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COMPUTERS AND EDUCATION: MAIN THEMES AND A GUIDE TO THE LITERATURE*

by

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1. Introduction

In a recent issue of Computers and education A.E.Blandford, while reviewing a book on Computer Assisted Learning, complains that the book "opens with the (inevitable?) brief description of what a computer is and does, followed by a superficial analysis of what is involved in 'education' ...". The danger of being "superficial" is indeed ever present, and more so in a short introduction to a book; but a reflexion on the social projects related to computer technology and the school institution is indeed "inevitable". It seems to me that, if there is anything to complain about, it should be rather the scarcity than the abundance of these kinds of reflexions.

The fact that most books on the general theme "computers and education" avoid these issues, taking for granted some sort of implicit, common agreement on the fundamental choice of invading by computer technology social relations (and, in particular, teacher/pupil relations), is neither a choice of style nor the fear of being necessarily "superficial". It is instead the choice to submit passively to some variety of the dominant technological imperative: "everything that can be (technically) made should be - or will be - realized". This leads people to ask: how?; I rather think we should ask first: why?

It is only if we merge the theme "computers and education" in the larger context of the social representation of both informatics and the school project that we shall be able to pose efficiently the problem of the possible choices and of our possible critical acceptance of some aspects of the new technologies. How can we explore the very complex world of the children's representation of the space of informatics, if we do not also explore that of the corresponding adults' (and therefore teachers') representation? But an analysis of the social representations is not enough; we should try and get at the same time some sort of technical understanding of the roots of computer power.

It is certainly true that computer science can open for us "possible worlds"; but we should be ready to recognize why, by whom and in the interest of whom these worlds are made possible to now. Not all possible worlds are easier to live in than the present one. Remember the title of a Broadway musical: "Stop the world, I want to get off!"; perhaps, at some station, we too should try and get off...

2. The social representation of the computer

"Only another gift of science has been so universally recognized as marking a new era of human life. That was atomic energy". So it has been said of the computer (Turkle (1984), p.65). A "new era", perhaps; but a "gift"?

Every new machine-wonder has been presented as a "gift to humanity";

so often, "humanity" (whatever this term means) had not asked for it. But every new machine has been claimed to solve, each time, the "problems of society"; strangely enough, those problems were generally defined as just those that the new machine could help solving (and, sometimes, did indeed create).

So it is now for the computer. The social representation that is being constructed starts from the definition of the new needs: rapid communication, intense exchange and retrieval of information, transfer to automata of previously human data handling. What is generally ignored is that these new needs have mostly been created by the same social forces that at present offer new solutions for them. When you become conscious of this troubling fact, some sort of healthy skepticism and mistrust becomes necessary with respect to the extravagant claims of "a new, post-industrial (computerized) society".

The social imagery of the impact of the computer in the social context is cloudy, but it seems to oscillate between the poles of metaphorical dicotomies of the sort: "computers and thought", "computers and intelligence", "computers and freedom" and the like. These metaphores introduce to a dream-world of total and fast control on nature, on society and on the (material and conceptual) production processes, but they do not help to discover the forces and the interests driving the necessary transformations towards the dream-world. On the contrary, they all participate in creating the passive acceptance of the technological imperative.

Computing science is there, and computers are there to stay. It is urgent to define the space and scope of our possible choices and, when no choice is left, to identify the space and scope of those choices due to other forces and interests in our society. What should be clear is that no choice is imposed on us by technology alone.

3. The social representation of the school institution

A similar situation holds true for the introduction of computers in the school institution. Equally cloudy metaphores occlude the possibility of identifying the relevant forces and interests and the corresponding pedagogical projects. The social representation of computers as providers of "powerful or exciting ideas", "self-construction of knowledge" and "creation of microworlds" for and by the pupils helps covering the fact that the difficulties encountered in the teacher/pupil and in the pupil/knowledge relations are definitely not due to technological problems. Paper and pencil can solve (and create) relational problems almost as much as a computer does.

An abstract discussion of the need and impact of computers in education is nonsense. What is needed is a clarification of the social projects that are differently realized, in different contexts, through the school institution. Some of these projects either do not need computers, or can make use of them only marginally; other on the contrary badly need computers, irrespectively of their social cost. Once again, no technological imperative should be accepted. A school institution (and the corresponding pedagogical projects) that accepts computers as an integral part of its didactical machinery chooses to do so, it does not comply to technology. It is therefore important to learn and ask why it chooses so, and what the social costs of the choice will presumably be.

4. The technical roots of computer power

The easy acceptance of the above mentioned cloudy metaphores about computers and learning are favored by a very general lack of information (and, sometimes, of interest) in the technical roots of computer power. A better understanding of these roots and of the underlying physical and logical phenomena can give us, if not necessarily more power in countering the devastating effects of the technological imperative, at least a more lucid outlook and some useful tools for making choices and defining priorities.

Hardware (the physical implementation of the logical structure of the computer) and software (the languages and texts that allow human/computer interaction) have been artificially separated; the former is seen as the realm of the experts in computing engineering (and therefore as inessential for most of us), the latter as the realm of the computer user. Even in the domain of software, a sharp separation is more and more becoming clear between those who write computer programs (programmers) and those who make use of them as they make use of a television program (consumers). The more these separations are passively accepted, the harder it will be to move with some ease in the space of informatics. Even if the technical tools of contemporary hardware are beyond the comprehension of the general teacher, so that the physical anatomy of a computer can be impossible to master, its functional anatomy can be understood and can help understanding the main choices and potentialities of the different programming languages. Even more, it is essentially this network of relations among structure/function/language/program that gives the computer its power. Taking hold only of the last link of the chain and transforming ourselves into pure consumers on the computer market implies a severe weakening of our possibility to argue, to counteract, to oppose any mystifying pretence about computer power.

5. The computer in the school

So many different motivations have been given for the need to integrate the computer into the school system that one gets sometimes the uneasy feeling that we are looking for a school for the computer, and not for a computer for the school (a rich sample of these motivations is given in O'Shea (1983), p.2). One of the possible typologies of the potential interest of the computer in a pedagogical project has been given by Taylor (1980): the computer as a tutor (e.g., in programmed learning), as a tool (e.g., in the exploration of mathematical models) and as a tutee (in, e.g., advanced information processing). Another typology is that discussed, for instance, by Neuwirth et al (1984): learning with the computer, learning through the computer and learning about the computer. These typologies have their merits, but they seem to me too rigid to accomodate some of the most interesting aspects of the present debate on the role and space of informatics in the school institution. These aspects are essentially related to the epistemological and psycho-cognitive components of the relation of teachers and pupils to a programmed and programmable machine. How do they learn to make use of a formal as opposed to a natural language? How and why do they restructure their knowledge and their ways to get new knowledge in order to be able to interact with the computer?

The crucial point in the present debate is therefore the choice between an active participation of both teachers and pupils in the triangular pupil/teacher/computer relation, as opposed to a passive participation of the pupils in the more instrumental pupil/computer relation. Both active and passive attitudes can be found in the act of learning with, through and about computers. A tool can be used as such (and you can even be unable to resharpen it after use), as in so many CAL (Computer Assisted Learning) programs; but it can also be actively contructed by the class, as in some intelligent utilisations of the LOGO language. A programming language can be accepted as such, but it can also be seen as an object of knowledge, to be continuously transformed and enriched to satisfy new needs (by defining into it, for instance, new primitives).

It is only in the frame of a well defined pedagogical (and social) project that the choice between active and passive participation will be possible. Emphasis on memorisation of notions, fast reading, respect of cognitive and social norms, and clever learning of problem solving tricks will favour the passive approach. If the product will be (social) automata, you will not say that the school system has failed, but on the contrary that it has produced the goods they were looking for. Emphasis on critical learning, experimenting, group participation in the acquisition of knowledge, and intense teacher/pupil interaction will favour the active approach. One should be aware of the choices and of the projects and ideologies beyond it, and act consequently.

5.1 Methods and choices

I shall assume henceforth that an active participation has been chosen. This, unfortunately, is not the end of the story! Many other choices lie ahead, and should be made on the basis of the specific project which is being studied. To list a few of them:

- at which grade to introduce children to computer literacy?
- what defines the specificity of the space of informatics at each given level of schooling?
- which relative emphasis has to be given to an understanding of the computer's functional anatomy, of programming, of using the programs in the context of the curriculum, of exploring open regions of mathematics etc., of using the computer as a word processor, a calculator, a tabulator, a drawing board, etc.?
- which formal language(s) to choose?
- how to integrate autonomous with guided learning in a computer environment?
- how to integrate personal activity with group and class activity in a computer environment?

It is clear that many of these choices demand a previously defined philosophy of education, which is much broader in scope than the integration of the computer in the school system. Very often, the choices made in the name of the computer are indeed ideological choices covered by the computer's glamour.

5.2 Against baroque software

One choice should be evident: that against all sorts of baroque software. The educational software proposed for school use is more and more filled by useless, showy material (brilliant and changing color displays, Gothic letters, dazzling moving indicators, etc.) that are generally useless and hide the cognitive and pedagogical poverty of the program. They do worse than that, howewer: they convince teachers and pupils of the impossibility to create themselves the required software and other pedagogical aids. You can easily compete with the creators of many software programs on the level of cognitive significance and pertinence, but you cannot compete with them on the level of graphic display!

Another choice should be evident: that against all sorts of baroque graphic representations. As a matter of fact, a subtle tendency is taking hold of recent: that of the ready-made iconic representations. Windows, menus, "objects' symbols" and the like are invading the screen. Three-dimensional (and even four-dimensional) coordinate systems plop on the screen with the help of the "mouse", turn at your will, project down on any desired plane... Much of this machinery could be of use at a research level, where the underlying conceptual components can be assumed to be already mastered by the scientist. But, at school level, the very richness of the offered representations hardly will stimulate the personal effort of visualisation, spatialisation and anticipation necessary for the active mastery of a cognitive domain; and even less, the collective effort of the teacher and the pupils to construct and motivate the necessary tools (geometric and informatic) that make these representations possible.

Remember that the best antidotes against baroque software and baroque graphic displays are still the paper and the pencil!

5.3 Formative evaluation of the computer impact

Several forms of evaluation are proposed to teachers, to assess programs, classroom curricula, teacher/pupil relation, knowledge mastery, etc. They generally run through a sophisticated ritual of pre-tests/tests/post-tests and seem to be better esteemed if they make use of the most modern statistical machinery. It often happens that the data, and the evaluation context, are just not strong enough to tolerate this machinery; the result being nonsense given with several significant digits.

In a formative evaluation, the risk of producing nonsense is smaller if not absent. What one tries to evaluate there is more the processes leading to the mastery of some specific knowledge than the actual knowledge; this implies a more subtle approach and a technique that can be similar to Piaget's "clinical interview": the results should be more qualitative than quantitative. A task is assigned, the tools necessary for analysing and solving it are discussed and if necessary constructed by the subject, the results are then submitted to a critical review by both the subject and the experimenter. An additional advantage of this technique of evaluation is the fact that the psycho-cognitive and the psycho-pedagogical components in the acquisition of knowledge can be evaluated in an integrated way and in contexts that are specific to each given domain.

It seems to me that specific forms of formative evaluations should be developed and used to assess the impact of the computer presence in the school. The other forms (in particular, the traditional summative evaluations) are too rigid to lead to significant results. The space of informatics is multi-dimensional, and several quite different paths can lead to a seemingly identical mastery of the subject. But the different paths will be highly non equivalent, from the psycho-cognitive point of view, and it is only the exploration along these paths (and not at the final stage) that can illuminate the impact of the opening of these new dimensions in the structuring of the cognitive charts of the pupil.

5.4 Computer literacy and the learning processes

When you start teaching music in the school, you do not ask yourself about the impact that this new domain will have (or should have) on the learning of, let us say, geography. You have rather the impression that you are opening up a new dimension and offering new possibilities of expression and representation to your pupils. It is then up to them (in the given scholastic and social context) to integrate this new dimension into the rest of their cultural background.

It should be the same with informatics, even if in this case it is not computer science as a new domain that should enter the curriculum (at least at elementary and secondary level) but rather the several components (formal language, data handling and structuring, problem solving, interpretation and representation of results, etc.) that constitute the space of informatics, integrated into the curriculum. These dimensions are not necessarily new, as they should be present in any domain of active teaching and learning; but they are surely present with a very specific emphasis in the domain of informatics, where they have to be made explicit to the pupils together with their limits and shortcomings.

Therefore it seems to me that some of the current discussion on the impact of computer use on the learning processes is biased by the misconception that the entrance of the pupils into this new space of informatics should necessarily, and directly, improve their skills in some other clear cut domain of the curriculum, be it physics, geometry, etc. As a matter of fact, it could even make things worse for them, by making them more conscious of the repetitive, passive, uninteresting way in which the other domains are covered. If you get some taste of the pleasure to explore, for instance, open mathematics (i.e., mathematical domains where some of the most interesting solutions are not already known and trivial to the teacher), the task of learning standand formulae and Euclidian theorems could become even more boring.

The emphasis of any evaluation of computer introduction in school practice, therefore, should be not so much on how much better pupils could afterwards realize traditional curriculum tasks, as on how many new tasks they could realize that go beyond the traditional tasks. This will not suffice, however; an analysis of the pertinence and relevance of these new performances in any given pedagogical project should be carefully assessed, to avoid creating *a priori* new (and sometimes highly artificial) needs - as in the graphical presentation of a text, etc. - just in order to solve them through the computer. The new performances should therefore be such that their transfer to the more traditional school practice be both possible and useful.

5.5 Computer literacy and school curriculum

Among the choices outlined in point 5.1., one is particularly important: that between teaching informatics versus teaching to integrate informatics into the school curriculum. At the primary and secondary school level, I think that it will be coherent with the ideas developed so far to choose the second solution (which implies that there should not be teachers of informatics, but only teachers acquainted with informatics and with access to computers in the laboratory or in the classroom).

Once this choice is made, there is still the choice of how to integrate the computer to the curriculum. To integrate it separately in each given and traditional discipline would be to waste the interesting interdisciplinary potentialities of the space of informatics. It is clear that some mastery of programming and spatial representation by computer could help the traditional setting of mathematics, physics, ... learning, but it would be silly to keep at these restricted applications. The real strength of the new tool is its possibility to confront several domains of open investigation, as I have already noticed; and these domains are almost always highly interdisciplinary (one could say that they are open just because they are interdisciplinary: the traditional reduction of complexity to foundations has been impossible for them in the frame of a single discipline). A very good example comes form ecological thinking (in many domains: biology, economics, sociology, psychology, ...), where the interaction of the different factors and their relevance can only be studied by introducing concepts, formalisms, representations proper to several disciplines.

"Learning by doing", therefore, demands the introduction of the computer in the curriculum to be centered on the exploratory activities it could make possible (without at any moment forgetting that quite meaningful and active exploration by the pupils and by the entire class is possible and desirable without the computer). We should therefore isolate those exploratory activities that could not be realized without a computer, and show their continuity and relevance with respect to those exploratory activities that, on the contrary, could indeed (and should indeed) be realized without a computer. This unfolding of a given task from the personal reflexion, the analysis of the personal experience, the qualitative and conceptual approach, the discovery of the limitations of the conceptual and formal tools at our disposal, to the more complex and often quantitative analysis allowed by the computer describes the best possible way to integrate the computer practice into the school curriculum.

5.5.1 Early and primary education

How "early" this computer literacy should start is a matter of choice, and the relative debate reflects more the ideological push to computerize society than any deeper reflexion on the process of children socialisation. Piaget has been used (and misused) to discover that the "active manipulation" needed by children to develop operational skills could be perfectly provided by the manipulation of the keys of a microcomputer; and that the "active construction of spatial relations" needed to master the topological, projective and euclidean nature of physical space could be equally well provided by the guided motion of a "tortue" on a (two-dimensional) computer screen. An exploration of the literature requires therefore a very careful and diffident approach: a few claims could be true (the interest for play and games where interaction is possible and pleasant, for instance), most will at best be doubtful and a few will be squarely dangerous. Beware of the personal, commercial, industrial, political interests that underlie the projects to use the preschool period as "an excellent psychological conditioning period to introduce computers" (R.Palamara, in Long (1982), p.312) !

As always, the new technologies (including computers) have been presented as the obvious response to the difficulty of learning to read, to write, to operate with simple geometrical and arithmetical concepts in primary schools; as always, the social, affective and psycho-cognitive roots of these difficulties have not been either explored or taken notice of, to show that computer manipulation could indeed be of help in solving them. The problem is therefore still open and a careful evaluation of the specific social and scholastic context should be made before embarking in costly programs of computer helped spelling, arithmetics and geometry.

5.5.2 Secondary education

The role of computers and educational software in secondary education is better defined. I think that the main point to keep in mind is that computers should never come first; they should, at the contrary, be a sort of last appeal when and where the simpler and often qualitative tools of discussion, reflexion, gestual and paper-and-pencil representations reach their limits. Qualitative analysis (which includes order of magnitude guessing, topological understanding of spatial relations, probabilistic and modal approaches to deduction schemes, etc.) should therefore create the interest and the need for a more quantitative approach, which can often receive a considerable help by computers.

On the other hand, computers could themselves provide the domain of exploration of some of the qualitative properties of a system, as in the study of the time evolution of a dynamical system (where some qualitatative properties - e.g., the presence of closed orbits - can be studied independently of a careful quantitative calculation).

Simulation and modelling are therefore the most useful activities in the mastery of open domains of knowledge by computers, once the first qualitative and cognitive analysis of the given problem has been performed and the need for a deeper analysis has been recognized.

Most of these models will be interdisciplinary, even if centered on specific disciplines: ecological models of species and environment interaction by finite difference equations, biological models of morphogenesis and evolution by cellular automata, chemical models of periodic reactions by negative feedback systems, physical models of dynamical systems by dynamical simulation on the screen, etc. What is more, mathematics, that most rigid and dogmatic of all disciplines as seen from the pupils' point of view, can become delightfully experimental. I do not want to imply that some of this exploratory and modelling activity cound not be performed without the computer, but it would surely be too difficult to pursue it beyond certain very limited boundaries.

More in general, the modelling activity itself can become an object of knowledge, irrespectively of the specific domain to which it applies (to speak of an "object of knowledge" implies of course not only to explore its interest but also to understand its limits); and this can lead to a useful investigation on the notions of variable, parameter, constant and of their functional dependence.

Another object of knowledge that presents itself in the interaction of the pupils with the computer is the computer language; more in general, the need to go from natural languages to formal languages to deal with delicate matters (as in mathematics) and with machines (as in programming). What is gained? What is lost? But, on any object of knowledge, you should be able to perform transformations; and so with programming languages and other sort of educational software (which excludes the baroque and obscure software that is invading the market).

And then, I would not forget games as a significant computer domain in secondary education; games to invent and construct anew, not only to play; new games to extend well known children games into the new space offered by the computer (an exploration of new rules and their effect, and the discovery of potential contradictions, for instance, are both good introductions to axiomatics and model-building).

5.5.3 Higher education

In college and university education, as well as in professional and technical schools, the computer obviously becomes a necessary tool, but no general assessment can be made of its role and impact, outside each specific educational field and project. Which of the three tutor/tool/tutee aspects should dominate will clearly depend on the relative emphasis to be given to the mastery and control of information, to the simulation/modelling activities, to the professional skills required in software and hardware control.

I think however that it could still be said, in general, that active mastery of the space of informatics at each level of professional competence will always be highly preferable to a passive, consumer-oriented approach. Some understanding of the essentials of hardware and of programming, some ability to have access to and to transform the software employed in any project, some awareness of the limits of any modelling activity should always be welcome in students and stimulated by teachers. Teachers and students will be less easily victims of baroque software if they are used to think of computers as powerful interactive systems and not as (highly perfected) television or radio sets.

6. Conclusions: the computer and the pedagogical project

The considerations above lead to a few conclusions, concerning the potentialities and the interest of computers in the educational system. I shall try and list them in a very schematic, but perhaps still useful, way:

a. There is no objective, intrinsic need for a massive introduction of computers at all levels of schooling. The arguments to the contrary are ill defined and often depend on wishful thinking ("things go so badly in schools that any new gadget will surely help") or, even worse, on commercial, economical and ideological outside pressure. The deep difficulties encountered by the present pedagogical project in our schools do not depend on the presence or absence of yet another technological gadget. If the (social and cognitive) roots of these difficulties are not recognized, the introduction of the computer will only be useful to hide and cover them for a short while.

b. A massive investment on computers and a passive use of their processing, computing and graphic potentialities in the educational context could only emphasize the mechanical way of learning that characterizes our schools and that satisfies the social need to create (socially and cognitively) normalized automata.

c. An overemphasis on the power of the computer, and the creation of a new computer-dependency, will make the children own's construction of knowledge poorer and more hesitant, as the true and perfect knowledge will be, by definition, that enbodied into the machine. The limits of the computer and of any quantified and computerized approach to knowledge should be studied and made explicit at the same time as their obvious advantages.

c. A careful use of computers, preceded by personal analysis, reflexion and qualitative reasoning, collectively discussed at class level, could provide some interesting tools to teachers and pupils, help them in exploring and unfolding tentative guesses and more formal models, allow them to keep, trace and process a large quantity of information.

d. The positive scenario of point c. could only become reality if the introduction of computers in the pedagogical project is controlled and gradual, and if it takes place at the same time as more fundamental changes: a larger autonomy of the students in the learning projects, a deepened sensitivity of the teachers to the affective, psycho-cognitive and psycho-pedagogical realities of the children construction of knowledge.

As a last warning, I would like to propose to the reflexion of the reader the following sentence:

"... <u>the computer is a powerful new metaphor for helping us to understand many aspects of the world, but it enslaves the mind that has no other metaphors and few other resources to call on</u>." (<u>Weizenbaum</u> (1976), p.277 of the 1984 Penguin edition).

7. <u>A guide to the literature</u>

A warning: don't be scared by the abundance of the literature in this field. One just cannot read <u>everything</u>. So start from the most recent publications and, if needed, go backward to the older ones; you will discover that many things have been said many times again.

1. <u>Introduction</u>

The basic and indispensable reference is still to <u>Weizenbaum</u> (1976); see, in particular, the new Preface to the Penguin (1984) edition.

Several recent contributions on the general theme "Computers and education" can be found in <u>Barcelona</u> (1987). A very useful and clear presentation of the cognitive space covered by computer science is given by <u>IREM</u> (1986) and <u>Di Sessa</u> (1985). See also <u>Dionnet et al</u> (1987) for an analysis of computer literacy relevance in an extra-scholastic context.

2. <u>The social representation of the computer</u>

Here again, <u>Weizenbaum</u> (1976) is a necessary tool for the exploration of the different roots of the social representation of the computer; see, in particular, chs.1 and 6.

Books: <u>Bolter</u> (1984), <u>Nivat</u> (1984), <u>Turkle</u> (1984), <u>Card et al</u> (1983), <u>Papert</u> (1980), <u>Dreyfuss</u> (1979), <u>Feigebaum et al</u> (1963).

Relevant sets of articles: <u>RSJ</u> (1985), <u>Boston Review</u> (1982), <u>Byte</u> (1982).

On the technological imperative: <u>Taylor et al</u> (1986), <u>Boyd</u> (1983), <u>Weizenbaum</u> (1976), ch.10 .

Just for an example of the worse mystification of the role of a computer culture in industrialised societies, see <u>Naymark</u> (1985).

On the possible social costs of a computer education (and society): <u>Lepper</u> (1985).

On the self-representation of children with respect to their relation to computers: <u>Clarke</u> (1985).

3. <u>The social representation of the school institution</u>

The most detailed and emphatic presentation of the ideology surrounding the school institution and its pedagogical projects in industrialised societies is the UNESCO-sponsored <u>Apprendre à être</u>, edited by E.Faure (<u>Faure</u> (1972)).

See also Walker (1986), Papert (1980a), (1978), (1972).

4. The technical roots of computer power

A good introduction to the functional anatomy of a computer is given by Weizenbaum (1976), chs.2 and 3.

A definition and a detailed discussion of the relevant dimensions of the space of informatics is given in Dionnet et al (1987); the computational environment is carefully described in Di Sessa (1985).

On the human/computer interaction: Newell et al (1985), Card et al (1980).

5. The computer in the school

The literature here in immense; I have tried to choose a few significant contributions only.

Books: Chen et al (1986), Delval (1986), Culbertson et al (1986), Siegel et al (1986), O'Shea et al (1983), Steinberg (1984), Tinsley et al (1984), Bundy (1983), Lesgold et al (1983), Megarry et al (1983), Yazdani (1983), Bossuet (1982), White (1982), Bork (1981), Schwartz (1981), Simon (1981), Hallworth et al (1980), Papert (1980), Taylor (1980), Von Feldt (1977), Lecarme et al (1975).

Articles and contributions to Conferences: Barcelona (1987), Chevigny (1986), Schank (1986), Searson (1986), Computers and education (1985), Extending the human mind (1985), Hoyles et al (1985), Lepper (1985), L'ordinateur et l'écolier (1985), White (1985), Moonen et al (1984), Neuwirth et al (1984), Papert (1981), Wertz (1981), Papert (1972).

For a more critical outlook: Olson et al (1986), Shallis (1985).

On CAL (Computer Assisted Learning), see CE (1986); the tenets of CAL are clearly presented in Bundy (1983), pp.259ff.

Several journals cover the field, for instance: Computers and Education, Computers in Human Behavior, Computers in the Schools, The Computing Teacher, Educational Technology, Education et Informatique, European Journal of Psychology of Education, Human-computer Interaction, International Review of Education, Journal of Computer-based Instruction, Journal of Educational Computing Research, Journal of Research on Science Teaching, Machine-mediated Learning, Savoir, Simulation/games for learning, University Computing.

5.1. Methods and choices

On the general theme of the choices that should be made: Margiotta (1987), Leron (1984), Howe et al (1983).

On the choice of teaching and learning methods: Howe et al (1983), Wertz (1981), Papert (1972).

On the choice of a formal language: Pea (1986) (on language independent conceptual bugs), Harvey (1982) (a confrontation of

FORTRAN and LOGO), Howe et al (1982) (a confrontation of LOGO, LISP, PASCAL and BASIC), Bork (1981) (a confrontation of FORTRAN, ALGOL and BASIC), Laubsch et al (1979) (for a LISP-based educational system), Higman (1973).

On LOGO and its pedagogical and psycho-cognitive implications: see for instance Hillel (1987), Samurcay (1987), Samurcay et al (1987), Bourbon (1986), Mendelsohn (1985), Papert (1980), (1980a), (1978).

5.2. Against baroque software

A tentative to give some general guidelines for an evaluation of the didactical software is discussed in Marucci (1986); see also Sanders et al (1983). For early and primary education software, see Clements (1985), ch.7.

5.3. Formative evaluation of the computer impact

On formative evaluation, see Bendon et al (1987). The classic presentation and confrontation of the different sorts of evaluation is still Bloom et al (1971); see also IJER (1987). A careful assessment of the danger of separating (formative) evaluation from pedagogical practice is in Bain (1986).

For same examples of evaluation of the computer impact on education: Watt et al (1987), Atlanta (1986), Pea et al (1984); for the special case of mathematics, see Brown et al (1978). Two good general reviews of evaluation studies on the effectiveness of CBI (Computer Based Instruction) are given by Niemiec et al (1987) and Hasselbring (1986).

For an example of formative evaluation of informatics outside the school context, see Dionnet et al (1987), (1987a).

5.4. Computer literacy and the learning processes

Books: Lawler (1985) (with a rich bibliography), Wilkinson (1983).

On the general theme: Clements (1987), (1986), Dalbey et al (1986), Linn (1986), Linn et al (1986), Rogalsky et al (1986), Unterwood (1986), Linn (1985), Linn et al (1985), Mohamed (1985), Pea at al (1985), Retschitzki (1985), Pea et al (1984) (with a rich bibliography), Brown (1982), Howe (1980), Papert (1978).

On the deployment of "higher order thinking" through computer experience: Laubsch et al (1979), Patterson et al (1986).

On the novelty and richness of the space of informatics: Dionnet et al (1987), Di Sessa (1985).

On the development of spatial representations: Mendelsohn (1986).

On the possibility of defining "developmental stages" in programming skills: Howe (1980).

5.5. Computer literacy and school curriculum

On the general theme: Mudd et al (1987), Hoyles et al (1986a), (1986b), (1987), Walker (1986), Brown (1982), Dennet (1982), Howe (1980).

5.5.1. Early and primary education

A very complete and informed book is Clements (1985), with a very rich bibliography; see also Berdonneau (1984).

Articles: Biancaniello (1986), Niemiec (1985), Mohamed (1985), Robert (1985), Lôthe (1984), Noss (1984), (1984a).

5.5.2. Secondary education

On the general theme: Plomp et al (1987), Bell (1986), Extending the human mind (1985).

On simulation and modelling: Oeren (1982) and, more generally, the whole book edited by Cellier (1982).

On specific disciplines:

- mathematics: Hillel (1987), Christianson et al (1986), Hoyles (1986), Hoyles et al (1986a), (1986b), (1986c), ICOMIDC (1986) (on mathematical teaching and computers in developing countries), Mintz (1986), Robson (1985) (for an African experience), Howe et al (1983), Dennet (1982);

  - in particular, geometry: Clements et al (1987), Atlanta (1986), Abelson et al (1981), Papert (1980);

- programming: Rogalski et al (1986), Tempel (1986), Laubsch et al (1979) (for a learning environment based on LISP);

- physics: Kocac (1986);

- chemistry: Kocac (1986);

- biology: Vitale (1987) (on the predator/prey system), Finney (1986) and Silverman (1986) (on a model of morphogenesis, "life"), Kocac (1986) (on evolutionary models), Perception (1985) (on optical illusions);

- musics: Berdonneau (1984), Bamberger (1982), (1976), (1975);

- games: Malone (1980).

5.5.3. Higher education

On the general theme: IREM (1986), Nivat (1983).

On simulation/modelling activities: Kocac (1986), Cellier (1982) (with a very rich bibliography on system analysis).

On specific disciplines:

- mathematics: Schroeder (1986), Noss (1985), Bundy (1983); ICME (1983), ch.18;

- informatics: Dalbey et al (1985), Du Bouclay (1986), Arsac (1984), Nivat (1983), Howe (1980);

- physics: Wepfel et al (1987), Bork (1981);

- chemistry: INCE (1982);

- psychology: Mudd et al (1987).

6. Conclusions: the computer and the pedagogical project

On the general theme: Bliss et al (1986), Walker (1986), Boruta et al (1985), Mehan (1985), Bossuet (1982), Simon (1981).

On the necessary autonomy of learning: Bishop et al (1986) (with a good bibliography), Linn et al (1986), Hawkins et al (1986), Leif et al (1983), vol.IV, Piaget (1969).

On the need for more sensitivity to the psycho-cognitive components of the pedagogical activity (in particular, for the learning of informatics): Samurcay (1987), Bromme et al (1986) (with a good bibliography), IREM (1986), Rogalsky et al (1986), Dalbey et al (1985), Dionnet et al (1985), (1985a), Kurland et al (1985), Mendelsohn (1985), Leron (1984), Wertz (1980).

Appendix: Experiences in different countries

The situation of the different CAL, CML and CAT (Computer Assisted Learning, Managed Learning and Assisted Training) approaches in Canada, Germany, Geat Britain, Japan and United States of America is discussed in Simon (1981), Annexe II.

What follows is a very sketchy outline of the relevant literature for specific countries and projects:

- Great Britain: Bell (1986) (Coventry computer-based learning), LOGO development (1984) (London, primary school);

- France: Roberts (1985) (primary school), Simon (1981), Annexe I;

- Holland: Plomp et al (1987) (science CAL);

- Hungary: Vari (1986);

- USSR: Kerr (1987);

- USA: Biancaniello (1986) (Pittsburgh), Hawaii (1986) (university), Linn (1986) (Berkeley), Linn et al (1986) (Berkeley), Peper (1986) (Colorado), Silver (1986) (PLATO project);

- Japan: Sakamoto (1986), (1986a);

- developping countries: ICOMIDC (1986) (mathematics), Robson (1985) (Africa, mathematics and natural sciences), Diliman (1986) (South East Asia, physics).

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