, in the first study, registered no difference between expert and novice players. Overall, the studies showed (a) that experts at utilizing the game technology had better developed strategies for dividing visual attention than did novices and (b) that practice with this technology improves strategic competence in monitoring events at a relatively improbable location.

Recent research confirms Greenfield et al.'s finding regarding the effect of video game playing on attentional skill. Green and Bavelier (2003) reported that adult video game players (who had played action video games on at least 4 days per week for a minimum of 1 hour per day for the previous 6 months) had enhanced attentional capacity compared to nonvideo game players (who had little or no video game usage in the past 6 months). The attentional skills were assessed using an enumeration task (reporting the number of squares in a briefly flashed display), a flanker compatibility effect (the effect of a distractor on a target task), and a modification of the "useful field of view" task (measures the ability to locate a target among distractors to assess attention over space).

In addition, Green and Bavelier provided action video game training to a group of nonvideo game players by asking them to play the action game Medal of Honor for 1 hour per day for 10 consecutive days; a control group was asked to play the game Tetris for the same time span. Tetris is a dynamic puzzle game in which only one event takes place at a time; in contrast, Medal of Honor is a battle game in which multiple entities are simultaneously engaged in various actions. The results suggested that Medal of Honor led to greater improvements in attentional strategies on all the tests than did Tetris.

The transfer effect of video game playing obtained by Green and Bavelier on entirely different attentional tasks is noteworthy. Also noteworthy are the very consistent effects in both the correlational and experimental study and the effects across a wide range of attentional tasks. Although the two pairs of studies cannot be directly compared, we think the greater consistency of effects in Green and Bavelier's studies is due in large part to the fact that the study was carried out a good decade later. In the intervening time home video sets, computers, games for younger children, and hand-held games had become pervasive in U.S. homes, allowing participants more prior experience with electronic games, and, most important, more experience earlier in their development (Vanderwater, Wartella, & Rideout, 2003). We believe that earlier practice with a technology will lead to a larger impact on the cognitive skills that define intelligence in a particular culture, as well as to more precocious development of those skills (LeVine, 2002).

Finally, strategies for dividing visual attention have come to be necessary for handling recently developed computer formats now omnipresent on television, as well as on the Internet. On TV, there are divided screens with textual information running across the bottom and, on financial programs, down one side of the screen, all while a talking head holds forth in the rest of the screen space. On the Internet, teenagers (and others) often move from window to window, simultaneously monitoring their instant messages, e-mail, and homework, all while downloading music videos (Gross, 2003). Skills developed in video games can be useful in monitoring these contexts that also require parallel processing.

Representation

Experience with computer video games has also been found to affect the development of mental representation skills. Salomon (1988) asserted that symbolic forms in computer tools can be internalized as cognitive modes of representation as a person interacts with a computer. Both iconic and spatial representation are crucial to scientific and technical thinking; these modes of representation enter into the utilization of all kinds of computer applications.

Iconic Representation. One important representational skill embodied in computer games is iconic or analog representation—or the ability to create and read images such as pictures and diagrams. Indeed iconic images are frequently more important than words in many computer games. Greenfield, Camaioni, et al. (1994) found that playing a computer game shifted representational styles from verbal to iconic. In the study, undergraduate students played the game Concentration either on a computer or on a board.

The goal of the game was to open either virtual or real doors to identify the location of pairs of numerals. The computer version was comprised of icons: virtual doors and a cursor in the shape of a hand. The board version had no icons, but involved direct action on an object—the participant used his or her hand to lift a solid door in order to reveal a numeral. A pretest and posttest included several dynamic video displays from Rocky's Boots, an educational computer simulation designed to teach the logic of computer circuitry; Fig. 2.2 provides an example of what the participants saw. Their task was to try to figure out what was going on; they were given no clues as to the content or operation of the displays.

When asked to explain on a pencil-and-paper test the operation of displays such as the one in Fig. 2.2, those who had played the game on the computer offered more iconic diagrams in their descriptions, whereas those who played the game on a board offered more verbal descriptions (see Fig. 2.3). Thus, playing a computer game that used icons influenced participants to use icons in their representations; the game technology had shifted the construction of representations from verbal to iconic.

This study was a cross-cultural one, comparing students in Rome, Italy, where computer technology, at that time, was much less diffused, to students in Los Angeles, where the technology was much more diffused. Participants in Los Angeles preferred to use diagrams or icons compared to the Italians, who used words in responding to the test (see bottom of Fig. 2.4). We see this as a correlational finding that indicates the ecological validity and generality of the experimental result. In other words, technology appears to operate in the real world, not just in a specific experimental setting.

But not only did the technology make participants create more iconic representations, it also seemed to make participants understand iconic representation better. Corresponding to their relative exposure to video games, experienced players, Americans, and males understood the dynamic iconic simulations of the logic of computer circuitry presented on a video screen better than did inexperienced video game players, Italians, or females (see top of Fig. 2.4). These correlational data indicate that computer technology, as instantiated in action games, not only increases the frequency of iconic representation, it also increases comprehension of this mode of representation.

Spatial Representation. Spatial representation is considered a domain of skills rather than a single ability (Pellegrino & Kail, 1982) and includes skills such as mental rotation, spatial visualization, and the ability to deal with two-dimensional images of a hypothetical two- or three-dimensional space. Spatial representational skills are used in all kinds of computer applications, including word processing, programming, and the recreational medium of action video games (Gomez, Bowers, & Egan, 1982; Greenfield, 1983, 1984a,

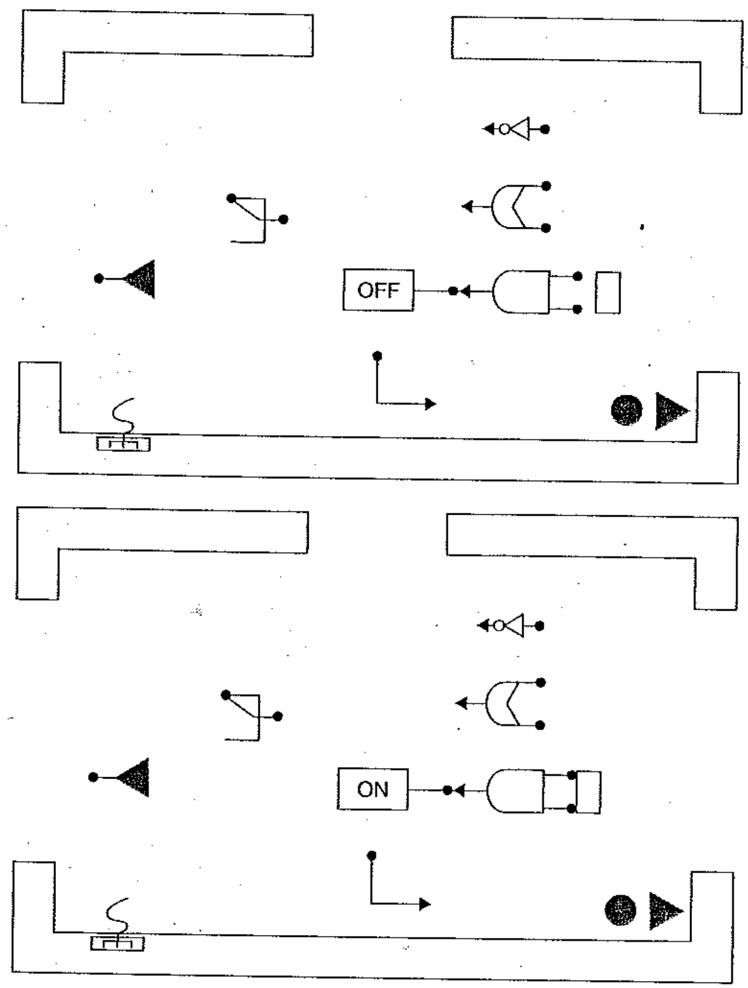

Fig 2.2. Two screens from the pretest–postest of scientific–technical discovery. Shaded areas, which were orange in the actual displays, represent the flow of power. The sequence of screens shows an "and-gate" being turned on. An "and-gate" is activated when two input nodes are simultaneously touched by the power source. An "and-gate" contrasts logically with an "or-gate," which can be activated when either one or the other input node is touched by the power source.

1990a, 1990b; Roberts, 1984). Consequently, repeated practice with games and other computer applications may enhance selected spatial skills.

Spatial representation is required by many, if not all, action video games. The action takes place in a virtual space that is shown one screen or one shot at a time. In order to play most games, one must develop a mental

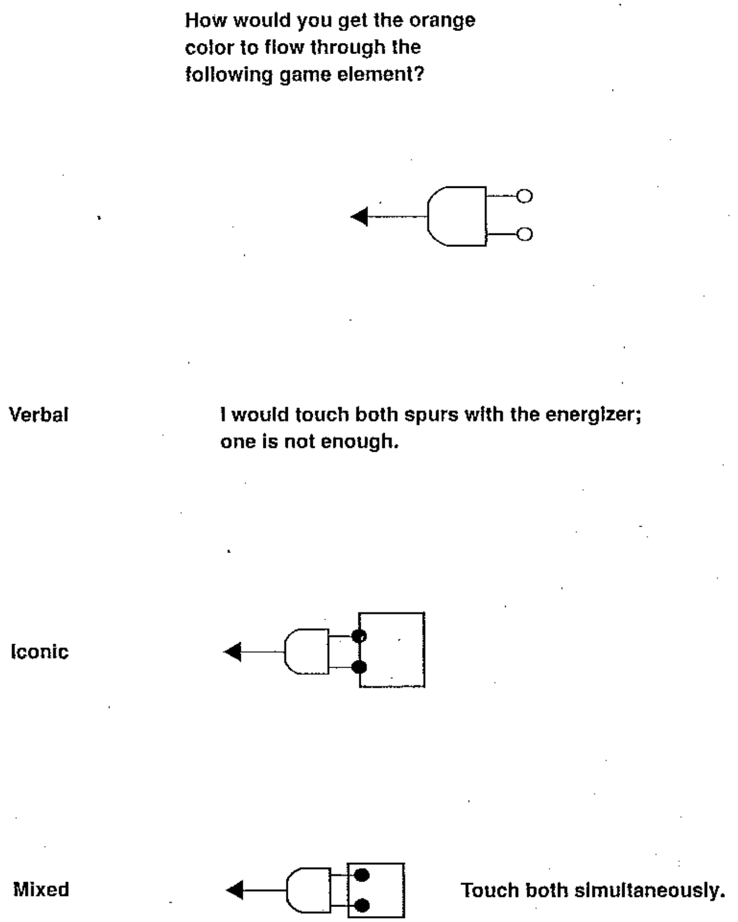

Fig 2.3. Different modes of representation used to answer pre- and posttest questions.

representation of the whole space and understand how each screen relates spatially to other parts of the space shown on different screens. One example is Castle Wolfenstein, a maze game in which a prisoner tries to escape from the castle, a Nazi prison; the prison is represented as a series of linked mazes. Each maze, in turn, represents a room in the castle; rooms are linked by virtual doorways into floors; floors are linked by virtual stairways into various levels of the castle. In the initial version in the 1980s, Castle Wolfenstein was represented as a series of two-dimensional mazes; later, it was represented as a series of three-dimensional mazes. In both cases, the principle is the same: To play effectively, one must figure out how a maze shown on one screen relates to mazes shown on other screens. In other words, in order to escape,

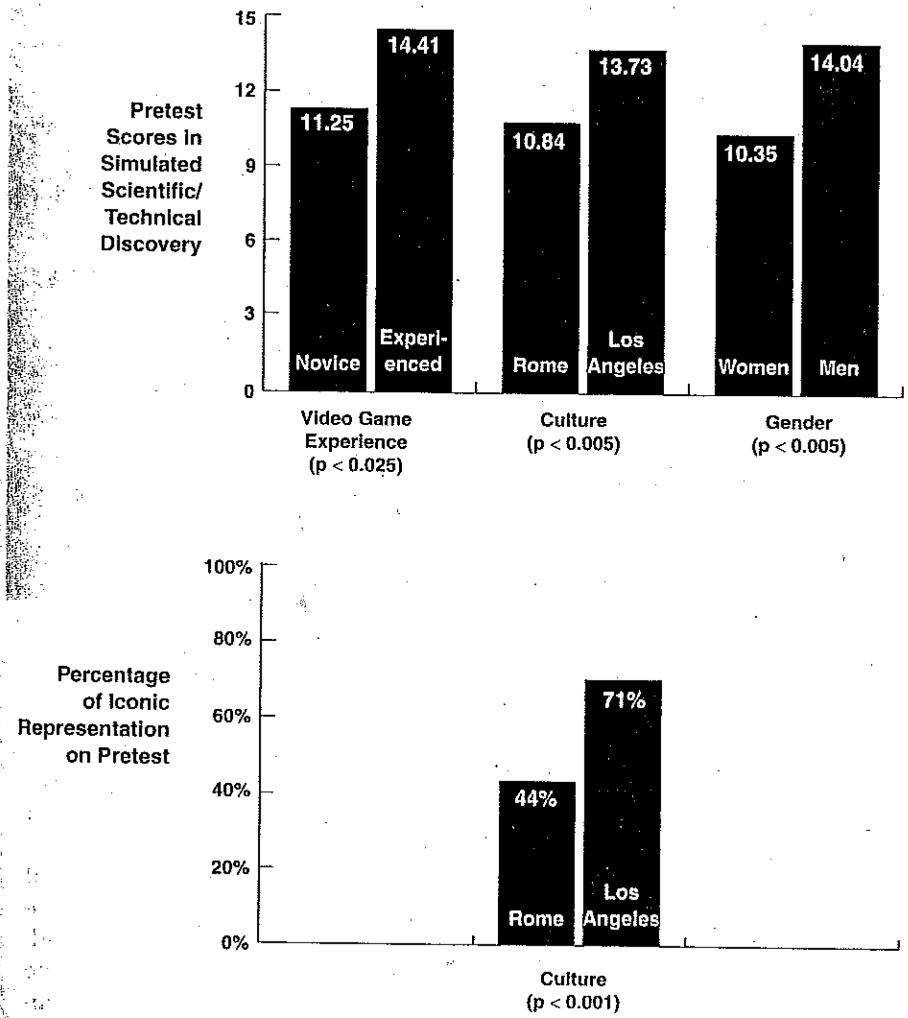

Fig 2.4. Significant long-term influences on simulated scientific-technical discovery and mode of representation.

one must figure out the layout of the castle. As a player becomes more expert in the game, he or she develops a spatial representation of the castle. Fig. 2.5 shows how this spatial representation expanded and elaborated as one player, age 15, gained more experience in the play. Note that the representation includes not just the castle, but also the location of various key objects within the castle. This example illustrates how skill with the technology of an action video game both requires and provides practice in

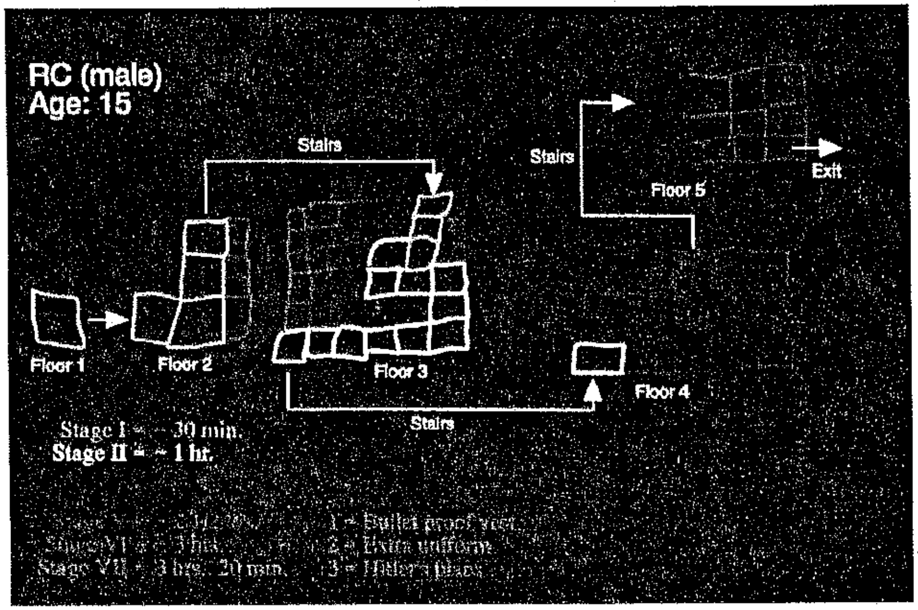

Fig 2.5. The progressive development of a spatial representation of Castle Wolfenstein over the first 3 hours and 20 minutes of play.

spatial representation. The external representations of separate mazes are transformed as they are internalized as one unified spatial representation of the castle as a whole.

The available evidence suggests that action games may serve as informal cultural tools for improving spatial skills more generally (Greenfield, Brannon, & Lohr, 1996; Okagaki & Frensch, 1994; Subrahmanyam & Greenfield, 1994; Subrahmanyam et al., 2001). Along similar lines, McClurg and Chaille (1987) showed that playing video games enhanced the spatial ability to mentally rotate three-dimensional objects in fifth-, seventh-, and ninth-grade students. Miller and Kapel (1985) found a similar positive effect of video games on the rotation of two-dimensional objects in seventh and eighth graders.

In a study of 10½- to 11½-year-olds, Subrahmanyam and Greenfield (1994) found that practice on a computer game (Marble Madness) reliably improved spatial performance (e.g., anticipating targets, extrapolating spatial paths) compared to practice on a computerized word game called Conjecture. Marble Madness involves guiding a marble along a three-dimensional grid using a joystick—the player has to keep the marble on the path and prevent it from falling off and prevent being attacked by intruders.

Verbal Representation. Another equally important question concerns the impact of Internet use on verbal representational skills. At a very basic level, Internet use involves reading and navigating around Web sites. In addition, the popular Internet applications such as instant messaging, e-mail, bulletin boards, and chat rooms involve the use of writing. Thus, the frequent use of the Internet may have important consequences for verbal representational skills. Unlike the medium of television and video/computer games, the Internet involves reading print and its use may actually result in more reading than before, albeit reading in a different medium. Second, the writing involved in online discourse is different from that found in traditional forms of written discourse, such as books and magazines, in that it has the features of both oral and written language. This is especially true of the Internet applications that are used for communication such as e-mail and instant messaging. For instance, chat conversations consist of shorter, incomplete, and grammatically simple and often incorrect sentences (Herring, 1996). Novel abbreviations are also rife (Greenfield & Subrahmanyam, in press). A question for the future is what will be the cumulative impact of such online reading and writing on verbal representational skills and ultimately for cultural definitions of verbal intelligence.

Mental Transformation

Video game expertise appears to have an impact on the development of mental transformation skills, such as those used in mental paper-folding tasks. In mental paper folding, a two-dimensional stimulus is mentally transformed into a three-dimensional stimulus. Greenfield, Brannon, & Lohr (1994) studied 82 undergraduates to assess the relationship between expertise in a three-dimensional action arcade video game, The Empire Strikes Back, and the skill of mental transformation as assessed in a mental paper-folding test (see Fig. 2.6 for sample items from the test). Although they found that short-term video game practice had no effect on mental paper folding, they found that video game expertise, developed over the long term, had a beneficial effect on the spatial skill of mental paper folding.

Implications for Intelligence

It is quite clear that a number of the skills being enhanced by computer technologies are also part of our cultural definitions of intelligence. Indeed, selective increases in nonverbal or performance IQ scores in recent years may be related, in part, to the proliferation of computer technologies in the environment that has occurred during the same period of time (Flynn,

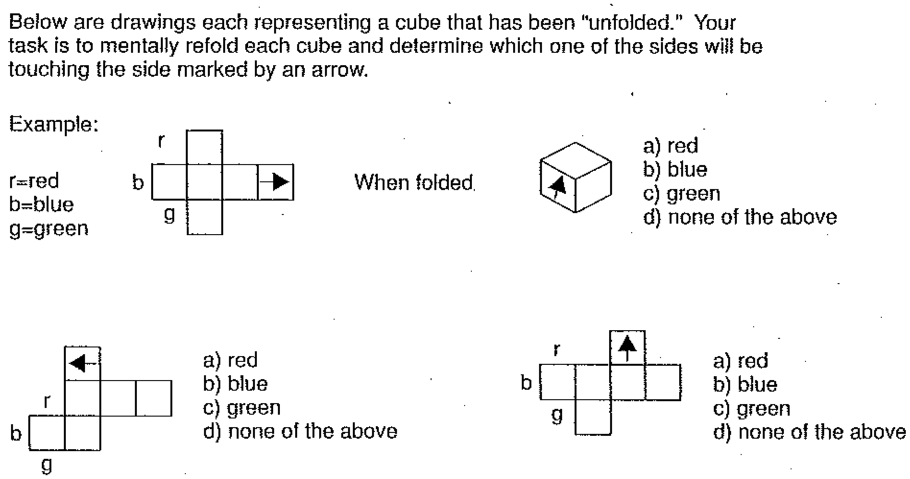

Fig 2.6. Sample item from the mental paper-folding test used in the study by Greenfield, Brannon, & Lohr (1994).

1994; Greenfield, 1998). Nonverbal or performance IQ tests and subtests are basically tests of different sorts of visual intelligence. For example, Chatters (1984) found that playing a video game exerted a significant positive effect on sixth-grade children's performance on the Block Design subtest of the Wechsler Intelligence Scale for Children (WISC). Similarly, Okagaki and Frensch (1994) reported that practice on the computer game Tetris (a game that requires the rapid rotation and placement of seven different-shaped blocks) significantly improved mental rotation time for undergraduates. However, note that mental rotation items are a traditional item type in ability tests. Indeed, in an early study, Gagnon (1985) found that 5 hours of practice on the action video game Targ improved performance on the mental rotation items of a vocational aptitude test. All of these findings contribute to our thesis that there is a tight relationship between a culture's technologies and its definitions of intelligence. They provide a clue that the changing modes of verbal representation seen on the Internet will ultimately lead to changed definitions of verbal intelligence.

WEAVING TECHNOLOGY AND COGNITIVE SKILLS

We now turn to a different kind of technology: Mayan backstrap loom weaving. It too has tight links with the three levels of cognition: attention, representation, and mental transformation. Although the levels of cognition are

the same, the particular skills are different. As in the case of computers, the relevant skills are those that are engaged by this particular technology.

Attention

The transmission of weaving technology both utilizes and further socializes processes of visual attention (Greenfield, Brazelton, & Childs, 1989). Relative to Euro-American babies, Zinacantec Maya infants are born with extended visual attention spans (Brazelton, Robey, & Collier, 1969). Zinacantec caregivers then capitalize on this skill as they teach girls to weave (Maynard, Greenfield, & Childs, 1999). Learning by observation, which depends on extended focused visual attention, becomes extremely important as girls learn to weave (Greenfield, Brazelton, & Childs, 1989). A young girl must watch her mother or sister for months before trying weaving herself (Haviland, 1978). Even the first time girls try weaving themselves, they watch an expert model weave more than they weave themselves: First-time weavers spent 53% of their time observing the teacher, 39% weaving, and only 8% distracted (Childs & Greenfield, 1980). Learners in the United States, who have not received practice in the extended visual attention required by observational learning, can become very frustrated at having to watch so long before weaving themselves (Greenfield et al., 1989).

Representation

Facility with weaving technology influences strategies of visual representation (Greenfield & Childs, 1977; Greenfield, Maynard, & Childs, 2003). Greenfield and Childs (1977) found that unschooled girls who were weavers showed attention to the construction of cloth as they made thread-by-thread representations of striped woven textiles when given wooden sticks as a representational medium; unschooled boys of the same age (who were not weavers) did not create this type of representation. Not being practiced in weaving technology, they did not represent the actual construction of the textile designs; instead, these boys focused on how the textiles might look from a distance in their representations. However, formal schooling, for a small group of boys who received it, had the same effect as knowing how to weave. Schooled teenage boys also provided thread-by-thread analyses of the textile patterns in their representations. Apparently the cognitive tools provided by formal education were a substitute for weaving technology in developing this type of visual representation of textile patterns.

Other researchers also found a link between expertise in the use of weaving technology and skill in pattern representation. Comparing expert adolescent Navajo rug weavers to other Navajo who did not know how to weave, Rogoff and Gauvain (1984) found increased ability in representing familiar, but not novel patterns. In another kind of weaving, straw weaving in rural Northeast Brazil, Saxe and Gearhart (1990) found that experience with the psychological technology of knowing how to weave influenced representation of topological information in novel patterns. Knowing how to use a particular technology influences representation of spatially related information.

Mental Transformation

Experience with weaving technology also enhances relevant skills in spatial transformation. Maynard and Greenfield (2003) investigated the link between experience in weaving and the development of spatial transformation by examining mental transformations involved in creating the warp of a loom. Prior fieldwork produced a hypothesis that Zinacantec weaving tools are adapted to the developmental status of learners (Greenfield, 2000a, 2000b), specifically whether or not they have reached a stage where they are capable of mental transformation.

Most girls first learn to wind a warp on a toy loom (see Fig. 2.7), which is adapted to young girls, ages 3 to 5 or 6. Older girls, who usually have had some experience in weaving, wind on a warping frame (see Fig. 2.8). The winding tool that is adapted for older girls reflects an advanced stage of cognitive development, one that requires mental transformation. For

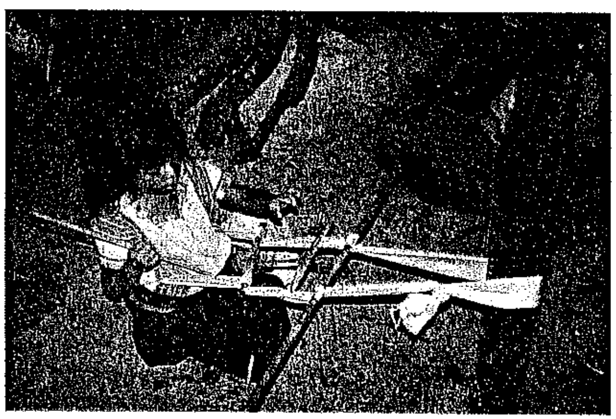

Fig 2.7. A toy loom. The weaver has wound her warp directly on the loom between the two end sticks. Photograph by Patricia Greenfield, Nabenchauk, 1991.

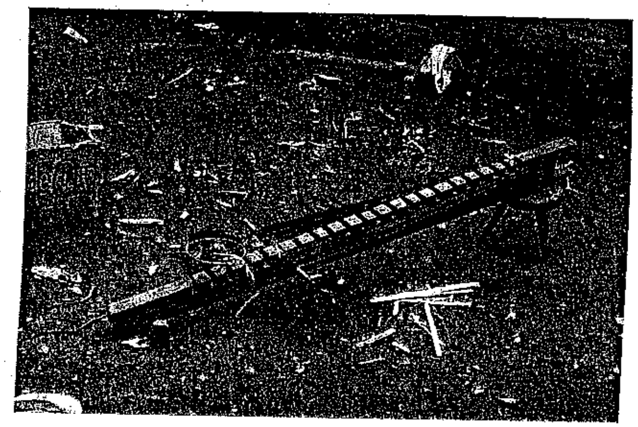

Fig 2.8. Warping frame, or *komen*, which requires mental transformation to visualize how the woven material will appear. A warp has already been wound. The left side of the threads will go to one end of the loom, say the top, while the threads on the right side will go to the other, the bottom.

example, one needs to understand that the left side of the threads in Fig. 2.8 will end up at one end of the loom, for example the top of the loom shown in Fig. 2.7, while the right side of the threads in Fig. 2.8 will end up at the other end of the loom, for example, the bottom of the loom shown in Fig. 2.7. Once this transformation is carried out, either mentally or in practice, one implication is that the resulting piece of cloth will be approximately twice as long as its length on the warping frame, where it is in essence folded in half.

The winding tool that is adapted to younger girls reflects a less advanced stage of cognitive development because it does not require mental transformation (Piaget & Inhelder, 1956). The weaver simply winds the warp in figure eights from top to bottom; the length of the resulting cloth matches the length between the top and bottom sticks. The relationship is one of perceptual matching rather than mental transformation. In contrast, the warping frame requires an ability to perform mental transformations; mental transformations are required to predict what the cloth will look like once it is woven. We created two types of tasks related to weaving: the toy loom tasks (an example is presented in Fig. 2.9) and the warping frame tasks (an example is presented in Fig. 2.10).

It was predicted that children over the age of 6 would be able to perform the mental transformations involved in understanding the warping frame if they had had some experience in weaving. Children with experience in weaving were Zinacantec girls, whereas children with no experience were Zinacantec boys and American children.

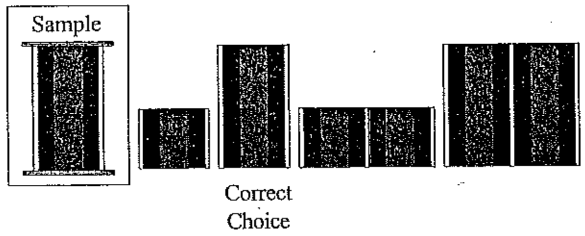

Fig 2.9. An example of a loom with four choices. This is a direct perceptual-matching task. The second choice to the right of the loom is what the warp will look like when woven.

A crossover task was designed to measure transformation abilities cross-culturally as well as to examine domain transfer across the two types of tasks. The crossover task, a more familiar task type in the United States, was referred to as the "knots" tasks, based on work by Piaget and Inhelder (1956). The knots were loops of string ("necklaces") with spools of different-colored thread on them. We turned the first loop of each set into a figure eight, thus, creating a situation that requires mental transformation to predict what the configuration of the spools will be once the knot or figure eight is unlooped. An example is presented in Fig. 2.11.

Participants in Los Angeles and the Zinacantec Maya community of Nabenchauk, ages 4 through 13, were asked to perform match-to-sample tasks of three different types: the toy loom, the warping frame, and the knots tasks.

Zinacantec girls performed significantly better on the warping frame tasks than did the Zinacantec boys or American children of either sex. This pattern of results demonstrates that only direct experience with weaving technology has an impact, not the passive familiarity experienced by Zinacantec

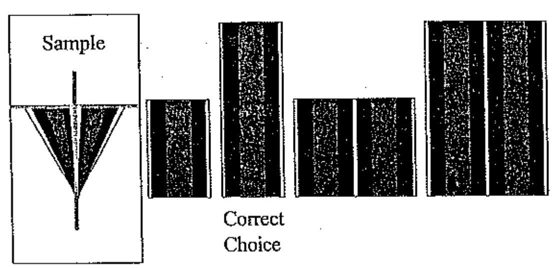

Fig 2.10. An example of a *komen* with four choices. This is a task requiring mental transformation. The correct answer is the second choice to the right of the *komen*.

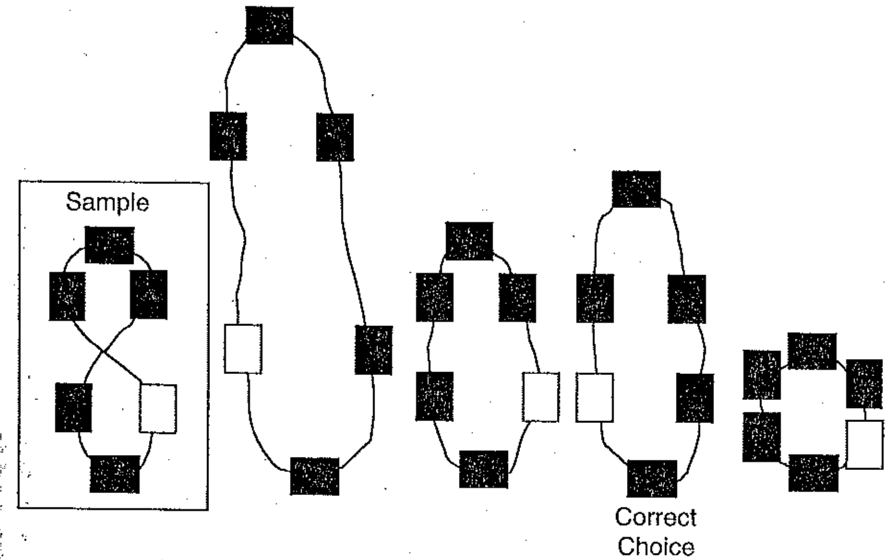

Fig 2.11. An example of a knots task with four choices. This is a task requiring mental transformation. The correct answer is the third choice to the right of the figure eight.

boys who have seen, but not used, the technology. Although children in Los Angeles performed less well on mental transformation in the context of the warping frame problems, they performed better on the knots tasks, a task whose structure was probably more familiar to these schooled children. These results indicate that a particular technology can develop mental operations that are tailored to a particular domain; the operations then take on a domain-specific form. These mental operations, as they are used in the culturally relevant domain, we hypothesize, will then be considered part of a cultural definition of technological intelligence.

At the same time, Zinacantec weaving apprenticeship also respects stages in the development of mental transformation skills. We found that Zinacantec girls begin to wind a warp on a warping frame at the age at which they have the requisite level of cognitive development. Analysis of patterns of children's answers revealed that children were using perceptual matching at the age (less than 6) when they would be winding a warp on a toy loom; they then switched to mental transformation at the age (over 6) when they would be winding a warp on the warping frame. These results indicate that weaving apprenticeship not only develops relevant skills in spatial transformation, it also respects the developmental timetable by which those skills develop.

The Adoption of New Symbolic Tools

The nature of symbolic tools used by a particular group of people also changes over time. Although the backstrap loom, of ancient Maya origin, has remained the same, there are new symbolic tools used in the production of textiles. Specifically, paper patterns designed for embroidery are now being used by the Zinacantecs. Greenfield (1999) labels the paper patterns metarepresentational because they are tools for creating patterns, that is for creating other representations. Whereas there were no metarepresentational tools in Zinacantán up through the 1970s, Zinacantec females began using paper patterns designed for embroidery to weave sometime in the late 1980s. The technology was not indigenous to Zinacantec culture, but rather imported from Mexican culture and adapted to weaving. The use of the cross-stitch patterns for embroidery relies on perceptual matching, as there is a one-to-one relationship between the grid on the paper and what is to be embroidered onto cloth. However, Zinacantec girls began using the paper cross-stitch patterns to weave, a task which required a mental transformation because weaving is not done in squares. The conversion was one square to one warp thread. However, a one-to-one ratio could not be used in the cross-wise or weft thread dimension. Some weavers transformed the length of each square in the pattern to four weft threads. Zinacantec girls had appropriated a new symbolic tool, the printed pattern, and transformed it, as part of the process of cultural appropriation (Saxe, 1999). In so doing, they revealed some skills in mental transformation.

CULTURAL VALUES AND THE USE OF CULTURAL TOOLS

The development of intelligence is influenced by cultural values that apply relatively greater emphasis to technological or social intelligence (Mundy-Castle, 1974). Zinacantec weaving is connected to their ethnotheory of development that implies that a girl will weave when she has enough soul, meaning that she can listen to instruction, follow instructions, do what is needed, and tolerate frustration (Zambrano & Greenfield, 2004). Relatedly, weaving is not valued as a technical skill; rather, it is valued for its social aspects: the social and interactional aspects of the learning process, the social utility of what is woven, and the enhancement of a girl's marriageability by being a skilled weaver. Whereas we have been focusing on the role of weaving in developing particular forms of technological intelligence, the Zinacantecs have traditionally been much more focused on weaving's role in reflecting and developing social and emotional intelligence. This focus on social and emotional intelligence contrasts with American attitudes toward computer technology, where developing technological intelligence is of

primary importance. A video game has, by definition, no external social goal or purpose, whereas in Zinacantán weaving does. In addition, electronic games are often played in an individual or private setting, whereas weaving is generally done in a social setting—the family courtyard. Finally, weaving apprenticeship depends more heavily on interaction with others than does learning how to play an electronic game. When playing a video game, one is also playing with or against virtual, rather than real, people, and, in the more recent multiplayer online games, one is playing with or against real people, but people who are anonymous and disembodied. For all these reasons, video and computer games might foster technological intelligence at the expense of social intelligence. This would be less likely in Zinacantán where weaving is social in function, setting, and mode of apprenticeship, although equally technological in its execution.

CONCLUSIONS

In this chapter we reported the ways in which different technologies develop intelligence on the three cognitive levels of attention, representation, and mental operations. Though our focus was on two specific technologies about which there has been a lot of research, there are many other findings demonstrating the effects of technology on the culturally valued cognitive skills that constitute intelligence. For example, on the level of visual representation, Stigler (1984) showed that expert abacus users develop a mental representation of an abacus and make errors reflecting that representation when asked to perform mental calculations.

Additionally, we discussed the specific tools of computer technology and weaving. The skills developed by those cultural tools are very different ones. Because a culture's technologies determine that culture's view of technological intelligence, then, to the extent that one has different technologies, one is going to have different definitions of technological intelligence. Tools differ across different ecological niches; thus, the forms of intelligence that may develop vary also. For example, the divided attention that is useful in handling video games and the Internet would be anathema to the Zinacantecs, who favor the undivided visual attention skills that are useful in learning to weave.

At the same time, tools and their ecological settings are not constant even within a single cultural context. The pan-human capacity to invent and use tools leads to adaptation of those tools to new cultural places or activities. As the environment changes, the nature and function of tools may change as well. Will new verbal conventions developed in adaptation to the Internet lead to new definitions of verbal intelligence in the United States? Will the use of paper patterns in weaving lead to new definitions of technological intelligence in Zinacantán? We predict that both of these changes will occur. Just as technologies are not static, neither are cultural definitions of technological intelligence; the two, by their very nature, must evolve together.

The movement from subsistence to commerce in Zinacantán has already begun to transform weaving apprenticeship from a socially guided process to one involving more individual experimentation and discovery (Greenfield, 1999; Greenfield, Maynard, & Childs, 2003). Will the accelerating movement from subsistence to commerce in Zinacantán change the emphasis from weaving as a set of social skills to textile production as a set of technological skills with commercial value? On a trip to Nabenchauk just a few weeks before this chapter was completed, Greenfield noted the beginnings of this transition. Not only the nature of technological intelligence but also its relative social importance are both culturally variable and historically contingent.

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