

4 First schooling

*the gods don't hand out their gifts at once,
nor build and brains and flowing speech to all*

THE ODYSSEY, BOOK 8, 167-8
HOMER (TRANS. R. FAGLE, 1997)

My friend Nico is a normal child. Only his brain images remind us of his brain condition. This is a kind of well-kept secret inside his skull. If Nico is invited to a party where nobody knows about his medical history, he is welcomed as an attractive child with a slight limp and some restriction of movement in his left arm and hand. It is impossible to infer from his overt behavior what has actually happened to his brain. But the computer magnetic resonance images are there to remind us of his neurosurgery. And he knows that too. He does not actually know the technical details but if asked he will say he underwent brain surgery when he was small. He regularly undergoes medical tests, EEGs and the like, and he took anticonvulsive drugs for some three years following surgery, but no longer needs them. He is certainly a healthy, charming boy.

When I first met Nico he was five years old and I did not know much about the extent of the surgery performed two years earlier. His parents came to ask for precise advice on education and computing for him. I was not consulted as a physician but as a pedagogue. I asked, however, for a detailed account of the neurosurgery protocols and some recent images of his brain. I immediately started to work with him at a computer in order to evaluate his visual



Figure 4.1

First computer graphic at age five. Nico learned to move and copy small images of people, animals, plants, and other objects on the monitor. He also used the mouse to draw lines and curves on the screen. The result was a fascinating computer art composition.

and motor capabilities when using the mouse and the keyboard. Nico was very friendly towards my assistant and me and we were quite impressed to see this hemiplegic boy trying so hard to operate the computer. He displayed no visual neglect on the screen and in a few minutes he was able to click and drag the mouse with ease.

I observed that he loved using the computer more than the usual toys he was offered. He was hyperactive throughout the whole session. He was eager to play with icons, letters and colors but was so excited that my assistant and I had difficulty in following an organized program on the computer. He liked changing tools, erasing, exploring. In the six sessions that followed, however, we succeeded in making Nico carry out some simple Piagetian tasks, such as seriation and classification on the computer screen. He was able to perform one-to-one visual correspondences with the icons but could not seriate



Figure 4.2 One-to-one visual correspondence on the screen at age five. The computer task was to copy and paste a collection of small images and to put one above the other (dog – moon, strawberry – palm tree, ice cream – cactus).

consistently. His verbal comments about his computer work were incredibly articulate, witty and humorous, and showed a remarkably rich vocabulary. It was not until the end of this evaluation that I received the corresponding neurological records and brain images. I could not believe my eyes! Nico had had a complete functional right hemispherectomy yet was performing on the computer like any normal child of his age.

My recommendation to the family was to start a normal education with the aid of computer tools. Accordingly I went to talk to the headmaster of a

traditional school, with a good reputation, willing to accept Nico in kindergarten. I had the good fortune to know the headmaster of that institution quite well. In fact I had been working for a number of years as a consultant on 'digital education' in several teaching and learning activities, and the school was already prepared to accept the technological (computer and communications) challenge to make the necessary digital shift to help Nico. Taking care not to over-simplify the problem, I explained how important it would be for Nico, his family and the school, to take up this educational challenge. We did not have the slightest idea how to teach a half-brained child. He agreed to have a go. The first year at school was a kind of day-by-day experiment. The teachers were informed about the case and everybody took pains to find new ways to help this charming hemiplegic child in his daily activities. His hemispherectomy was not mentioned again. What Nico needed was a pleasant environment in which to grow up. And so it was.

In the first months at kindergarten he was often tired, but he was given plenty of time and space to relax on a mattress or take a nap. He was then taking a mild anticonvulsive medication. His companions were very kind to him and the adults grew more and more confident as his teachers. The education of this exceptional child was becoming a natural and common task for all. Nico was very happy at school. It is an excellent school with more than one thousand students of both sexes, at primary and secondary levels, advanced computer and communications equipment, large buildings, extensive gardens and open fields. It is a private school with a solid reputation earned from decades of teaching, not a special school for handicapped children.

After kindergarten Nico was accepted in first grade without any problem, but we were concerned about whether he could manage the stress of formal learning. He did very well. He also started to attend classes in English as a foreign language in the afternoons, in which he is now obtaining the highest grades! He did not exempt himself from any school activity. Furthermore, he had a good attendance record throughout the year. Only gymnastics and sports were specially tailored for him, taking into account his motor disabilities, with an emphasis on his long-term rehabilitation. I recommended giving Nico a laptop computer, and this was done. His computer became his copybook. He also had the use of his father's PC at home and another one in

his class, but Nico was the first pupil at that school to carry a laptop computer around. In fact a portable computer is a perfect tool for students of all ages, but for some reason adults are reluctant to give them one. For Nico it was not only an innovation but the perfect companion, and more than that, the computer became his "information prosthesis," to use Seymour Papert's phrase (1978). And now, thanks to his example, the whole class is moving forward. Pupils, teachers and parents are now learning to use email. And the remarkable fact is that Nico is leading the transformation! There is a moral lesson here. The more I work with disabled people the more I learn that they are teachers. "The one that you are supposed to carry will really carry you," as Paul Claudel (1957) said in his *Prière pour les paralysés*: celui que tu crois porter, c'est lui réellement qui te portera.

There is a myth about handwriting being the 'educationally correct' way to acquire literary skills. But in Nico's case, there was no justification for not allowing him to use a typewriter from the outset. He had too much difficulty in holding down a sheet of paper or a copybook with his left, disabled, hand. As I have mentioned, Nico is still behind for his age in drawing skills, and he has real difficulty in forming the letters of the alphabet and numbers with his right hand. I shall return to this important point later, when we discuss the differences between 'analog' and 'digital' perceptual and cognitive abilities in a half-brained child. To sum up, with the aid of a computer Nico learned to write and was able to keep up with the normal pace of his class. Nico mastered the basics of spelling and grammar at the same age as most normal children do. He loved writing long sentences on the computer and seeing them printed in Spanish, his mother tongue, or even in English.

The following are some typical texts produced by Nico at different ages with the aid of a computer. It is amazing how well he uses the word processor to write, correct, delete and print. The computer is his favorite tool to copy a text, compose a description, take down dictation or write a letter.

DIA MIERCOES21

GOLOSINAS

DERRITE

PEGAJOSO

UVA



BANANA

CARAMELO

REDONDO CUADRADO

DERITE

MARRON

BLANCO

DURO

RICO

CHOCOLATE



Figure 4.3

A computer task at age six: To write the attributes of a candy (raisin and banana) "melts, sticky, round" and a chocolate: "melts, brown, white, hard, good."

age 5:

Copy

LEON

MAMA

age 6:

(a) Description

DIA MIERCOLES 10

HIDROPONIA

FORMA DE CULTIVAR PLANTAS QUE NO NECESITA TIERRA

NECESITA AGUA I SALES MINERALES.

EXPERIMENTAMMS:

1- ELEGIMOS LOS MATERIALES

2- PONGO LAS SEMIYAS

3- RIEGO CON MUHA AGUA

Day, wensday 10

Hydroponics

Way to cultivate plants that don't need earth

Need water and mineral salts.

We experiment:

1. select the materials

2. I put the seeds

3. I sprinkle with a lot of water

b) Assignment:

PARA TENER UNA LINDA SONRISA DEBEMOS

SPILLARNOS LOS DIENTES

IRA DENTISTA

NO MORDERCOSAS DURAS

COMER POCAS GLOSINAS

COMER CARNE FRUTAS LECHE VERDURAS PESCADO

LAVARNOSCON FLUOR

To have a nice smile we need to:

brush our teeth

go to the dentist

do not bite hard things

eat few candies

eat meat, fruits, milk, vegetables and fish

wash with fluoride

age 7:

a) Dictation

DIA VIERNES 2 DE MAYO

DICTADO

LA CASA DE I TIA QUE DA EN OLIVOS

MI MAMA COSINO UNA RICATORTA.

EN EL JARDIN FESTEJARON EL DIA DE LOS ABUELOS

MI BANDERABLO SELESTE

Day Friday 2 May

Dictation

The house of my aunt is in Olivos

My mother baked a good pie.

In kindergarten they celebrated grandparents' day

My flag is white and blue

b) Description

DESCRIPCION SOBRE EL HORNERO.

SU COLA ES ROJISA.

CUANDO TIENE UNA CRIA ABANDONAN SU NIDO Y HACEN

OTRO.

EL HORNERO CANTA PARA ENAMORARSE

MIDE 20 CM. EL NIDO PARECE UNA PELOTA DE FUTBOL.

Description of a bird (hornero).

Its tail is reddish.

When they have a chick they leave their nest and make another.

The homero sings for love

It measures 20 cm. The nest looks like a soccer ball.

c) Letter

QUERIDO ANTONIO

TE SPLICO QUE SE ME ESTA CALLENDO UN DIENTE.

APRENDI QUE EL HUESO MAS LARGO ES EL FEMUR.

TE PIDO QUE VGAS A VISTARME AL SALON PERO UN RATO

LARGO.

UN BESO

NICO

Dear Antonio

I tell you that I am loosing a tooth.

I learned that the longest bone is the femur.

I ask you to come to visit me in the classroom but for a longer time.

a kiss

Nico

age 8:

Nico's first email

HOLA ANTONIO SOY NICO. FLOPI ESTA BAILANDO LAURA NO

ESTA EN ITALIANO.

TE QUIERO MUCHO. NICO.

Hi Antonio! I am Nico. Flopi is dancing "Laura is not here", (a song) in Italian.

I love you much. Nico.

The process of handwriting is cumbersome for all children, whereas type-writing is always easy. Pressing a key on the computer is much simpler than holding a pen and making a mark on a paper. Even now, after two years of handwriting practice Nico has consistent difficulty in mastering this particular skill. He still inverts Ns and Ss, writes capital letters too large, and misplaces letters or words on the horizontal lines, etc. His poor handwriting is in marked contrast with his skill on a word processor. Stressing the absolute necessity of a computer from the outset to help Nico in his learning process was the right choice. (This issue will lead us to a discussion about word processing and the brain, confronting texts and hypertexts.)

And what happened with regard to his reading abilities? We know that the cortex that writes is not the cortex that reads. We also know, from lesion analysis that agraphia and alexia are separate neurological disorders (Gibson and Levi, 1985; Gray and Kavanagh, 1985). We can say that with his intact left hemisphere Nico should be cognitively well-equipped to read, but what about his defective left visual field? Nico has a left hemianopia because the functional hemispherectomy has severed all the neural paths that project the hemi-right retinas to his disconnected right visual cortex. How then does he manage to read, and read so well? This is an open question that will require further investigation. Nico has a very particular way of moving his head in order to focus his central field of vision. We can also expect to find an atypical pattern in his saccadic eye movements during reading.¹ But the fact remains that he reads and enjoys reading very much. And how does Nico get on in arithmetic? He is good at that too. Nico is a good learner and enjoys numbers. The same goes for music. He loves to sing and has memorized many melodies and songs. Nico is an average child in his class in most tasks, at the top of his class in verbal (oral and writing) skills, towards the bottom in drawing. He could be described as a typical "verbalizing" and not a "visualizing" child, in the terms used by Howard Gardner (1982).

But schooling is much more than a learning program. It is a learning human environment in which social and emotional skills are required to

develop an identity. Nico is a child who suffered from intractable epilepsy, which began in his second year of life. It was by all accounts a devastating condition with constant seizures, loss of consciousness, fear and medical treatment which culminated in critical brain surgery performed abroad, a long way from home. Nico remains a highly sensitive child, overprotected at times by his family and friends. He has a younger brother and a sister who attend the same school and there is a clear rivalry between the siblings. What could be expected at school of a child with such a background? Some emotional and affective imbalance perhaps, due to the complete removal of his right limbic system, amygdala and hippocampus? There is also some evidence of a right dominance for emotions (Gainotti, 1972; Heilman *et al.*, 1983; Borod, 1992). But, the expected symptoms did not appear. On the contrary, Nico behaves like any emotionally balanced child of his age. Nor have we detected a specific "attention deficit disorder," which is so common at this age. He is friendly towards everyone, young or old; he has a remarkable sense of humor; he is very affectionate and popular; he loves and is loved.

Nico has undergone several Piagetian cognitive developmental tests in a longitudinal study which we expect to continue (Piaget and Inhelder, 1963). We have not yet found any sign of impairment or deviation in his cognitive abilities. On the contrary, he has shown a normal development of all the abilities we have been testing. For instance, we observed that at the age of five-years-and-eleven-months he reached the stage of the conservation of quantity for the 1-1 correspondence between icons using the computer as a tool. According to the Piaget-Inhelder scales, 50 per cent of children of his age also reach this stage. The conservation of substance was tested in the standard way with two small, identical clay balls, A and B. B is then transformed into a sausage B'. The "conservator" child affirms that A and B' still have the same amount of clay. The arguments offered by Nico related to the conservation of 'identity' under transformation. When tested at the age of six-years-and-four-months, he had reached a full conservation of substance, a stage only reached by 16 per cent of children according to the same Genevan scales. However, at the age of six-years-and-four-months he was a non-conservator for quantity of liquid. The conservation of liquid was tested using a simplified technique: two glasses of identical shape and volume (A, B) contain the same amount of water; then the water of one glass (A) is poured

into a larger but shallower glass (A'). The question is whether there is the same amount of water in B and A'. Nico gave non-conservative answers using the same kind of argument as that reported in 40 per cent of children of the same age: "A' has less water because it's lower." When tested seven months later, however, he had attained full conservation. In the test of seriation of rods of increasing length we made use of the computer to draw lines of different color and length, in order to improve his motivation. At the age of five-years-and-eleven-months we obtained a typical stage I response but by the age of seven he had reached stage III seriation with a correct intercalation of (solid) rods. At the age of six-years-and-six-months he was tested in logical thinking (class inclusion) with a bunch of ten flowers B, consisting of eight roses A and two daisies A'. He was able to quantify the two subclasses within the whole class of all flowers B ($A + A' = B$). Only 13 per cent of children of his age quantify class inclusion. To sum up, we detected no significant developmental problems, according to these standard Piaget-Inhelder tests.

The conflict between what could be termed the 'analog' and the 'digital' cognitive skills in mental development is an interesting point. The technical terms analog and digital are essential to the computer sciences but are not so widely used in psychology. However, they can help us to have a better understanding of the plasticity of the human brain subject to hemispherectomy. As we have seen, Nico has poor drawing skills. Drawing is a highly analog activity in that it is mostly continuous and smooth at the motoric-gestural level. However, Nico is very skilful on a computer with a mouse, the equivalent of a pencil. Moving a pencil or a mouse are both analog activities, but the mouse has the "click option," and this can make a significant digital shift in our spatial abilities. Computer graphic software is a good instrument with which to evaluate the "digital aspect" of the spatial skills of an individual of any age. In the case of a right hemispherectomized child this digital shift amounts to forging a new way of representing space with the left hemisphere. In fact Nico has an astonishing ability to move in hypertextual space, where buttons and icons may open new windows, change colors and shapes, produce sounds, create drawings, and letters, etc. As I have mentioned, his "analog drawings" and his representation of space and objects in two dimensions are some two or three years behind his age, but in the organization of his digital cyberspace he is well ahead of his class! Other interesting results have been

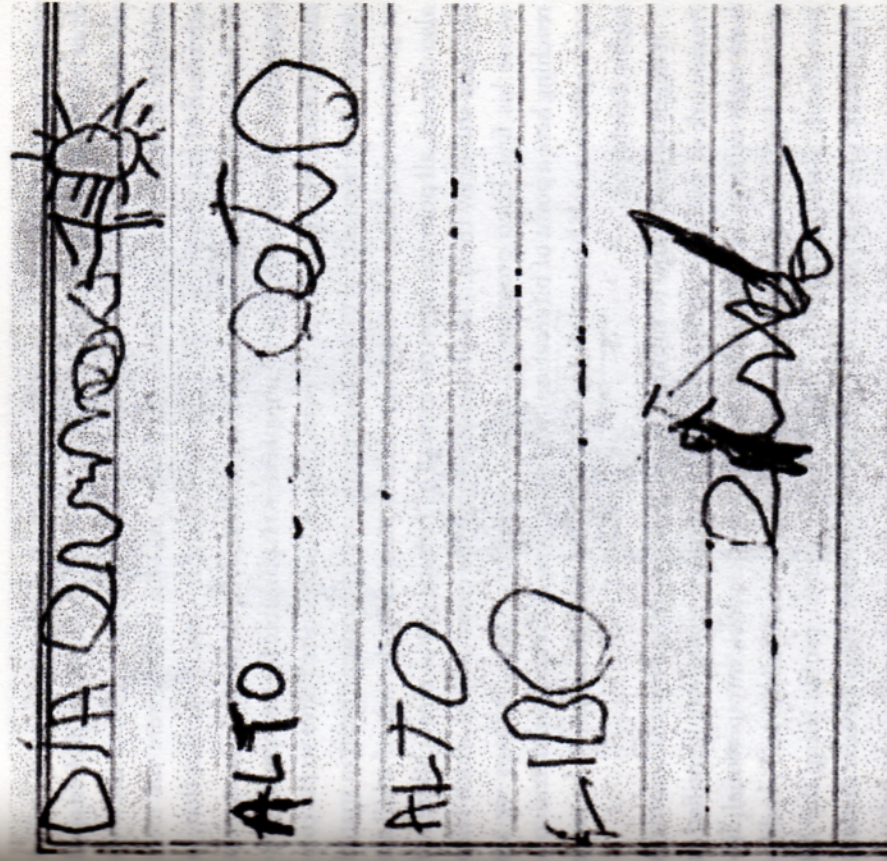


Figure 4-4 Handwriting at age seven. Nico shows poor writing skills with a pen while he manages to produce a good text with a computer.

obtained with the Raven Progressive Matrices test. The problem consists of completing geometric matrices of increasing difficulty. Nico performed at an advanced level, solving thirty-five out of the thirty-six figures tested (percentile 95). This is a remarkable result for a right-hemispherectomized child who would be expected to perform poorly in non-verbal thinking tasks.

The difference between perception and the representation of space is also a good theme to investigate with a half-brained child. Piaget, Inhelder and Szeminska (1947, 1948, 1961, 1966) studied this cognitive problem in depth. For instance, they were able to show that the perception of the horizontal

evolves independently from its representation. A classic test is to request a drawing of the horizontal level of a liquid in a tilted glass. Most children aged six draw a line perpendicular to the sides of the glass, yet Nico drew an oblique (though not quite horizontal) line, and his results were the most advanced of his whole class! This is quite striking in view of the fact that, in the first place, Nico shows poor drawing skills and, in the second place, most researchers agree that the right hemisphere is responsible for processing geometric tasks (Franco and Sperry, 1977). But in all the tests I have so far conducted, I have been unable to find any specific deficit or impairment in spatial or geometric thinking. His drawings of trees planted on the side of a hill are also correct, all pointing upwards instead of fanning out as most children of his class still draw them. I shall discuss below the clever way in which Nico wrote his first Logo program to draw a geometric figure. Perhaps we are reaching here a point of bifurcation, where drawing skills and geometric concepts split in a half-brained child. In Nico's case the latter seem to be more highly developed.

It might be useful now to summarize our findings using Howard Gardner's framework of multiple intelligences (MI). Gardner (1999) has identified at least eight different intellectual capacities: interpersonal, intrapersonal, linguistic, logical-mathematical, spatial, musical, naturalist, and bodily-kinesthetic. I shall attempt to sketch Nico's mental profile using the MI framework. Our pupil excels in interpersonal relations. He is a leader in many situations involving verbal interaction. It is interesting to see how he behaves in a social situation, for example. I first noted this when I invited him to visit my home with his family. I have a nice garden but rather than going out to play he preferred to stay with the adults, asking questions about everything and participating in our conversation. If I ask him to do a drawing he will take the time to give somebody else a pencil so they can do one too. He does not like to work in isolation but prefers to share his activities. It is also interesting to record his group behavior at school. We videotaped him during some psychological tests at school. When we invited some of his classmates to do a Piagetian test with him he explained the task to the others; for instance, the best way to classify a collection of objects, etc. Nico has many friends of both sexes. They help him in many ways, especially when he is having difficulty in reaching an object or doing some hard manual task. During his second year at

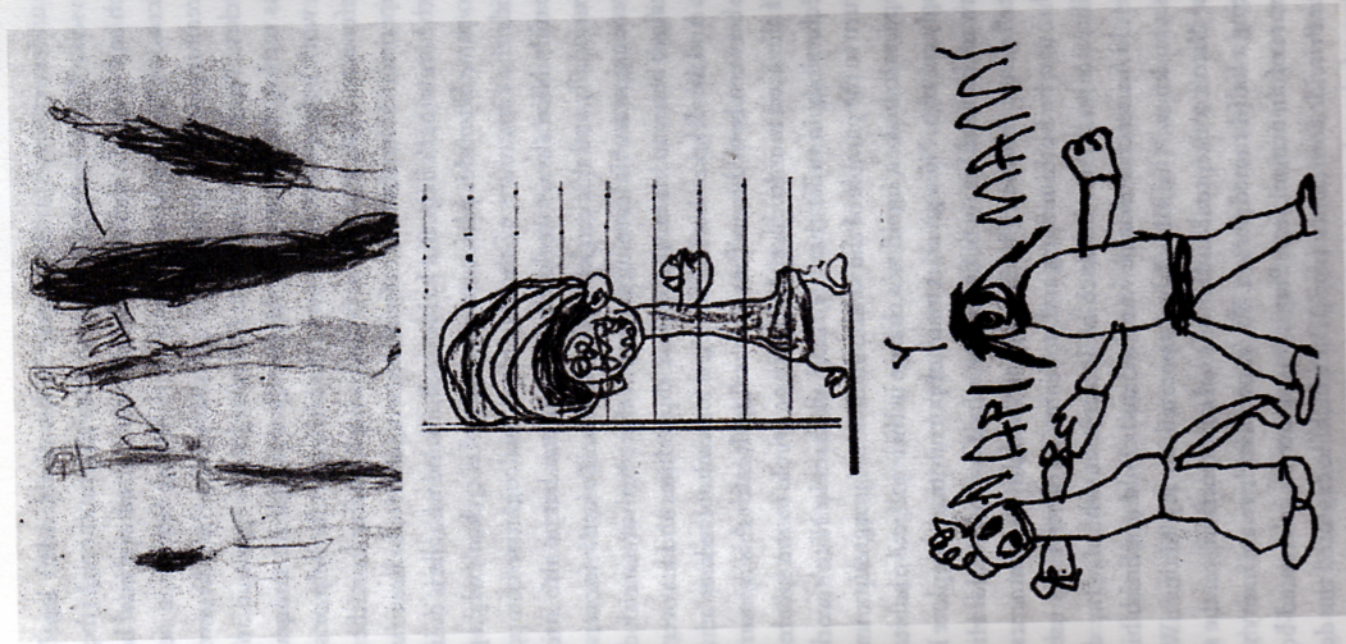


Figure 4.5

Three typical drawings at ages six, seven and eight. Nico shows poor drawing skills, but he is now making significant progress.

school he underwent reparatory surgery in his disabled left leg. When he returned to school in a wheelchair everyone was vying for the right to push him along which he enjoyed immensely. When he first started at school he used to wander incessantly and spend a lot of time flitting from one activity to another, dreaming up new things to do or interrupting the others while they worked in class. Now this hyperactive behavior has disappeared and he has become less restless (or lazier?). He frequently waits for his companions to finish their work before starting his own. He often asks for help or says he is tired and refuses to work. Perhaps he is beginning to suffer from the stress of school competition. When he fails to finish his work in time he has to work late at home with his mother's help. But he loves school and what he is doing there. Although to some extent his performance at school is cyclical, when properly tested outside the constraints of the classroom, his cognitive competence is growing steadily. Nico always works on his computer but he also attempts to work conventionally and this can lead to problems. We know for certain that the computer empowers his learning skills, but there is always a risk of a progressive décalage between his inner cognitive capabilities and his overt school production. And we all know how difficult it is for a school to keep a harmonious balance between both dimensions of learning. It is for this reason that we are aware of the need to introduce the class as a whole to the sphere of new computer technology in order that they may all share in Nico's work. Once again we return to the parable of the weakest individual in a group stimulating his stronger peers to make a significant change in their collective habits.

Interestingly enough, Nico gives us many opportunities to explore in some detail how aware he is of his own identity as a half-brained child. His intrapersonal intelligence manifests itself in some insightful comments about himself and it can be both moving and amusing, to observe his use of his brain disability to justify an instance of laziness at school. One day, for example, he told his teacher that he was tired and could not finish his work because, "as you know," he said, "they operated on my brain." We shall closely follow Nico's conceptual and emotional constructions on the specific subject of being a half-brained person. We know that there are many ways of becoming aware of an action. Jean Piaget has written a celebrated book on that topic, *La Prise de conscience* (1974), in which he explored the developmental process of the relationship between the affective and the cognitive

unconscious. The philosopher Daniel C. Dennett in *Consciousness Explained* (1991) discusses split brain experiments which demonstrate the new ways which patients find to do the same tricks they used prior to surgery. Maybe we should re-define consciousness in the context of one hemisphere alone doing all the exploration.

Nico's linguistic intelligence is remarkable. He began speaking quite fluently before the age of two and lost no linguistic ability at all following surgery. Nico's verbal performance is now above average. This is not simply because he has scored 118 in verbal IQ (which is in any case a somewhat controversial measure of linguistic ability), but because of the richness of his vocabulary and syntax. A conversation with him is always interesting. He can give a lively account of any particular event, be it a holiday trip, a video or a sporting activity. He has a pleasant voice and speaks with great self-possession. It is a pleasure to hold a conversation with him. I have suggested stimulating his linguistic skills by learning easy poems and dramatizations, which he seems to enjoy very much. It is also interesting to note his joy at learning a second language. In the afternoons he attends English classes at school, in which he attains a high level of success, and has a collection of English songs at home which he loves and knows by heart. The extent of the so-called "neuronal crowding effect" in his left brain needs further exploration. So many compensatory functions and still enough 'room' to incorporate a second language and maybe others as well!

His written language skills, on the other hand, seem to need extra space — a kind of external memory. As I have said, his laptop serves him as an "intellectual prosthesis." It would be extremely difficult, if not impossible, for Nico to remain at school without this empowering instrument. And lately an innovation is bringing about a significant change: email is now transforming his life. We have prepared an interface to enable him to select any of his digital penpals with a single click, and I am on his list. What does it mean to an eight-year-old half-brained child to be connected to the Web? Nico has a close extended family, some of whose members live abroad, and they usually communicate through the Internet. His classmates and teachers are also beginning to use email; Nico is now in contact with some of them. As Papert (1997) says, he belongs to a "connected family"! This development has far-reaching implications for his linguistic intelligence. For instance, it stresses the pragmatic

dimension of language. Although syntax and semantics are formally taught at school, "how to do things with words" in the pragmatic use of language – if somehow a mystery. Consider how many letters or memos are written in a year by a pupil in the third grade and what they convey! In general, whilst the requirements of the school curriculum may be satisfied, the children's real interests are not. Email on the other hand is an enormously powerful pragmatic tool for all of us, children and adults alike. I must confess how proud I was of Nico when, using my computer, he sent his first message to a dear colleague of mine at Harvard! When I first met Nico such a feat would have been difficult to imagine... The enormous impact on Nico's life of the new computational technology is still a source of constant wonder to everybody. Email is one of the bridges that technology is building around us. This is only a beginning, but I can predict a qualitative leap forward when the whole class interacts with Nico on a daily basis.

Nico loves music. A recent gift from me was a beautiful radio I brought back from Singapore. I know he is enjoying listening to it (I always try to make him participate in my travels – next time we should be in contact by email). I have a piano at home and the first time he came he asked my permission to play. I tried to teach him a short tune with his right hand and he was eager to learn. Every time he visits me he asks to go to the piano and he enjoys playing with an electronic musical keyboard at home. He needs some help with an instrument like this, but fortunately, nowadays, digital synthesizers can supply the left-hand accompaniment. At school he is learning to play some simple percussion instruments and he enjoys singing, whether solo or in a choir. The development of a musical intelligence in a right hemispherectomized child is certainly a challenge for neuroeducation. It may be of interest to note that some authors have detected a difficulty in locating sounds which are contralateral to the ablated hemisphere. For instance, a right hemispherectomized sixteen-year-old girl was subjected to a precise auditory test, the results of which were worse for moving sounds than for stationary sounds (Poirier et al, 1994). Of course, this would not seem to present a major obstacle to a serious musical education.

It is in the act of drawing that we see Nico's principal cognitive deficit, but I have no proof that his visual-spatial intelligence is impaired. This raises a very interesting point of discussion. Many authors have linked the right

hemisphere to spatial processing. As I have already mentioned Nico's spatial sense was "forced" into his left hemisphere, first by the epileptic and disabled right hemisphere and subsequently by surgery. Furthermore, his left visual field is impaired. It is quite remarkable how he compensates for this major visual deficit by means of eye and head movements in most situations. As a consequence of the hemianopia his reading ability is somewhat diminished. He reads well but cannot follow the written lines easily, or at least not at the same speed as his classmates. It is a well-known fact that the saccadic eye movements in the process of reading are very precise, that they improve in efficiency with practice and undergo specific changes when there are visual or brain lesions. I fully expect that with continuous exercise his eye-scanning pattern will improve and that new reading methods will develop with age and practice. This expectation is supported by the impressive example of Nico's ability to process three-dimensional cyclopean images with his left visual cortex against all the odds.

Nico is perfectly well oriented in space and time. With the exception of drawing I have so far been unable to find a single specific cognitive impairment produced by the right hemispherectomy. I have tested some aspects of his precocious spatial ability by means of the representation of the horizontal level of a liquid in a tilted cup. And now, at the age of eight, he has revealed full operatory spatial thinking in some Piagetian tasks: the construction of a projective line using the alignment of solid objects between two marks on a table. And if we shift to the circumscribed space of the computer screen, Nico's spatial performance is outstanding. He drags the mouse with ease and moves the small cursor with great precision and without hesitation. I shall discuss below how well he manages to program the translations and rotations of a turtle on the screen using Logo computer language. But his drawing by hand is still well behind his spatial cognition. We are currently offering him a wide variety of possibilities and techniques for improving his drawing abilities.

Logical mathematical intelligence has been widely identified as a predominantly left brain activity. But studies on left hemispherectomized children show that under certain circumstances the right hemisphere can, to a large extent, compensate for the loss of the dominant hemisphere. Correspondingly, the development of logic in a right hemispherectomized child such as

Nico should not be a problem. In fact I could show that his logical thinking follows the normal developmental pattern. This is important because for Piaget the concept of number is the operative synthesis of classification and seriation. But how does the transition from an "unschooled mind," as defined by Howard Gardner, to scholastic learning take place in a half-brained child? How is Nico learning arithmetic at school? He has told me several times that he greatly enjoys arithmetic and he is very proud of his good grades. But although he appears to have no specific difficulty in the subject areas of elementary arithmetic and geometry and has no difficulty in keeping up with the rest of the class, he shows no particular talent for mathematics. His main gift is for language. Nico is also developing as a budding naturalist. He is collecting all sorts of specimens and he told me he wanted to start a small museum at home. In this task he is collaborating with his younger brother.

Finally, let us attempt to describe Nico's bodily-kinesthetic intelligence. A right hemispherectomy produces a left hemiplegia and left hemianopia. These are Nico's principal disabilities and they are in striking contrast to his cognitive and emotional capacities which are predominantly intact. His motoric handicaps are now the main focus of concern to family and teachers alike who try to provide him with the best physical rehabilitation available. From a neurological point of view he has some voluntary control of the axial and proximal set of muscles in his left limbs. These control the elbow, shoulder, hip and knee via the ventromedial corticospinal (ipsilateral) tract which represents one tenth of the pyramidal fibers coming from the left motor and premotor cortex. Nico's motoric rehabilitation depends on this secondary bundle of ipsilateral connections (Müller *et al.*, 1991). Thus, his remaining left hemisphere has the potential to control the proximal movements on both sides of his body. But the lack of contralateral motor connections from the right cortex via the lateral corticospinal tract disrupts the voluntary control of the distal muscles, especially of his left hand and fingers.

When I first met Nico he was a very slim, delicate boy. Now he has grown and is capable of some physical activities which were impossible a few years ago. For instance, he can now go up and down a long staircase at school several times a day without assistance. He also achieves a reasonable level of outdoor

activity at school despite his hemiplegia. He successfully underwent orthopedic surgery in his left foot at the age of seven and his gait is now improving. His father is a sportsman and has first-hand knowledge of the beneficial effects of physical training. He became his son's coach in more senses than one. Nico likes swimming and has recently discovered tennis. But for obvious motoric reasons, I imagine, he intensely dislikes soccer – he even refused to watch the national team playing in the World Cup in France on TV! Careful motoric rehabilitation will certainly help to enhance the bodily-kinesthetic intelligence of a half-brained child. To sum up, as expected, Nico shows the superior language skills of a left brained child. But we now also have a more coherent view of the large number of compensatory effects which take place following hemispherectomy, particularly in many spatial tasks. The discussion of these and other, as yet undiscovered, developmental facts may in future help us to obtain a clearer understanding of the underlying neuropsychological dynamic.

used in handwriting or typewriting. We have set up a new cognitive space on the screen which supercedes the cumbersome task of writing with paper, ink, rubber, tape, glue, scissors, and stamps, and enables us to edit, print, save, and mail with ease. It is not simply the substitution of the old instruments by the computer keyboard that makes such a difference but the use of different cognitive strategies. It is not a motor change but a mental change. And different writing strategies entail the activation of different cortical areas too. Thus, just as a hemispherectomy forces a massive cortical shift, so may computers also elicit a more (limited) cortical shift. As we shall see, both the natural and the artificial cortical shifts gently merge in the education process of a half-brained child. But we must now take a detour to explain the impact of computers on cognitive development in general before discussing their role in the education of a hemispherectomized child.

Digital processors are machines that have changed the way we interact with the environment, with other people, and with ourselves. In particular they have changed the way we interact with our brains. The essential unit is a triad which comprises the person P, the machine M, and the environment E: {P, E, M}. The environment is either exogenous or endogenous. The brain belongs to the latter. The triad is internally connected by the symmetrical relations PE, EM, MP. These represent the three possible functional interfaces between: the person and the environment (eg. a pencil), the environment and the machine (eg. a sensor) the machine and the person (eg. a word processor). Each triad can be connected to many other triads. The fundamental external connections are of three kinds: person to person PP, machine to machine MM, environment to environment EE. These three (not always symmetrical) external connections are of different physical natures. A face to face communication is a PP relation (audio-visual-gestural). The network between computers on the Internet is an example of an MM connection. The interaction of photons and the retina is a case of an asymmetrical functional relation EE between the endogenous environment of the brain (the neuronal layer of rods and cones) and the exogenous illuminated environment. The network between a pair of triads is reflected in a prism which allows a multiplicity of functional connections via different pathways and nodes. Let us suppose a teacher is on the telephone to her principal (PMMP). At the same time she makes a gesture with her hand to motion a student to come in (PP) whilst monitoring the printout

5 The cortical shift

The Brain – is wider than the Sky –

For – put them side by side –

The one the other will contain

With ease – and You – beside

EMILY DICKINSON, 1862

We are now ready to take a further theoretical step. In the place of standard lesion analysis we have proposed compensatory analysis as a means of dealing with hemispherectomized individuals. We have also collected some psychogenetic data from the first school years of a half-brained child with a normal mental development. I shall now deal with the notion of "cortical shift": the substitution of one brain area by another. This relates both to compensatory analysis and to education. In our case Nico has developed a new left brain in the sense that it performs many of the neural functions currently attributed to the right hemisphere. A cortical shift probably began at birth (or even before) because of his congenital left hemiplegia, then went a stage further at the early onset of his epileptic seizures and was firmly established following surgery. But there are other – artificial – means capable of producing a more specific kind of cortical shift. These are the computerized tools of today, which may act as genuine intellectual prostheses.

I want to show that with the help of computers it is possible to activate new brain areas and perform new cognitive tasks. For instance, when we use a word processor we organize new writing schemes which differ from those

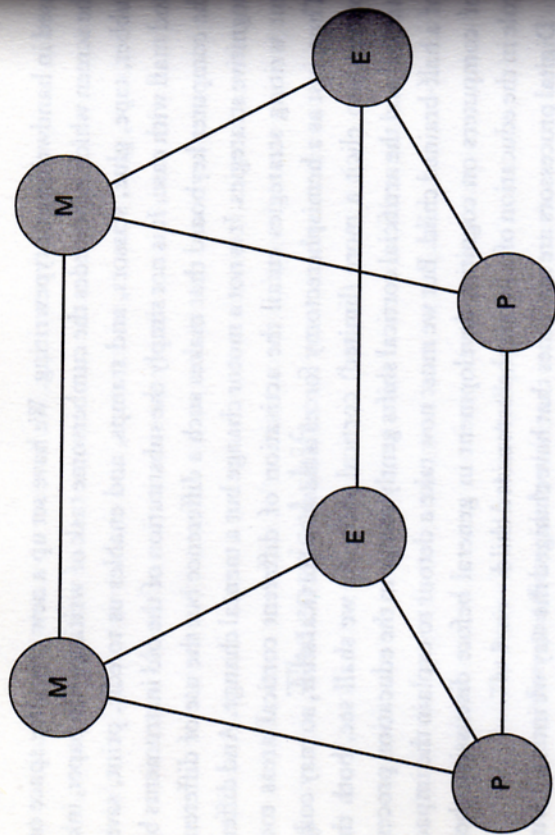


Figure 5.1 The connecting prism between Persons (P), Machines (M), and Environments (E).

of the memo (PME) she is sending via the local area network to the printer in the library (PMME). The connecting prism is activated here in four parallel ways emanating from the same source (P: the teacher).

This simple image may be useful in understanding the different relations between the components of our world, made up of artificial and natural things. The computer is "the machine of machines," the paradigm of the artificial, as Herbert A. Simon (1981) has brilliantly pointed out. The brain is, of all known natural objects, the most complex. Computers are now MM interconnected through the World Wide Web (WWW) by the millions. Brains have an inner-connectivity EE greater by many orders of magnitude than the WWW. I propose to call this EE network the "brain wide web (bww)." The idea of EE and MM as two interconnected fields might also help to give a wider view of our amazing capacity for connection as human beings. In the present case, the half-brain remains connected to both the natural and the artificial world.

In fact, Nico uses a computer to write, a digital machine that has changed his life and his experience of learning. As we have seen, instead of being handicapped by his poor handwriting, the word processor enables him to develop his writing skills with ease. In the prism of connectivity he is following a

longer path PME instead of taking the handwriting shortcut PE. He is better trained to use the machine than most children of his age. Furthermore, he has no trouble sending an email via the Internet at the highest level of distance interaction PMMP! This is the essence of the notion of an information prosthesis – it enhances human connectivity. The consequences of digital networking for the individual and society are considerable, particularly when the user is a disabled person. A half-brained child on the Internet is not a dream now, but when I talked about this possibility three years ago it sounded too good to be true!

And this is not all. With the computer's help his half-brain is capable of empowering its own inner-connectivity by making use of new cortical areas. This relates to the cortical shift in the brain which a computer can accomplish. Here we must take another detour to explore briefly the new field of information prosthetics before returning to the analysis of the artificial cortical shift in the half-brained child. The idea of using the computer as a cognitive tool for the disabled was introduced by Seymour Papert at MIT in 1978. He coined the expression "information prosthetics" at a time when few could imagine any possible humanitarian use for computers. This technological and sociological breakthrough opened up new ways of improving the quality of life of physically and mentally handicapped persons (Valente, 1983). Inspired by these remarkable models I myself became totally involved in the new field (Battro, 1986; Battro and Denham, 1989). I would now like to define "intellectual prostheses" as a subset of information prostheses in general. Indeed the latter category also includes "physical prostheses" (cochlear implants for the deaf, computerized limb stimulation for quadriplegics, banks of electrodes in the visual cortex for the blind, etc.). The intellectual prosthesis by contrast, does not imply any physical or direct contact between the nervous system and the computer. It is a purely functional prosthesis not a physical one. However, we can expect both "intellectual" and "physical" information prostheses to interact in the future in ways we can scarcely imagine today. To sum up: intellectual prostheses are computational devices which interface with human cognitive activities such as speaking, writing, reading, drawing, etc. In particular, they can "open" new cognitive pathways in the brain, produce a significant amplification of cognitive performance and the functional substitution of impaired cortical areas (Battro, 1994).

The notion of the cortical shift came to me when I was attempting to teach a quadriplegic architect how to use a computer. He was diagnosed as having multiple sclerosis at the height of a brilliant career and was forced to stop working. Our aim was to design an interface to communicate with the machine. The only choice was a voice recognition device, following the connection path PME. The learning process began with the vocal control of a "screen turtle" using the Logo computer language, initially with simple instructions (such as Forward and Right, Papert, 1980). He learned how to draw two dimensional pictures. Then, with the help of more powerful three-dimensional Logo instructions (such as Pitch, Roll and Veer), he began to draw elementary figures in space. The graphic results of three-dimensional Logo can be very beautiful and it gave him the ability to experiment with different scales and perspectives (Reggini, 1985). Having mastered voice-controlled Logo the architect embarked on a systematic training with voice-controlled CAD (Computer Aided Design). After several months of intensive practice he developed amazing vocal skills for drawing and was able to make a successful return to his profession as an architect. By means of a digital network link with his office he was able to send the layouts and plans from his home, where he worked. The connectivity was established via a complex series of interfaces, PMME. The end result was the printout of the architectural project at a remote printer (Battro, 1994).

From a neurocognitive point of view it is interesting to analyze the difference between the practice of prosthetic drawing using speech recognition devices, and common hand-drawing. The difference between the two situations is in the topology of the cognitive pathways activated in the brain. It is known that many cortical areas are involved in saying a word. Even the cerebellum is active during a simple speech utterance (Posner and Reichl, 1994). Other cortical areas however are involved when moving the hand, as in the act of drawing or typing. Used as an intellectual prosthesis, the computer functions as a switch to pass from one modality (hand-drawing) to the other (speech-drawing).

Drawing by hand is a typical analog skill. Speech-drawing, by contrast, is a digital one in the sense that spoken sentences are chains of discrete elements such as words, syllables or phonemes. When drawing by hand the cognitive pathways must be kept open to continuous motor control. This is not

necessary when the artist is drawing vocally with the aid of a computer because of the digital nature of speech. For example, it is difficult, if not impossible, for an aphasic artist to make a computer drawing using only speech instructions because of the specific language impairment. Yet the analog cognitive pathway used to make a drawing by hand may remain intact. It is recognized that a right-handed draftsman can produce the same pattern as a left-handed one, i.e. it is quite impossible to distinguish between brain dominances from the quality of the drawing. Moreover, clinical practice shows that even with severe (written or spoken) language impairments, many right-handed hemiplegic aphasics can readily learn to use their left hand to draw and paint.

One thing is certain, before the arrival of computers no human mind had ever produced a drawing using speech instructions alone (although in ancient Peru, Inca architects were known as "the men who give orders aloud"). We cannot imagine Michelangelo drawing up the plans for St Peter's by giving his assistants step-by-step instructions on how to produce the layout, or painting the Sistine Chapel by shouting out "some red there" or "a line here" to his apprentices. Nowadays, however, such a feat is technically possible. A computer can make such a cortical switch possible. When a human operator uses his voice to draw he activates a new neuronal network never previously engaged in the act of drawing. This switch to a new cognitive path is the essence of every intellectual prosthesis. In other words, intellectual prostheses help the brain to perform cognitive tasks previously processed by a totally different area of the cortex. Neuronal networks can be substituted or bypassed by new cognitive paths driven by computer instructions. This fact has very important consequences in clinical practice and special education, particularly in the education of a half-brained child.

The "architect who drew with his voice" followed a learning process involving a sequence of prosthetic tools: Logo 2D, Logo 3D and finally CAD. The teaching of geometry at school also starts with two-dimensional flat figures and ends with three-dimensional volumes. This is a secular pedagogical tradition dating back to the times of Euclid, and even for Piaget, the spontaneous cognitive development of Euclidean geometry follows this two-dimensional to three-dimensional sequence (Piaget, Inhelder and Szeminska, 1948). But perhaps this sequence is not so formally ineluctable or psychologically compelling, as was thought. Computers can radically change

the teaching of geometry and graphic design, and also our view of the cognitive processes involved. For instance, we are now entering the virtual reality VR era which will transform the way we look and manipulate things. The post hoc (VR) simulation of Nico's right hemispherectomy illustrated in Chapter 2 is a pertinent example of this.

Let us analyze Nico's specific difficulty with drawing by hand, his "analog" drawing using a pen, and the alternative strategy of "digital" drawing using a computer. We can compare the two cognitive processes, analog and digital, with the use of a simple but powerful computer tool such as Logo. Papert's original idea was to enable the user, usually a child, "to teach" the machine to produce a drawing (and many other things) on the computer screen. The small figure of a turtle on the screen behaves like the actual tip of an electronic pen. Nico is learning Logo at school and he likes it very much. One day I asked him to draw a bridge (a rectangular figure) using the simple instructions Forward and Right. He carefully began to explore how these two instructions moved the turtle, step by step: Forward 40, Right 90, then Forward 40 and Forward 40 again. In order to make the turtle "go down" he typed Left 90, but the turtle "turned up," a common error. He corrected the rotation by typing Right 90 and Right 90 again. This is an interesting strategy for coping with a subtle question of orientation in space. Finally he ended with a Forward 40, and the "bridge" was complete. Nico arrived at a satisfactory solution by using local on the spot corrections via the visual feedback on the screen, the "direct" mode of teaching the turtle (pen) to draw. I next tried to explore a higher cognitive process which the "procedural" mode would imply, i.e. to write a small program in abstracto, without the benefit of the visual feedback from the turtle on the screen. Nico was receptive to new things that day and he wrote a Logo procedure without hesitation:

```
To bridge
Forward 40
Left 90
Forward 40
Forward 40
Left 90
Forward 40
End
```

He repeated the numbers 40 and 90, but he switched from Right to Left, which shows that he had not simply memorized the previous sequence of instructions but was creating a new way of doing things. When he typed "bridge" a neat, correct rectangular drawing appeared on the screen. He was amused and continued to type the word "bridge" making many new drawings. The session finished at that point. Nico returned to class and I began my analysis of the cognitive process involved in this simple but highly significant procedure. I have been working with Logo and handicapped children for nearly two decades and I am still convinced that it is a remarkable educational tool. But now, in the neurocognitive era, I feel that Logo might also offer a new and simple way of identifying the cortical shift in some spatial and geometric skills. For example, as we know, Nico is unable to use a ruler and set square with his left - disabled - hand and his capacity to draw geometric figures (the connecting path PE) with his right hand is therefore greatly reduced.

The important thing is that after a brief explanation Nico was able to conceive and execute some simple Logo procedures which produced correct geometric designs. In less than ten minutes he learned to program the machine (the path PME) to produce a diagram of a rudimentary bridge. Elementary though this graphic production might be, it is a cognitive feat. First, it supposes an accurate representation of the screen space and second, a sufficient command of the computer language. Besides "turtle geometry" is an "intrinsic" geometry, the concepts of left and right only make sense "locally" without reference to the actual computer co-ordinates or to the user's own body schema. Any Logo teacher knows how difficult it is for a child to detach the concept of right and left from the corresponding parts of his body when the turtle on the screen is "pointing down," for example. How much more difficult must it be for a right hemispherectomized, hemianopic and hemiplegic child with a lopsided body scheme! Not only does Nico's left brain compensate for the geometric skills of the missing right cortex, it is also an indication of the intra cortical shift from an analog to a digital representation of geometric shapes. Programming the figures in abstracto on the computer screen implies a cognitive anticipation of the graphic results and a fair representation of the computer procedure.

One year later Nico was able to carry out some more complex programs with Logo (using microworlds, lcsi). In a couple of sessions he produced a

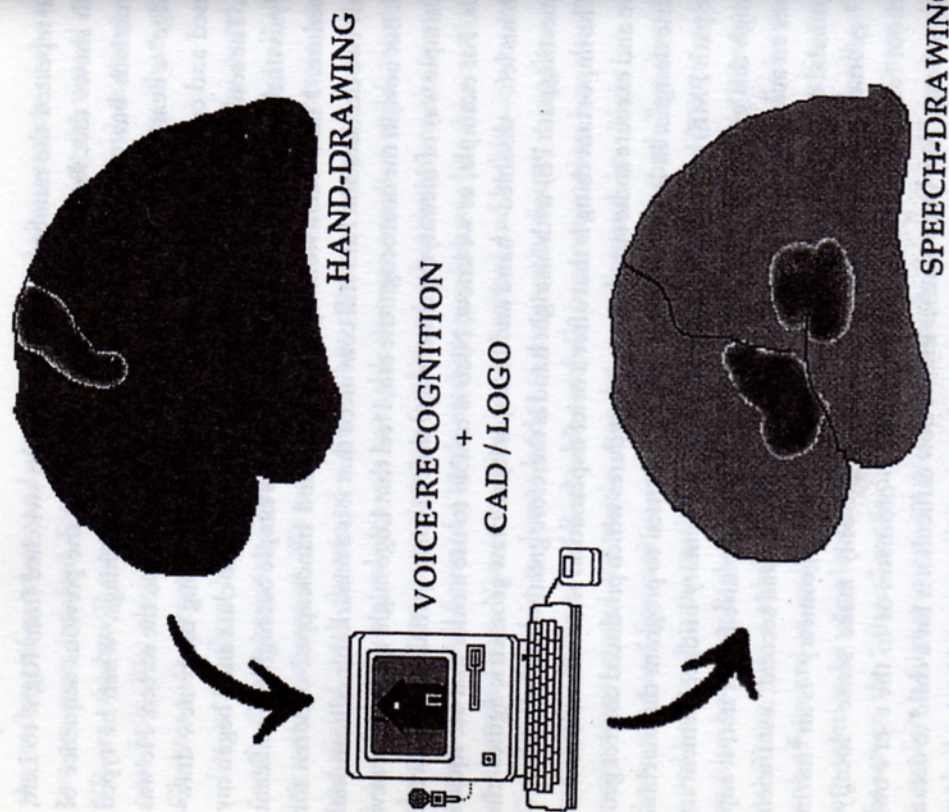


Figure 5.2 The computer can switch the brain from one cognitive mode (hand-drawing) to the other (speech-drawing).

remarkable piece of art, a frame of colored squares with his signature. This is an example of the dual property of his graphic skills. On one side he has written the instructions "to square" and "to frame" (using "repeat . . . square"), a purely digital task. On the other, he has used the mouse to draw and paint the letters of his name in the center of the picture, an analog task.

I predict that brain imaging will soon reveal the disparity of the cortical processes involved in this particular cognitive substitution of the analog by

the digital language. Such a disparity has also been discovered in the cortical location of first and second natural languages (Dehaene *et al.*, 1997).

Nico enjoys using the computer. It is gratifying to see his laptop always open during class hours. This is the realization of a success story made possible by the continuous work and tireless technological efforts of a multitude of scientists and teachers round the world over the last two decades. Nowadays there is almost no sensory or motor impairment that cannot be overcome by an appropriate prosthetic device (Borden, Vanderheiden *et al.*, 1994). In Nico's case any standard computer can be used because he needs no special aid to operate the keyboard, control the printer, hear the sounds or see the images on the monitor. He is also lucky to have so many computers at his disposal and, what is even more important, to be the recipient of so much good-natured support in his computer work. The principal cortical shift in his left brain, forced in the first instance by the disabled right epileptic brain and subsequently by the right hemispherectomy, is empowered by this secondary cortical shift produced by the computer which substitutes his poor handwriting and drawing. Here then we have a double cortical shift in the same half-brain: one biological — the left hemisphere taking on most of the functions of the right hemisphere, the other artificial — the computer operations which change the very nature of writing and drawing and open new cognitive pathways in the brain.