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Cognitive Socialization by Computer Games in Two Cultures: Inductive Discovery or Mastery of an Iconic Code?

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This research is a cross-cultural and experimental examination of computer games as cultural tools of cognitive socialization. It also investigates the cognitive processes involved in mastering computer games. The research took place in two countries, the United States and Italy, which differ in their exposure and attitudes to computer technology. Exposure to computer technology, either over the long term, as a member of a culture, or in the short term of our experimental computer game treatments, was associated with greater skill in decoding scientific–technical information graph-

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ically represented on a computer screen and with a preference for iconic diagrams, rather than the written word, in communicating this information.

Games generally socialize children for the adult roles valued and needed by a particular society (Roberts & Sutton-Smith, 1962). One aspect of such socialization is the provision of cognitive skills required by adult work. Video games have become a mass medium, particularly for children. It is therefore of great interest to know whether these games are providing cognitive socialization for the adult skills required by contemporary society.

One of the most interesting points about video games is that no one tells you the rules in advance. The rules must be figured out by observation, trial and error, and a process of hypothesis testing (Greenfield, 1983, 1984, 1993). Several other researchers have also noted the problem-solving/discovery aspect of video games (Strover, 1984; Turkle, 1984).

In essence, players create a part of a complex, dynamic representational system using a joystick; they must figure out how their representation interacts with screen objects controlled by the computer. The rules go beyond the decoding of meaning for individual icons on the screen. In addition to figuring out what the symbols mean, players must discover how they act.

This process of making observations, formulating hypotheses, and figuring out the rules governing the behavior of a dynamic representation through a trial-and-error process is basically the cognitive process of inductive discovery. It is the process by which individuals learn much about the world, and, at a more formal level, it is the thought process behind scientific thinking and discovery. If video games functioned to train this process, they would have great educational and social importance. They would indeed provide cognitive socialization for the much needed scientific work of contemporary society.

To test this idea, the process of inductive discovery in the course of video game mastery was documented. The ultimate goal was to determine whether video games could function as a method of informal education for the inductive discovery processes so fundamental to the scientific method. Our goal was to investigate whether discovery skills could transfer from an entertaining action video game to a scientific–technical representation. The scientific–technical representation selected for study was an animated computer simulation of the logic of computer circuitry. The study had a cross-cultural aspect as well, involving a comparison between students in Los Angeles and students in Rome, where computer technology is less widespread (Camaioni, Ercolani, Perucchini, & Greenfield, 1990; Sensales & Greenfield, 1991, in press).

COMPUTER GAMES

From the simplicity of Pong, an early video game in which a spot of light moves across an electronic tennis court, action or "arcade-style" video games have evolved to a creative and complex form of entertainment used frequently by today's youth. When video games first became popular and highly visible, many people, including former Surgeon General C. Everett Koop, believed that the time spent playing video games was, from society's point of view, wasted time (Rebellion Against Video, 1983). Malone (1981), Strover (1984), Turkle (1984), Greenfield (1983, 1984), and Loftus and Loftus (1983) disagreed.

Malone (1981), on the basis of the first experimental research on video games, concluded that the informational features of video games that make them intrinsically motivating should be applied to instructional environments in general. Turkle (1984) stated, "There is nothing mindless about mastering a video game. The games demand skills that are complex and differentiated. Some of them begin to constitute a socialization into the computer culture" (p. 67). Strover (1984) also emphasized this latter point.

Greenfield (1983, 1984), in trying to promote more research on effects of video game play, hypothesized that playing arcade-style action games could develop skills in inductive discovery, iconic object constancy across visual transformations (required to recognize Pac-Man as both a whole yellow circle and minus a wedge-shaped piece), parallel processing (exemplified by the necessity to take in information from more than one screen location simultaneously during a video game), and skills in spatial representation (e.g., interpreting a two-dimensional display in the third dimension and coordinating visual information coming from multiple perspectives). Loftus and Loftus (1983), in an attempt to explain the psychology of video games, proposed video games as potential training aids for cognitive and perceptual disorders, for treating eye dysfunctions, and for developing memory skills.

Indeed, the U.S. Army and Air Force experimented with arcade-style games as training devices for skills such as rapid information processing and "multiplex" thinking (i.e., parallel processing; Trachtman, 1981). That video games do indeed involve complex cognitive skills was demonstrated by Rabbit, Banerji, and Szymanski (1989), who found that IQ, as measured by a standardized test, was highly predictive both of rate of learning and practiced performance on an action video game.

Low-cost microcomputers brought action video games into many American households; a 1982 report showed that 1 in every 10 households in the U.S. owned a home video game system (Perry, Truxal, & Wallach, 1982). A 1985–1986 survey in southern California found that 94% of all 10-year-old children had played some video games (Rushbrook, 1986). As of December 1988, the Nintendo phenomenon brought video game sets into 14 million homes in the U.S. The numbers have continued to increase: In 1992, Nintendo figures indicated that approximately 44% of all U.S. households had video game systems. Despite such wide acceptance of video games by the population, little empirical research has been conducted either on the cognitive effects of video games or the cognitive processes that the games engage.

It is important to distinguish noneducational action games, the focus of our study, from games with educational content. Games with varying graphic and action elements have been designed to teach a variety of educational subjects, including logic (e.g., Bank Street College Project in Science and Mathematics, 1984; Burton & Brown, 1979; Char, 1983; Dugdale & Kibbey, 1982; Levin, 1981; Piestrup, 1982; Robinett, 1982; Wood, 1980), and some have also been the subject of empirical research on cognitive processes and educational effects (Burbules & Reese, 1984; Burton & Brown, 1979; Char, 1983; Levin, 1981; Piestrup, 1982; Stein & Linn, 1985; Wood, 1980). Research and development have also focused on the use of arcade-style, action game formats to teach academic subjects such as mathematics (e.g., Chaffin, 1983; Chaffin, Maxwell, & Thompson, 1982; Mick, Konneman, O'Farrell, & Isaacs, 1983). However, the focus has been on the learning of particular academic skills specific to the *content* of a given game.

In contrast, the focus of our research is the acquisition of a general cognitive strategy inherent in the *format* of the whole class of noneducational action video games. To use McLuhan's (1964) terminology, we were interested in the unintentional cognitive "message" of a new medium: the recreational video game as a means of informal cognitive education (Greenfield & Lave, 1982). Our focus is on the popular action games, rather than on the adventure games that allow time for reflective decision making.

At the outset, the only study on the subject (and the inspiration for our research) was conducted by Gagnon (1985), who found positive effects of arcade-style video games on standardized paper-and-pencil tests of spatial ability after 5 hr of play on two games. Although men were initially better players than women, women improved during the 5 hr of game play to achieve game scores equal to those of their male counterparts, and they simultaneously improved their performance in spatial skill. Gagnon's results also showed that experienced video game players were better than inexperienced video game players on a number of spatial skills at the outset of the experiment.

In contrast to the cognitive effects orientation of Gagnon's (1985) research, Craig (1987) and Roberts and his colleagues (Roberts, Aman, & Canfield, 1989; Roberts, Brown, Wiebke, & Haith, 1991) ; Roberts, Wiebke, Valaer, Matthias, & Ondrejko, in press) recently explored the cognitive processes involved in the mastery of action video games. Craig found that the progression from novice to expert in the course of mastering Passport to Paris, an action game requiring logical problem solving, involved developing systematic organization, sensitivity to efficient use of constrained resources (time, money), and evaluation and revision. Roberts (1989; described in Roberts et al., 1991) found developmental differences in the efficiency of learning strategies: 12- and 20-year-olds showed improvement with practice in a version of the video game Asteroids, whereas 4- and 7-year-olds did not. Roberts and Ondrejko and Roberts, Brown, et al. found that expert video game players used anticipatory eye movements that helped calibrate future action.

Lancy and his colleagues experimented with the cognitive aspects of two nonaction genres of computer games—fantasy adventure games and interactive fiction—as well as with the cognitive effects of action video games (Forsyth & Lancy, 1987; Hayes, Lancy, & Evans, 1985; Lancy, 1987; Lancy, Cohen, Evans, Levine, & Nevin, 1985; Lancy & Hayes, 1988). An adventure game, Winnie the Pooh, led to the acquisition of game-related spatial knowledge (Forsyth, 1986; Forsyth & Lancy, 1987), whereas interactive fiction, requiring a great deal of reading, was enjoyed by reluctant readers (Lancy, 1987; Lancy & Hayes, 1988).

In terms of transfer to nongame cognitive tasks, the effects of two action games, Star Raiders and Missile Commanders, on a Piagetian-flavored battery of tests (Lancy et al., 1985) were ambiguous because of the nature of the design. The effects of the two games did not differ. However, without a no-treatment control group, it is impossible to know whether both or neither of the games produced a transfer effect. Issues of video game transfer with adults were explored by Frederiksen and White (1989). Their study was part of a large research program that focused on the learning processes and training conditions by which mastery of a complex action video game is achieved (Donchin, Fabiani, & Sanders, 1989).

INDUCTIVE DISCOVERY PROCESSES

Action video games have the interesting property that no one tells the player the rules in advance. The player must figure these rules out by observation, trial and error, and hypothesis testing. Essentially, this describes a process of inductive discovery: The player receives input of specific data on the video screen and must formulate (not necessarily on a verbal level) general rules, patterns, and strategies in order to become a skilled player. This process must include perceptual observation as well as learning action contingencies.

Mastery of other more traditional games, such as chess, involve inducing high-level strategies, but in these games the player is told the basic rules (e.g., the permitted moves for each piece) in advance. This is not the case for video games. Home games for the computer often have no printed instructions, and arcade machines have very minimal ones. In addition to the fact that most players never read whatever instructions exist (according to an informal survey of a few hundred UCLA students and Lancy, 1987), each video game has a huge number of rule-bound patterns programmed into it that are not to be found in the printed instructions on the machine. Talking about Pac-Man, which marked the beginning of the arcade game craze in the U.S., a young player stated, "At first it was thought to be incredibly hard. Then people realized it wasn't random and figured out the patterns" (M. Greenfield, personal communication, 1983).

Strover (1984) concluded that "in contrast to other games . . . video games involve discovering the rules rather than playing by those that are established *a prior*" (p. 17). For this reason, Turkle (1984) felt that the development of game strategy therefore involved "achieving a meeting of the mind with the program" (p. 68). Yet how are the rules discovered? How does this meeting of the minds come about? David Sudnow presented us with a first-person account in *Pilgrim in the Microworld* (1983) and Myers (1984) offered ethnographic evidence, but no experimental research on these questions currently exists. Our study was designed to fill the gap.

Two interrelated goals of our study were to establish the existence and explore the nature of this inductive process of rule discovery. Our major technique for establishing the existence of inductive processing was to document the gradual acquisition of rule knowledge through the repeated administration of questionnaires at various stages of video game play in one of our experimental conditions (the questions group, to be described later).

The process of inductive discovery as studied in information processing experiments (the earliest example being Bruner, Goodnow, & Austin, 1956) and modeled in artificial intelligence (e.g., Holland, Holyoak, Nisbett, & Thagard, 1986; Salzberg, 1985) has two major components: (1) a purely inductive component, in which the person goes from the specific to the general; and (2) a more deductive component, in which the generalizations from the first component become hypotheses to be tested with specific data (cf. Peirce, 1931, cited in Deacon, 1976). The results of such tests then confirm the hypotheses or generate new ones, and there is another cycle of the process. As Holland et al. (1986) pointed out, the initial observations never occur in a vacuum but are always guided by prior knowledge. From this perspective, the cycle in a given situation actually begins with a deductive component based on the application of general knowledge acquired in previously encountered situations.

We thought that this cycle of deductive and inductive thought processes would apply to video games where prior experience would guide initial hypotheses, which then would be tested by actual play. Because play is rapid and feedback instantaneous, many cycles of hypothesis–trial–feedback–new hypothesis could occur in a relatively short period of time. For inexperienced players or novel aspects of the game, the cycle would start with an inductive rather than deductive component.

In terms of induction tasks used in classic experimental studies (Pellegrino, 1985), action video games are most similar to series completion tasks, where one must induce repetitive patterns from one or a few examples. However, a major difference between any experimental test of induction and a video game is that the former uses static stimuli extended in space whereas a video game involves dynamic stimuli extended in both space and time. Although the nature of the rules in a video game could be precisely specified by analyzing the computer program behind the game, from the player's point of view there are a number of alternative formulations of the rules and so the rules may appear more imprecise than in an experimental test of induction. The rules of a video game are generally more complex as well.

As part of our exploration of the nature of inductive discovery processes in video game mastery, we wanted to separate the role of the inductive and deductive components of the discovery process. For this purpose, we created two specific experimental groups. In one, the subjects were free to use any and all cognitive processes as they moved toward game mastery in $2\frac{1}{2}$ hr of play. (This was the play group, to be described in more detail later.) In the other, we provided a detailed and specific basis for initial deduction by demonstrating the game, via slides and videotape, along with verbal commentary describing all rules, patterns, and some game-playing strategies. It was thought that this group (originally labeled the rule-instructed group) would learn how to use these rules in a fairly deductive way, moving from the generalizations provided in our instructions (plus any prior knowledge) to specific applications in the game situation. We therefore thought that the balance between induction and deduction would lie more toward deduction for the rule-instructed group.

The rule-instructed group was also relevant to the question of how much video game expertise is acquired independently and how much can be acquired through watching and talking to other people. In essence, subjects in the rule-instructed group were given the opportunity to watch an expert play and receive verbal instruction.

Another aspect of the experimental design specifically assessed the role of prior knowledge and experience in the inductive process occurring during the mastery of a particular game. By comparing novice and experienced players, we were able to investigate the deductive component by which previous experience is applied to the acquisition of knowledge in a new situation.

A third major goal of our study was to demonstrate that arcade-style video games train inductive discovery skills that transfer to other domains of clear social importance. Because inductive discovery is the heart of scientific thinking and technical problem solving, as classically described, we chose this domain to examine transfer. Hence, we developed a test of inductive discovery in which the subject had to make generalizations concerning the logic of electronic circuitry from viewing schematic, animated demonstrations of circuits on a computer screen. Experimental groups received this test before and after playing an arcade-style video game for $2\frac{1}{2}$ hr. Improvement from pre- to posttest (in comparison with the performance of control subjects) was our measure of transfer of inductive discovery processes.

The nature of inductive discovery processes required in the game and in the pre- and posttests was thought to be similar in several respects: In both cases the subject had to figure out rules governing the operation of computer-generated moving visual stimuli, and the context provided complete information with no extraneous events to confuse the learner. In this respect, the cognitive requirements of the tasks were probably closer to technical problem solving than to science, where the relevant information is usually open-ended and noise in the system is the rule.

One must also note that the test of scientific–technical discovery involved a representation of computer circuitry rather than the circuits themselves. However, scientists and technicians (e.g., medical doctors) increasingly deal with representations of physical data rather than with the data themselves. Ochs, Jacoby, & Gonzales (1994), for example, studied the communication processes that go on in a physics laboratory in which all data are read from a screen or dial and the primary phenomena remain invisible to the scientists. Consequently, the application of inductive discovery processes to computer representations of scientific or technical data will become increasingly important in the conduct of science.

The inclusion of more and less experienced players in the study served to test the ecological validity of our conclusions regarding video games as training devices for more general inductive discovery skills. Our hypothesis was that the video game experience in the real world possessed by experienced players would give them generalizable skill in inductive discovery processes—skill that would then transfer to scientific–technical discovery processes as measured by our screen-based test. This skill was hypothesized to result in higher scores on our pretest of scientific–technical discovery in experienced, as opposed to novice, video game players.

THE CROSS-CULTURAL COMPONENT

A problem of experimental design arose in the U.S. It was impossible to design a pure experiment to study the impact of video games because the population had already been universally exposed to the games, at least to some degree. The opportunity to extend our experiment to Italy meant an opportunity to expose subjects experimentally to video games for the very first time and, more generally, to have a population of more novices available. Indeed, Italy provided a setting in which computer technology was less diffused among the general population and where attitudes toward computers differed from those in the U.S. (Sensales & Greenfield, 1991, in press). Perhaps most important for present purposes, Italian university students have significantly more negative attitudes toward video games than do students in the U.S. (Sensales & Greenfield, 1991, in press). The addition of the Italian component therefore meant that we could assess the impact of being socialized in cultures with different levels of experience and comfort with computer technology.

Because the Italian component of the study was run after the American component, it also provided an opportunity to extend the study by adding conditions to the experiment. Two more control conditions were added: (1) a computer memory game condition, which provided *noninductive* computer game experience; and (2) a mechanical memory game condition, which provided exactly the same game experience without the computer medium.

METHOD

Subjects

Our sample was composed of 206 psychology students in Los Angeles and Rome. Table 1 shows the breakdown of the sample according to the background variables that were thought to relate to computer and video game exposure: culture, gender, and video game experience.

Subjects were considered experienced video game players if they scored 5,500 or better on a screening test of Pac-Man or reported having played more than 100 video games up to that time. These two criteria were used because we considered both practice and skill to be components of video game experience. The use of alternative criteria was especially important in Rome where Pac-Man was not nearly as widespread as it was in the U.S. In Rome, the skills of a relatively experienced player could have been underestimated from the Pac-Man test alone.

It is clear from Table 1 that most experienced players were men and most novices were women in both cultures. Chi-square tests indicated that the association between gender and video game experience was highly significant in both Rome and Los Angeles, ($\chi^2 = 13.895$, $p < .01$; $\chi^2 = 6.800$, $p < .01$, respectively. Whereas gender was not an original interest in carrying out the research, it was not possible to ignore its influence in analyzing the results.

Of the 206 subjects, 200 completed the experiment through the posttest. This subset of 200 therefore constituted the sample for assessing the experimental effects.

Design, Materials, and Procedure

The research basically used a pretest–postest design, with one of six conditions inserted in between.

TABLE 1
Description of Sample

	Experienced Video Game Players	Novice Video Game Players
Rome[a]		
Male	20	26
Female	10	65
Los Angeles[b]		
Male	17	31
Female	4	33

Note. N = psychology students.
[a]*M* age = 21 years. [b]*M* age = 19 years.

Conditions. Four conditions were initially run in Los Angeles. When the study was subsequently extended to Rome, two more control conditions were added (Camaioni et al., 1990).

Three of the original four conditions involved playing a relatively nonviolent video game, Evolution, for 2½ hr on an Apple II computer. Game play was spread over three sessions with two 5-min breaks in each session. Evolution consisted of six diverse levels of game play. Each level comprised a new set of rules and patterns to discover.

In one condition (play only), subjects simply practiced the game. In a second condition (game demonstration and instructions followed by play), subjects were shown the game via a lecture illustrated with slides of the game screens and a video recording of the computer screen during expert play before the game practice period began; the purpose of this condition was to see whether a more deductive approach to learning a video game would produce the same result. In the third condition (play plus questions), subjects filled out a questionnaire during each of the two 5-min breaks and at the end of each session. Subjects were allowed to finish the current game before each break. The questionnaire was designed to assess the development of inductively based game knowledge. The fourth condition was a no-treatment control group.

In Rome, two additional control conditions were added. The first was a computer memory game designed to provide computer experience without the discovery component. The game, resembling the traditional game of Concentration, was much simpler than Evolution and was explained in advance.

The second control condition, the mechanical memory game, held the content of activity constant while varying its medium; it presented the same game in a mechanical medium.

Within a given level of video game experience, subjects were randomly assigned to conditions in each city. There were two exceptions to random assignment: In the U.S., the group of subjects who were presented with game rules before playing the game for 2½ hr were added after the other groups were run as an additional control for inductive experience and consisted entirely of novices. This additional group was drawn from the same source (introductory psychology students) as the other Los Angeles groups; the students enrolled in the course the previous quarter. In Rome, because of a shortage of experienced players, the memory groups consisted entirely of novice players.

Pretest–Posttest of Simulated Scientific–Technical Discovery. We wanted to design a test that would involve forming generalized rules about dynamic processes in the domain of science, just as video games involve generalized patterns of dynamic processes in the domain of fantasy. For this test several dynamic video displays from Rocky's Boots (Robinett, 1982), an educational video game designed to teach the logic of computer circuitry, were used as stimulus material. Although it is hard to get across the nature of a dynamic color demonstration with

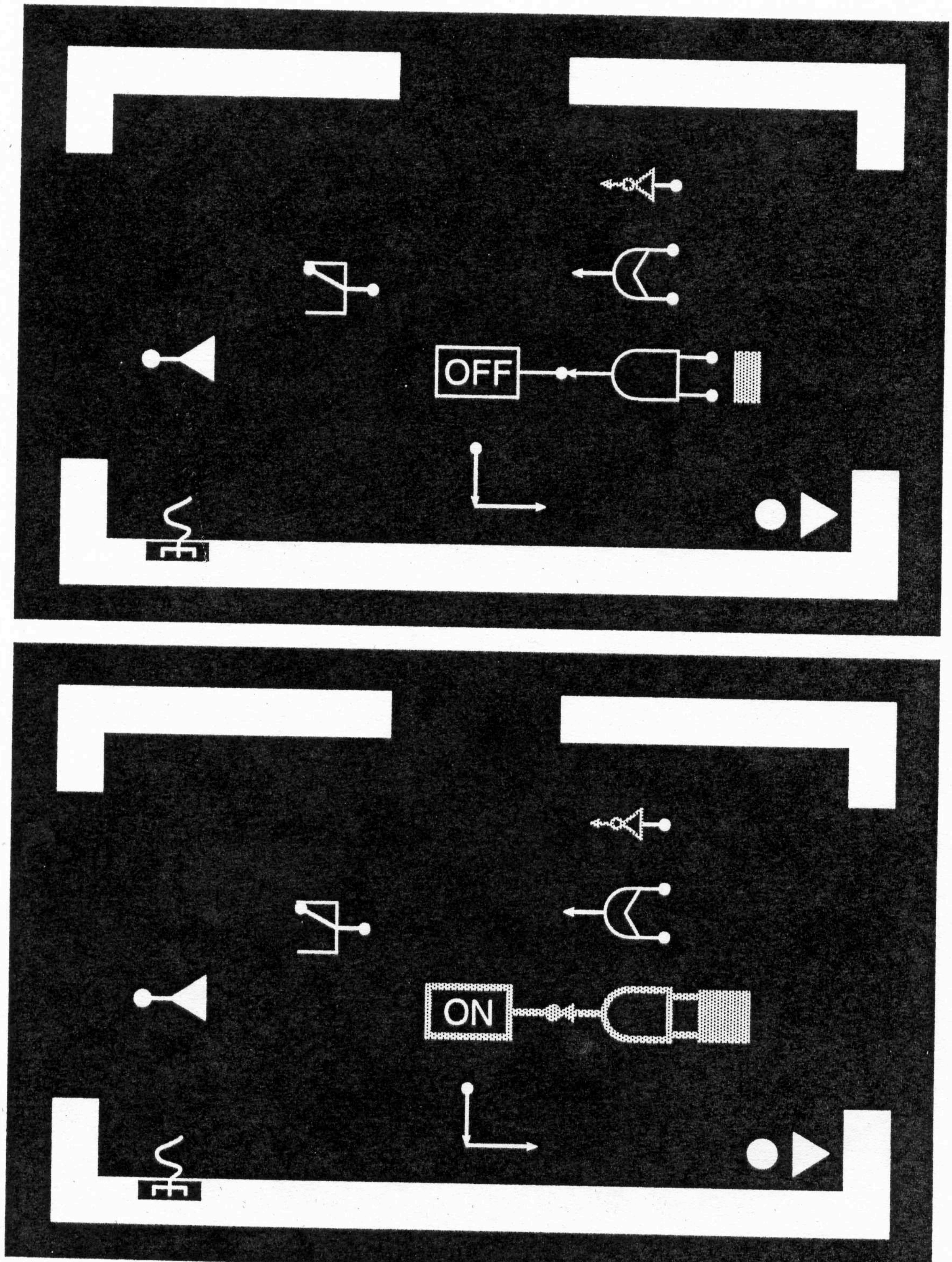


Figure 1. Two screens from the pretest–posttest of scientific–technical discovery. Shaded areas, which were orange in the actual displays, represent the flow of power.

static black-and-white visuals, Figure 1 gives an example of what the subjects saw.

The pair of pictures in the illustration show a sequence in the demonstration of a circuit. It represents the activation of an on/off indicator (middle element in both screens). The shaded quadrilateral in each screen represents a power source.

The lollipop-shaped protuberances are input locations. The pair of screens in Figure 1 shows the power source near a working *and-gate* attached to the on/off indicator. Electricity flows through an *and-gate* when the power source touches both its inputs, as in the bottom screen (shading indicates the flow of power). In the bottom screen, the *and-gate* has been activated in this way, turning the on/off indicator from "off" (top screen) to "on."

In addition to the concepts illustrated in Figure 1, displays exemplified concepts such as *not-gates* and *or-gates*. A *not-gate* (shown at the top right of both screens in Figure 1) is activated when there is not a power source touching the input; the power source deactivates a *not-gate*. An *or-gate* (shown under the not-gate in both screens of Figure 1) activates when the power source touches either one or the other (or both) of its two inputs. Other elements can be made to function if electricity flows through their input end; for example, the bell shown to the left of the *or* element in Figure 1 "rings" when a power source touches its input end. The bell was used in a number of circuit demonstrations. Although many elements were simultaneously on the screen, as Figure 1 shows, the relevant ones for a particular demonstration could be discerned because they were in motion or were involved in some sort of change of state.

The experimenter presented these schematic circuit diagrams on a color video monitor. Subjects were not told that the diagrams they were seeing represented circuits, nor anything else about what they were seeing. They merely were asked to watch carefully and try to figure out what was going on, so that they could answer questions about it afterward.

It is important to note that from the subjects' point of view, the pretest and posttest were in no way games. Although the materials were originally developed for a learning game, they were presented simply as screen displays in our experiment. That is, subjects did not "play": They were not given a joystick or keyboard and they therefore had no control over the displays. They merely watched about 5 min of demonstrations of circuits in operation on the video screen. Thus, at the very least, any transfer involved generalizing discovery strategies acquired in a game situation to a nongame context.

Subjects were shown at least three examples of every element tested so that they could observe the rules that governed their use. Immediately following each group of demonstrations, subjects answered questions about the displays on a paper-and-pencil test. No displays were visible while they were answering the questions. A sample page of questions is presented in Figure 2.

The pre- and posttest were developed to examine skill in inducing generalizations from a few specific examples of each circuit element. All but one of the test questions required the generalization of principles abstracted from the displays to new combinations of elements not shown in the demonstrations. In this way, the possibility that the questions could be answered by simply remembering the displays was eliminated. Instead, some level of inductive generalization was required. Some degree of generalization was also required because subjects had to go from dynamic color displays as shown on a video screen to interpreting

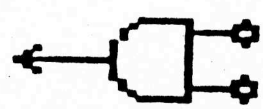
NAME:

DATE: FORM B

What does this represent? 

What is its function?

How would you get the orange color to flow through the following game elements?



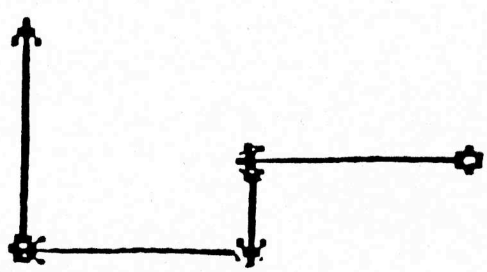


Figure 2. Sample questions from Form B of the pretest–posttest of scientific–technical discovery. The rectangle represents the power source. Both the power source and the flow of power were represented by orange in the screen displays of the pre- and posttest.

primitive black-and-white drawings in a different medium, print, on the test. In addition, the very use of words to answer some of the questions involved forming generalizations from specific visual examples, for as Vygotsky (1962) pointed out, every word is ipso facto a generalization that transcends particular instances. Or, to use different terminology, subjects had to move from the procedural level of the game to the conceptual level of the test.

Two alternate forms of this paper-and-pencil test were developed so that subjects would receive different questions on pre- and posttests. One of the two forms of the test was assigned randomly to each subject, and the alternate form of the test was used during the subsequent testing session, thus counterbalancing for any effect of form of test. Although the questions on each form of the test were different, the video demonstrations were the same. Because the Italian data revealed that the forms were not of equal difficulty (Camaioni et al., 1990), order of forms was used as an independent variable in the relevant analyses of variance (ANOVAs) to reduce variance accruing from this error factor.

Subjects in the experimental conditions were pretested about a week before their experimental treatment. They were posttested between 1 and 3 days after completing the treatment conditions. No-treatment control subjects were pre- and posttested at the same time as the experimental subjects, so that they had the same amount of time between pre- and posttest.

The test was administered to subjects in groups of two to four. There were four blocks of demonstrations, each followed by a block of questions on a printed questionnaire.

The test had a total of 17 questions. Subjects were free to answer the questions either with a short answer and/or by drawing a small diagram.

Coding and Recording of Data

Two points were awarded for each correct answer on the pre- and posttests, making 34 the total possible score. One point was awarded for answers that showed some understanding of the concept being tested but were not totally correct. Zero points were awarded, of course, for answers that indicated no understanding of the concept being tested and for questions left blank or marked, "Don't know."

Only certain questions had partially correct answers. For example, in answer to the question "How would you get the orange color to flow through an *or-gate?*", the subject could get one point by noting that the power source had to touch one or the other of the inputs, and a second point by noting that the power source could also touch both inputs.

In the U.S., interrater reliability was .94, based on a Pearson correlation coefficient calculated from a subset of 22 subjects (both pretest and posttest).

Each answer was also scored for the mode of representation used to present the answer: 1 = verbal representation, 2 = answers that mixed verbal and iconic representation, and 3 = iconic representation. A percentage score of iconic representation was then calculated based on the first eight items, which were considered most diagnostic for mode of representation. Examples of the different modes of representation used to answer one question are shown in Figure 3.

In the U.S., interrater reliability was .95, based on a Pearson correlation coefficient calculated from the same subset of subjects. Coding was calibrated in Rome and Los Angeles through communication of scoring rules and discussion of scoring decisions. In addition, calibrated scoring was facilitated by a visit of the senior author to Rome to collaborate on data analysis.

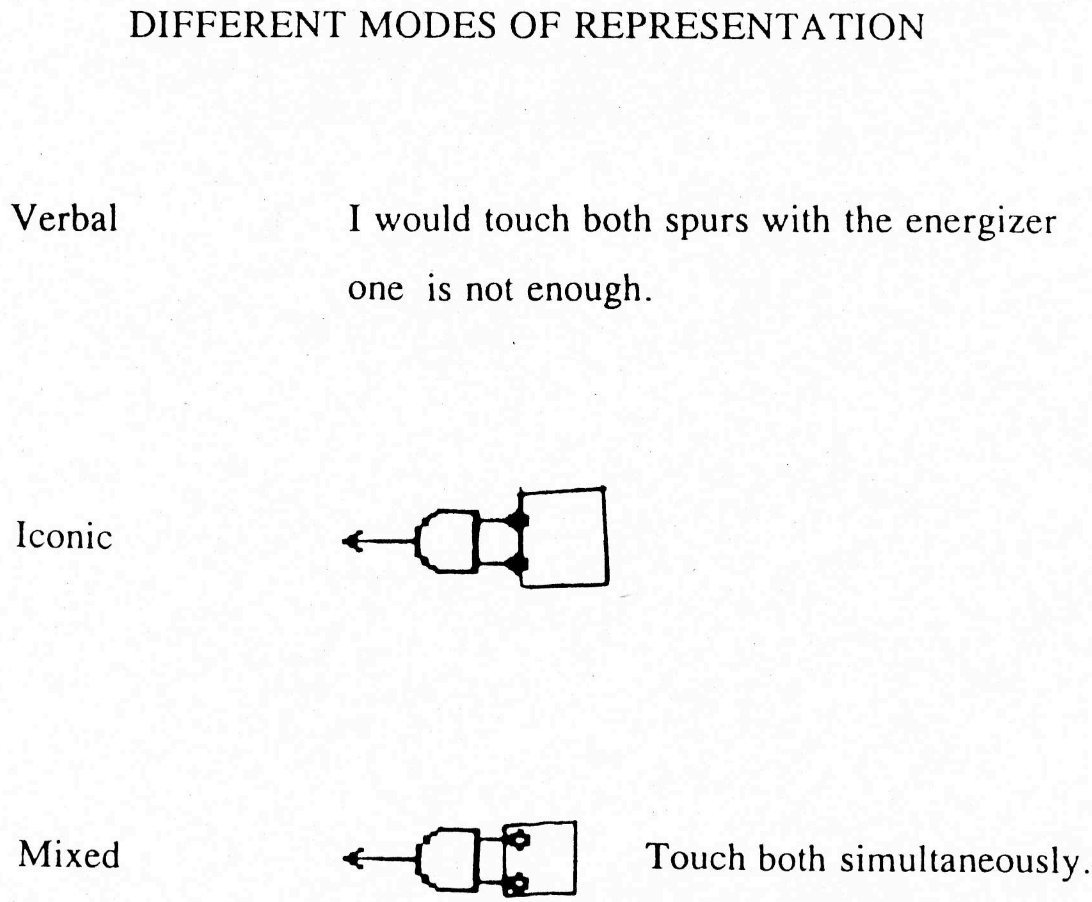


Figure 3. Different modes of representation used to answer pretest–posttest questions. The question being answered is shown in Figure 2.

In Los Angeles, subjects kept track of their Evolution game scores on a log sheet. Although inaccuracies were possible, there were no reward contingencies within the experiment that would provide a motivation to lie about scores; any inaccuracies should therefore have been random. In Rome, the experimenters corroborated subjects' Evolution game scores. The average of the first three Evolution game scores was calculated as a baseline measure, and the average of the best three Evolution scores was calculated as a measure of optimal performance.

RESULTS

A 2 (Experienced vs. Novice) × 2 (United States vs. Italy) × 2 (Male vs. Female) ANOVA explored the relationship of indices of past video game experience to pretest scores on the test of scientific–technical discovery skills. The analysis yielded main effects of video game experience, $F(1, 198) = 6.395$, $p < .025$; culture, $F(1, 198) = 10.477$, $p < .005$; and gender, $F(1, 198) = 12.034$, $p < .005$. There were no significant interactions. In line with their relative exposure to video games, experienced players, Americans, and males performed significantly better on the screen-based test of scientific–technical

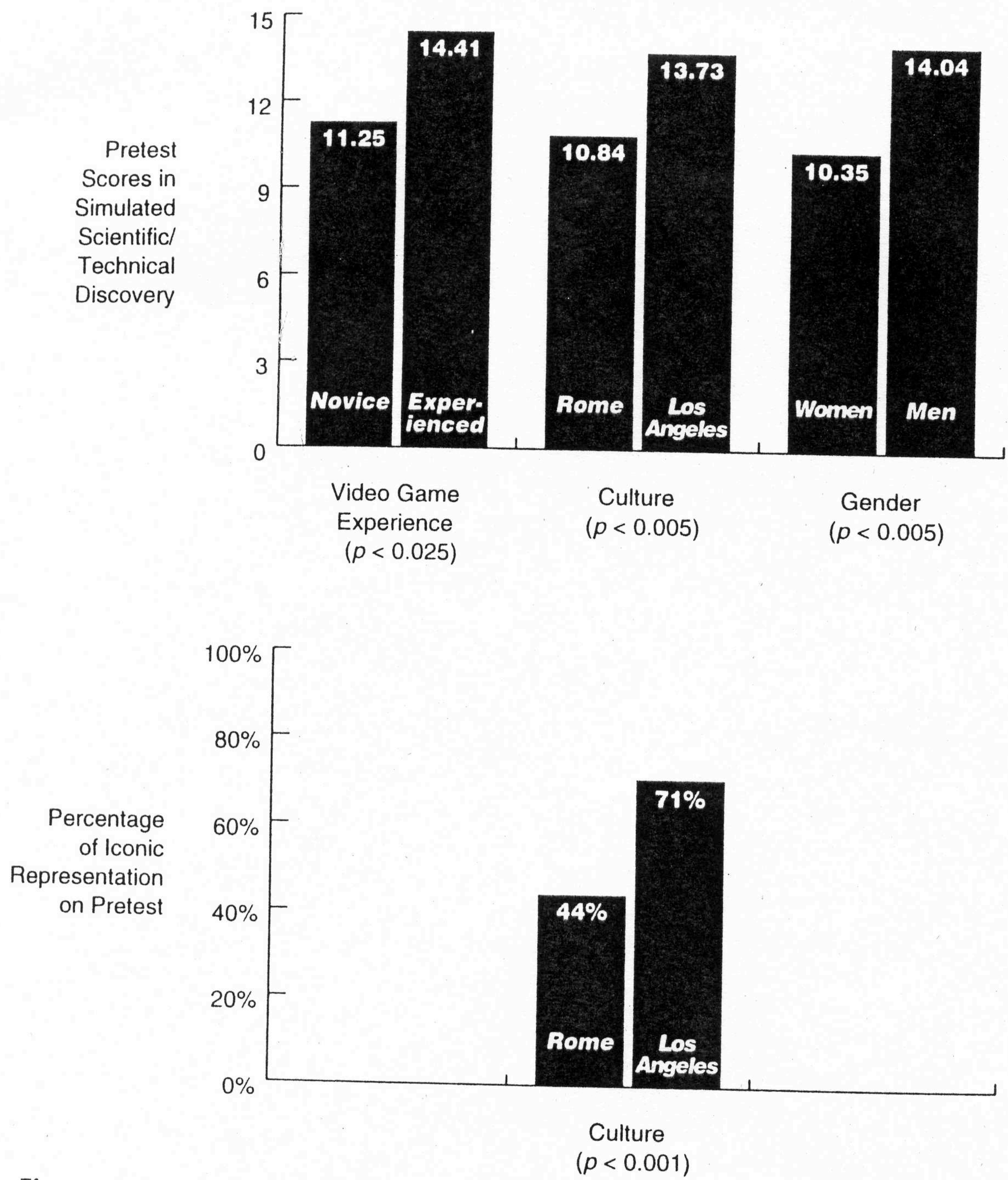


Figure 4. Significant long-term influences on simulated scientific–technical discovery and mode of representation.

discovery than did novices, Italians, and females, respectively (see Figure 4). In addition, a parallel ANOVA was done, using iconic versus verbal representation of pretest answers as the dependent variable. The analysis yielded a main effect of culture, $F(1, 198) = 176.463$, $p < .001$, showing that Americans preferred to use diagrams whereas Italians preferred to use words in formulating answers to the test. These results are shown in Figure 4. Again, there were no significant interaction effects.

The influence of culture was not surprising; as hoped, there was a significant subgroup ($n = 17$) of Italian novices who never played a video game before the experiment. In the U.S., as anticipated, this phenomenon was rare ($n = 2$). Probably because of this significant difference in group composition, $\chi^2 = 8.158$, $p < .005$, Italian novices attained significantly lower maximum video game scores during the experimental treatments than did novices in the U.S., $t = 8.11$, $p < .001$, although there was no difference in the practiced performance of experienced players in the two countries.

Consistent with the results presented up to now, previous game experience, culture, and gender were highly related to video game performance in the course of the experiment. A 2 × 2 × 2 ANOVA showed that the best video game scores were significantly affected by previous video game experience, $F(1, 169) = 97.829$, $p < .001$; culture, $F(1, 169) = 25.944$, $p < .001$; and gender, $F(1, 169) = 17.146$, $p < .001$. Significantly higher Evolution scores were attained by more experienced players, by Americans, and by males. There was also an interaction between experience and culture, $F(1, 169) = 18.948$, $p < .001$; its nature was elucidated by the t test described in the preceeding paragraph.

These factors affected initial scores as well as ultimate levels of game play. A second 2 × 2 × 2 ANOVA using the same variables showed that players' first three video game scores were also affected by video game experience, $F(1, 168) = 78.257$, $p < .001$; culture, $F(1, 168) = 124.245$, $p < .001$; and gender, $F(1, 168) = 11.622$, $p < .001$, just as their best three scores were. Significantly higher initial game scores were attained by more experienced players, by Americans, and by males. Again, there was a significant interaction between experience and culture, $F(1, 168) = 15.366$, $p < .001$. Novices in Italy initially scored lower on Evolution than did novices in the U.S., $t = 9.81$, $p < .001$, although there was no difference between initial scores for experienced players in the two countries. Thus experienced players, Americans, and males seemed to start playing Evolution with some combination of better initial hypotheses and better manual skills.

The effectiveness of actual discovery processes during $2\frac{1}{2}$ hr of game play did not seem to differ very much; for example, men and women each came close to quintupling their video game scores from their first games to their best games, as did both novices and more experienced players. Gender, experience, and culture seemed to affect initial game knowledge and skills more than they affected the cognitive processes of discovery.

The results indicating long-term developmental influences of video game and related central experiences on discovery skills were confirmed by the experimental results. An ANOVA using pretest and posttest as a repeated measure, with treatment group, video game experience, and order of test forms as between-subject variables revealed a significant two-way interaction between treatment group and pretest–posttest change, $F(5, 180) = 2.46$, $p < .05$, as well as a significant three-way interaction between treatment group, video game experi-

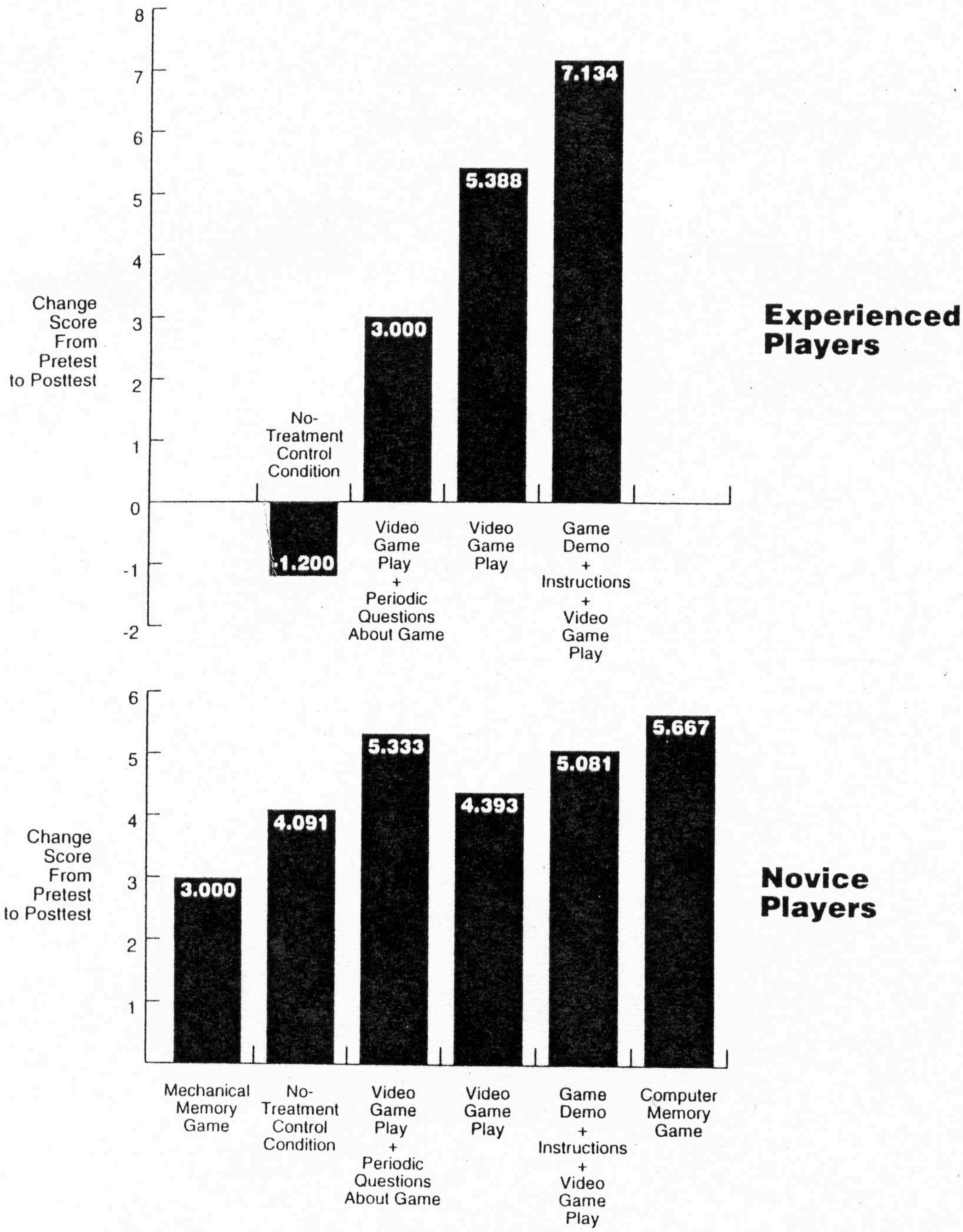


Figure 5. Pretest–posttest change in understanding a scientific–technical simulation: experienced and novice players under different experimental conditions.

ence, and pretest–posttest change, $F(3, 180) = 3.10$, $p < .05$. This interaction is graphed in Figure 5.

One import of the three-way interaction is to show that the transfer performance of experienced players benefits significantly more than that of novice players from game demonstrations and instructions before starting to play the game (Tukey test, $p < .05$). Apparently, off-line video game instructions have more effect if the recipient has more on-line experience with the games. In contrast, periodic questions during game play benefit novice transfer performance significantly more than they benefit that of experienced players (Tukey test, $p < .05$).

Further analysis of the three-way interaction showed that experimental effects were more pronounced for the experienced than the novice video game players. The Tukey test revealed that posttest improvement in comprehending scientific–technical material on the screen differed significantly for experienced players under every experimental condition to which they were exposed, $p < .05$. This was not the case for novice players. (This difference is manifest descriptively in the difference between the slopes of the bars in the two graphs in Figure 5.)

Taken together, the graphs indicate that the video game and computer memory groups improved the most from pretest to posttest, whereas two control groups (no-treatment, mechanical memory) improved the least. This major feature of the three-way interaction is preserved in the significant two-way interaction between treatment group and pretest–posttest change: According to a post-hoc Tukey test, each of the computer and video game conditions produced significantly greater pretest–posttest improvement than did either the mechanical memory or no-play groups, $p < .05$.

The pattern of results indicates that there is meaningful transfer from video and computer game experience to informal scientific–technical discovery in a screen-based task, but that, contrary to prediction, the degree of induction required makes no difference to the amount of transfer. Of all the conditions, the video and slide demonstration with verbal instructions before video game play produced the most improvement among experienced players (Tukey test, $p < .05$); yet it is the least inductive condition to which this group was exposed. For the novices, the computer memory game, the least inductive condition of all, stimulated pretest–posttest change that was significantly greater (Tukey test, $p < .05$) than the change produced by simply practicing a video game, the most inductive condition. These results went contrary to the original prediction.

Most interesting was the fact that the computer memory group improved in their understanding of the scientific–technical simulation significantly more than did the mechanical memory group (Tukey test, $p < .05$). The computer medium made a difference, even though game content was identical in the two conditions. Practice with a particular medium of presentation and representation contributed more to discovering the meaning of the animated scientific–technical simulation than did the opportunity to exercise inductive discovery processes.

Although inductive processes per se did not appear responsible for the transfer effect, periodic questioning about game knowledge in the game play plus questions group provided evidence that game experience nonetheless led to discovery of game knowledge. Figure 6 shows the gradual and significant increase in game knowledge from after 15 min of play to after about $2\frac{1}{4}$ hr of play that took place in the questions group in Rome, $F(5, 70) = 14.52$, $p < .001$. A Tukey test for multiple comparisons indicated significant, $p < .05$, improvement in the pre-

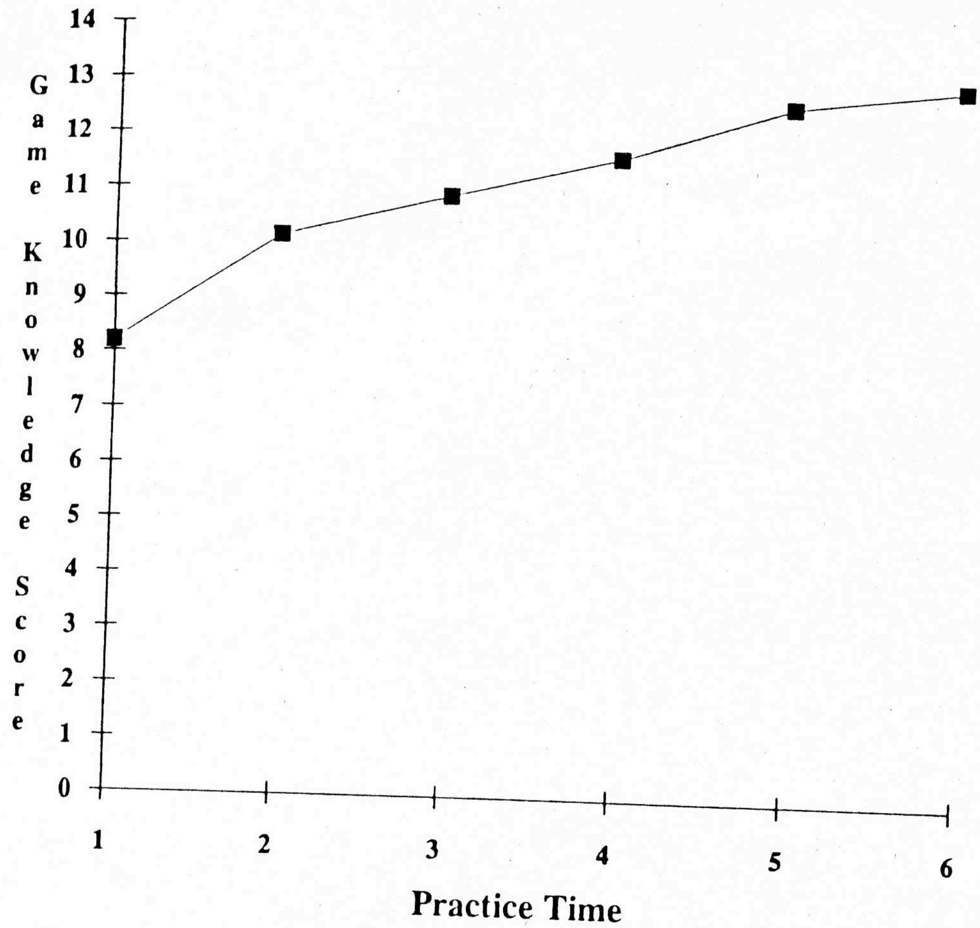


Figure 6. Induction of game knowledge through video game practice.

dicted direction between Times 1 and 2 and between Times 2 and 5. Of course, all improvements between more distant times (e.g., Time 1, Time 6) were also statistically significant at the .05 level.

We have seen that the provision of knowledge that could be used deductively to master a video game maximized transfer for experienced players; however, such knowledge was of little or no use in mastering the video game itself. A comparison of the ultimate skill level (the best three Evolution scores) of subjects who merely played the game (a more inductive condition) with that of subjects who, before playing, were given demonstrations and audiovisual descriptions of rules and patterns (a condition that involves more deductive elements), showed that there was no difference in maximum performance for either experienced or novice players (using initial scores as a covariate in an ANOVA).

Computer game experience made mode of representation more iconic. An ANOVA using pretest and posttest modes of representation as repeated measures, with treatment group and test order as independent variables, revealed a significant interaction between repeated measure and treatment group, $F(5, 142) = 3.09, p < .025$. This shift was mainly due to the computer memory game, which produced a significant shift toward iconic representation, $t = 3.84, p < .01$, two-tailed test. It was most interesting to note that despite the fact that mode of representation was independent of correctness from a measurement point of view, the two measures were positively correlated on the pretest, $r = .2308$, $p < .005$. More iconic representation was associated with better scores on the screen-based test of scientific–technical discovery.

The role of video games in producing the experimental effect was further strengthened by the fact that there was a significant positive correlation between the best video game scores and amount of pretest–posttest improvement on the test of simulated scientific–technical discovery, $r = .1883$, $p < .025$. The number of science courses taken significantly predicted pretest scores on the test of simulated scientific–technical discovery, $r = .2682$, $p < .001$. However, science background significantly predicted neither posttest nor improvement scores. Video game scores did: The correlation between best three video game scores and posttest was .3894 ($p < .001$). As might be expected from this pattern of results, all correlations remained significant with science background partialed out.

DISCUSSION

Our study succeeded in establishing that knowledge of a video game is acquired as a result of the inductive experience of playing the game as Greenfield (1983, 1984) theorized. We documented a significant and steady increase in knowledge of rules, regularities, and strategies as a function of time spent playing the video game Evolution. At the same time, we also established that the provision of initial information through slides, verbal instructions, and modeling did not make a difference in the ultimate game skill attained by subjects. Thus, it was necessary for players to form hypotheses from their own experience and test them inductively in the course of the game. A model and explanations that could aid deductive processes at the outset of the learning process were of no advantage for either novices or more experienced players.

In other words, we established that inductive discovery is crucial to mastery of an arcade-style action video game. On the other hand, Harris (1992) observed that "in video game play, young children as novices are introduced to game play by more experienced players, and once the basics are mastered, the novice further develops his skills on his own through interaction with the games. . . . more experienced players share secrets with less experienced players, often modeling game strategies or providing verbal guidance through difficult moves" (p. 6). At the same time, other research has indicated that explicit instructions beginning after some inductive practice can be of use in mastering a video game (Newell, Carlton, Fisher, & Rutter, 1989).

Given these observations concerning the role of expert instruction in the learning process, why did visual demonstrations accompanied by verbal instructions not make a positive difference in mastering the video game Evolution? One important factor may be the interactive and scaffolded nature of the novice–

master relationship described by Harris (1992). In other words, the experienced player can observe the learner's level and specific needs for information as the learner plays the game, and the learner can communicate his or her specific informational needs to the master. The master–novice interaction described by Harris (1992) occurs while the learner is on-line with the game, receiving inductively relevant input. The learner creates a representational model of the game by interacting both with the game and with other players simultaneously. A second, related factor may be the timing; Newell et al.'s (1989) findings indicate the possibility that video game instructions would be more useful after, rather than before, game play has begun.

We also established that experience with "noneducational" video and computer games can produce transfer to skill in acquiring knowledge from a scientific–technical computer application. For both novice and experienced players, practice on an activity utilizing the computer medium led to greater transfer; the absence of the computer medium (mechanical memory condition, no-treatment control condition) greatly reduced pretest–posttest improvement in the acquisition of knowledge from an animated computer simulation of the logic of electronic circuitry.

Most telling in relation to the impact of action video games was the following finding: The level of subjects' best performance on the arcade-style video game Evolution was significantly correlated both with pretest–posttest improvement and with posttest scores on the screen-based test of scientific–technical discovery. That this test actually tapped scientific skills is attested to by the fact that science background was a significant predictor of pretest performance. Yet science background did not significantly predict either posttest scores or improvement in the course of the experiment. Video game performance, in contrast, did.

Despite these experimental and correlational results, inductive discovery did not seem to be at the heart of the transfer that took place. First of all, recall that for experienced players, the most effective conditions in promoting transfer involved receiving explicit communication concerning the rules, regularities, and strategies of the video game before actually playing the game. This condition was less effective for the novices, whose most effective condition was one that minimized the necessity for inductive activity even more: the computer memory game, in which the very simple rules were all explained in advance to the subjects. Contrary to the original hypothesis, game play alone (the most inductive condition) was not the most effective in improving test performance for either novices or experienced players.

Another result that militates against the idea that video games provide training in inductive discovery skills was the fact that novice players improved their Evolution scores at about the same rate as more experienced players, indicating equivalent skill in discovering new rules, patterns, and strategies through game play.

If inductive discovery was not the cognitive key to transfer, what process was? Or, to put the question another way, what skill was being transferred and what skill was being tested? Several results led to the conclusion that the transferable skill was not induction but rather skill in decoding and encoding the iconic representational code of the computer medium. First, in the scale of transfer shown for novices in Figure 5, all computer conditions were at the top whereas the mechanical memory condition, the only condition involving a different medium of representation, was at the bottom.

Second, the fact that periodic questioning was more effective at generating transfer for the novices than for the experienced players might also constitute evidence that mastery of an iconic code was at play. As the sample questions in Figure 2 show, these questions called attention to the code units, perhaps helping novice players to identify the basic nature of symbolic elements on a computer screen. Because the experienced players started off with greater knowledge of this code (as shown by their significantly higher pretest scores), the basic level of screen symbolism addressed by the questions condition may have been of less use to them.

More direct evidence that the basis of transfer was mastery of an iconic code lay in two other results: (1) 2½ hr of playing the computer memory game produced a significant increase in iconic (as opposed to verbal) representation of the posttest, and (2) relatively greater use of iconic representation on the pretest was significantly associated with more correct answers on that test. In summary, whereas we had originally conceptualized the pretests–posttests as tests of scientific–technical discovery, the results made us emphasize that scientific content was being conveyed in a particular medium and code of representation, that of animated computer graphics. Not surprisingly, skill with the code facilitated comprehension of the content.

That computer games activate visual–spatial rather than verbal–symbolic processes was confirmed in a study by Logie, Baddeley, Mane, Donchin, and Sheptak (1988). These researchers found that after 3 hr of practice on an action video game, Space Fortress, performance was more disrupted by concurrent visual–spatial tasks than by concurrent verbal tasks.

Overall, the pattern of results led to the conclusion that it was not inductive discovery experience per se, but rather experience with a particular medium and code of symbolic representation that was at the heart of the transfer. What was being tested was not merely the process of scientific–technical discovery, but also the ability to decode scientific–technical information from schematic animated computer graphics. Results indicated that the construction of meaning was the important process underlying transfer; contrary to the hypothesis, it did not matter whether such meaning was constructed more inductively or more deductively.

Why was the computer memory condition the most effective in promoting a preference for iconic rather than verbal representation? One reason may have been that its schematic graphics were more similar to those of the transfer tests than were the graphics of Evolution; the graphics used in the computer memory game were also more prototypical of the computer medium than were those of Evolution. Another reason may have been that the action in the computer memory game was slower and, unlike that of arcade-style games, totally under the control of the player; the faster, uncontrollable action of Evolution may have been relatively distracting. And, finally, the computer memory game was simpler, perhaps allowing greater concentration on the code itself.

Our results indicate that mastery of an iconic code is a crucial element in computer literacy. This finding is very much in tune with Salomon's (1979) theoretical view that each medium has its own symbol system. Applying this view to computers, Salomon (1988) suggested that symbolic forms used by computer tools can be internalized as cognitive modes of representation through the process of human–computer interaction. Given the importance of mastering the symbolic codes of the computer screen, a possible pedagogical implication of our findings is that children should be exposed to prototypical computer graphics representing simple or familiar content before they are expected to use this medium to decode complex new information. As in print literacy, knowledge of the basic code must precede use of that code to attain new information. In terms of the relation of noneducational computer games to scientific and technical education, mastery of the symbolic codes used in computer graphics becomes increasingly important as more and more science and technology comes to be done on computer screens rather than in the material world.

As a corroboration of our results concerning short-term experimental influences, we found that long-term influences that subjects brought with them into the study also had an impact on the ability to decode scientific–technical information from a computer screen. The groups who had been more exposed to computer screens over the long term—males, Americans, and more experienced video game players—had at the outset of the experiment more skill than females, Italians, and less experienced video game players in decoding graphically presented information about the logic of computer circuitry. Finally, Americans were more iconic than Italians in their way of representing and communicating this information, possibly because of their greater exposure to computer screens and other sources of iconic visual imagery.

An important side effect of the computer revolution may turn out to be a shift from more verbal and symbolic representation to more iconic modes. Our study also showed that the representational skills developed by computer games transfer to scientific computer applications. In other words, entertaining computer games provide informal education for the scientific or technical use of computers. Contrary to early popular views of video games (summarized in Greenfield, 1984), they are not simply a waste of time. Lastly, computer games are cultural tools that, like other cultural tools, exist in a societal context. Our results indicate that the availability of computer tools in a particular society affects the representational competence of its members in communicating with computers across a range of specific applications. By influencing representational competence in a medium of symbolic communication, computer games serve as a cultural tool of cognitive socialization.

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