Cognitive Artefacts, Technology and Physics Education

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> *What I can not create I can not understand.*
> (Text found on Richard Feynman's blackboard at the time of his death).

Abstract

Computers are now a major tool in research and development in almost all scientific and technological fields, particularly in physics. Despite recent developments, this is far from true for learning environments in schools and in most undergraduate courses.

After discussing how relevant is familiarization and reification in the learning of physics, this paper argues that computers must be used as cognitive artefacts, as tools to think with, i.e., as tools that allow students to learn physics by manipulating concrete-abstract objects. The paper ends with a discussion how a lasting change in physics teaching and learning can be implemented.

Keywords

Physics teaching and learning, cognitive artefacts, technological change.

Learning physics: conceptual difficulties, familiarization and reification

Physics is a relatively new subject in the secondary curriculum (ages 13-18). Only in the second half of the 19th century did science education become part of the curriculum and only in our century did physics, or physics and chemistry, become an autonomous subject in the developed countries (Carvalho, 1985; Jenkins, 1991).

Teaching and learning physics has always been considered a difficult task by most teachers and students and common people (McDermott, 1993; Peters, 1982). Some experienced policy analysts even say that physics/scientific literacy is a myth (Shamos, 1995). Feynman, a famous physicist and a Nobel Prize winner, used to tell a story about a conversation with the Queen of Sweden during which she said, after asking what his field of work was: "Oh, well, we can't talk about that. Nobody knows anything about physics." Feynman, very politely, answered, "On the contrary, Madam, we can't talk about physics precisely because somebody does know something about physics. What we can talk about is philosophy or psychology, because nobody knows anything about those subjects." And "he would go on to say that subjects like philosophy and psychology are hard, but physics is easy and that's precisely why we know so much about it" (Goodstein, 1992). But, as Goodstein says, "If physics is easy, the question is, why do we do so badly at teaching it?"

Certainly, there are multitudes of reasons for that. One, surely not the least important, is that teachers soon face the "discovery of poverty" in their classrooms and that they somewhat naively tend to assume that kids are just as enthusiast on the curriculum as they are (Bruner, 1996).

Besides the many social-cultural problems teachers face in their teaching, it can be argued that learning science, and physics in particular, is like learning a second language—a new language where words are not what they seem to be:

> (...) When dealing with the definition of terms we do well to remember
> how abstract are some of the concepts we use in physics. If we recall the
> difficulty that Galileo, a superb physicist, had in dealing with acceleration
> we may have more patience with our students (Ebison, 1993, p. 361).

The language of physics was created in the last three hundred years. The history of physics is also an evolution of this language, the "invention of new vocabularies and new ways of talking about the world" (Gregory, 1988, p. 3). Physicists are aware that the language of physics is not the "proper" language to express themselves in many contexts. We all know, for example, that most of the language of physics is unsuitable to maintain an understandable social conversation about cold and hot things. Learning a second language is not a problem of knowing the structure of the grammar of that language. It is, essentially, a matter of *familiarization* with the language and its proper use in specific contexts. *Familiarization* is an important issue when learning science (and mathematics). And, for some eminent scientists, *becoming familiar with* is so important on the success of scientific ideas that new ideas only become triumphant because supporters of old ideas die, as Planck wrote in his autobiography:

(…) A new scientific truth does not triumph by converting its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it (Planck, 1950, pp. 33-34).

There are some relevant arguments to support the importance of familiarization in learning, as contrasted with understanding. One is that scientists frequently say that they do not understand some of the most fundamental concepts or theories in their own field. For example, Feynman wrote that he didn't know what force or energy really was and that no one really ever understood the theory of quantum mechanics… In an elegant manner, Feynman wrote (Feynman, 1982):

We have always had a great deal of difficulty
understanding the world view
that quantum mechanics represents

At least I do;
because I'm an old enough man
that I haven't got the point
that this stuff is obvious to me.

Okay, I still get nervous with it...
You know how it always is,
every new idea,
it takes a generation or two
until it becomes obvious
that there's no real problem.

It cannot define the real problem,
therefore I suspect there's no real problem,
but I'm not sure
there's no real problem.

Experienced physics teachers also alert us about our ignorance of the most fundamental issues in physics. In a very curious paper, Brian Davies, a well-known English physics educator, wrote:

At the heart of the problem lies what amounts to a connivance among successive generations of teachers regarding the nature of their science approaches to understanding abstract concepts, leading to a self-defeating reluctance to open and share their partial understandings with their equally perplexed students.

If I asked you, here and now, to write me a one- or two-paragraph explanation of your understanding of the nature of the Holy Ghost, you'd probably think it a tough challenge. If we then collected up your answers, we could be pretty sure that (i) they'd all be different, (ii) not one would satisfy all of us, and (iii), importantly, we'd be hard put to say which interpretation or explanation would be wrong, because there is no absolute in knowledge and understanding regarding The Holy Ghost.

Most of the useful concepts of physics are, for teenagers, as mysterious and as difficult to grasp as the concept of the Holy Ghost: the nature of an electrostatic charge, of a magnetic field, of electromagnetic wave propagation in a vacuum, or of charm and colour are examples. There is,

as the Holy Ghost, no absolute understanding or knowledge of the nature of these intangibles, yet any half-curious young adult will ponder on their nature. In physics education we need much more of the kind of humility shown by Feynman, who said openly that he felt no one really understood quantum mechanics.

If teachers continue to give the impression that they do have a better basic understanding of such fundamentals than their students, the students will see their own perplexity and uncertainty as a negative reflection on their own capabilities. Even in this group today there will be some of you who will remember the relief you felt when you could use some equation, and your mathematics, to answer a problem, rather than stay with your uncertainties regarding the concepts involved. We learn and teach others to use mathematics to manipulate the symbols associated with mysteries. This does not mean that we or they have a grasp of the mysteries themselves (Davies, 1997, pp. 420-421).

Physics deals with a special type of "objects": "objects" such as *force, velocity, energy, radiation*, etc. At a first glance, some, or even most, of these words seem *familiar* to a student. Nevertheless, they are not and they can't be. *Force*, in the language of physics, is the "instantaneous rate of change of linear momentum". The same sort of specifications is established for the other physics concepts. However, in the students' first language (Portuguese, English or any other), *force* means many things and in many contexts, surely not "an instantaneous rate of change"!

An important issue in learning such abstract concepts, one that is intimately related to familiarization is the issue of *reification*, i.e., of *concretisation of abstract objects*. According to Wright & Wright:

Reification is a central goal [… of learning science and mathematics]; it essentially defines scientific literacy. It is the foundation for common sense about how the world works […] (1998, p. 128).

Reification is an essential issue both for the learning of physics and mathematics as well. It is Roitman, a mathematician, which tells us that students can only learn at an abstract level when they consider mathematical objects as real as everyday objects:

The objects of mathematics are real objects, in a psychological, not necessarily ontological sense—they feel real; we act as though they are real. For example, 'number sense' is based on reification: we can compare numbers, operate on them, and look at their properties because they are real. Or another example, many young children have not reified the notion of fraction—for them, 1/2 implicitly carries with it the question "1/2 of what?" When the concept of '1/2' takes its place in the number system as just one of many rational numbers, to be thought about and used as we think about and use all rational numbers, it has been reified. (….) To take a third example, algebra cannot really be understood unless variables are reified—'x' is not a placeholder standing in for some unknown number, but an object in its own right. Reification cannot be forced, but its encouragement is a major part of the art of teaching mathematics (Roitman, 1998, p. 26).

Learning physics and the use of technology: cognitive artefacts and concrete-abstract objects

Assuming *reification* and *familiarization* as essential aspects of learning physics (and mathematics), we must ask how can this be improved with technology and, specially, with computers? Hebenstreit, writing about the role of computers in education, coined a term that seems essential to understand how computers can help in the reification of knowledge. For Hebenstreit, computers allow us to manipulate a new type of objects, objects that he calls *concrete-abstract* objects. *Concrete* in the sense that they can be manipulated on the screen and react as "real objects" and *abstract* because they can be only physical or mathematical constructs such as vectors, equations, fields, etc. (Hebenstreit, 1987).

Computers can be used in physics education as powerful *cognitive artefacts* (Norman, 1991). A cognitive artefact is a tool to enhance *cognition*, a tool to create and explore "concrete abstract-objects", a tool to create "worlds from ideas" and check how well these "worlds" can fit "real worlds", or make sense of "imagined worlds".

Teachers tend to teach what they can teach, not necessarily what they think it would be useful to teach. This is what Osborne calls *technological determinism* (Osborne, 1990): "that which we do teach is limited by that which we can teach" (p. 193). He gives a few classic examples and shows how most of the practical and theoretical teaching is really dependent on the available technological devices and on the *limited* mathematics that students (and also teachers) can use: *simple analytical tools* but that need complex algebraic manipulation. He follows his line of reasoning to propose that:

> The advent of powerful computational tools in the past decade has resulted in more emphasis being placed on numerical methods of solution in physics. The study of chaos and the generation of Mandelbrot plots would have been severely limited without this technology. Yet school physics has yet to deploy such tools to enhance the education provided. Introductory kinematics courses place pre-eminence on the analytical solutions of objects moving with constant acceleration. My argument is that one implicit reason why this is done is because it is one physical situation that is accessible to an analytical solution with limited mathematics, another instance of that which can be taught, being taught. Yet the solution is lost in a confusion of algebraic manipulations whilst the numerical approach is, in a fundamental way, easier than the analytic approach.

> The alternative approach through numerical methods forces attention on the basic physics. It asks the child to consider what are the dynamics of the situation? How can the acceleration be predicted? How can the velocity be calculated if the acceleration is known and then how can the new position be calculated? The solution is then generated by iterative calculation and the pupil is forced into judging whether the answer suggested is appropriate. The rule used for calculating acceleration can easily be changed to incorporate friction or to model a harmonic

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oscillator. Thus the emphasis is on the physics, not the mathematics. The issue that must he resolved is whether we should present pupils with problems of real-world complexity or adopt the reductionist approach, stripping the problem of anything but the simplest detail? The inevitable idealization of the latter approach, enhancing the separation of the world of physics from the real world of the child, again weakens our argument that physics can explain 'how we know' since the phenomena described are patently not commensurate with the child's perception of reality (Osborne, 1990, p. 194).

Osborne proposals only now seem feasible because hardware and specially software evolved to give us the possibility to emphasize *meanings*, even if complex calculations are necessary, in spite of simple analytical solutions that describe only idealized phenomena.

A characteristic feature of using a computer as a cognitive artefact is that the emphasis is on *meaning* and *semi-quantitative reasonin*g instead of algorithms and routine thinking. A good example of what is semi-quantitative reasoning can be done with the computation of, let's say, sin (35º). Using a computer, or a calculator, we can easily get the result: 0.574. From a *semi-quantitative* point of view, let's look if this result *makes sense*: it is smaller than 1 (*OK!*), is bigger than 0 (*OK!*); if I do a sketch of a trigonometric circle, I can easily *estimate how big* is the ratio between the segment that represents the sine value and the radius of the circle for an angle of 35º (*a little more than 1/3 of the 90° angle…*); with some sense of estimation, is possible to check that that ratio *can* be a *little more than 0.5*.
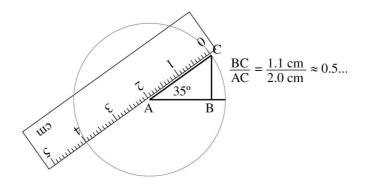

Figure 1 How to estimate sin 35º?

An *expert*—either student or teacher—can easily do this semi-quantitative reasoning even when either the teacher or the student never know how that value is really obtained! Moreover, they really do not think that is essential: it will not be of any help if you have a computer or calculator… The *experts* are *experts* when they can evaluate how *reasonable* that value is, *not* when they can *compute* it. Sure there is also place for a certain kind of experts that can think, let's say, of better and faster algorithms to compute trigonometric functions, but that is not for the "rest of us", who can, at best, be interested as a curiosity on such algorithms but understand that it is not the knowledge of the algorithms that help make sense of "sin (35º) = 0.574"…

The same kind of semi-quantitative reasoning can be done with a mathematical object such as $dx/dt = 4 \times t$. What does this inform us? First, we see that the rate of change of x

is proportional to t. So, for a bigger t, we will have a bigger rate of change. More precisely, when t is 5 units, for example, the rate of change will be, at that instant, $4 \times 5 = 20$ units. If t is 10 units, then the rate of change will be $4 \times 10 = 40$ units. That is, if t doubles, the rate of change doubles. And x is always increasing, for positive values of t. Let us see another example: $dx/dt = 4 \times x$. Now we have a rate of change of x that is proportional to x at any instant of time. For example, is x is zero, then the rate is also zero. For a positive value of x, at any instant of time, the rate of change is positive and so x increases.

In addition to supporting semi-quantitative reasoning, cognitive artefacts also can play an essential role in externalisation and negotiation of learning, as mentioned by (Orhum, 1995):

> The main function of cognitive tools is to enable learners to make explicit and negotiate meaning. Making meaning explicit requires the representation of thought processes in external models for examination and reflection, and it may help learners improve these cognitive processes. Negotiation of meaning involves exchanging views and interpretations in communicative acts among learners (p. 314).

This view is coherent with the now dominant view of learning, the constructivist view.

Since physics is a science where visualisation plays an important role, even when visualisation is only used to show mathematical objects, such as vectors or field lines, it seems very reasonable to suppose that computer visualisation can help learners create meaning from manipulations of abstract objects. This capability of computer have been extensively used in many contexts (e.g., in the beautiful TV-based course *The Mechanical Universe*, Goodstein & Olenick, 1988) and is stressed by many authors, such as Kozma, that points out the capability of making dynamic representations of non-concrete formal objects:

> Computers […] have the capability of creating dynamic, symbolic representations of non concrete, formal constructs that are frequently missing in the mental models of novices. More importantly, they are able to proceduralize the relationships between these objects. Learners can manipulate these representations within computer microworlds to work out differences between their incomplete, inaccurate mental models and the formal principles represented in the system (Kozma, 1991, p. 179).

This trend accompanies the increasing importance computer visualisation and simulation is playing in science and in physics in particular. Galison, for example, wrote about the new "epistemic position" of computers and simulations in the production of physics knowledge:

> Computers and simulations ceased to be merely substitutes for mechanical parts, they come to stand in a novel epistemic position within the gathering of knowledge—not quite a piece of empirical machinery, and not quite one with theoretical apparatus (Galison, 1997, p. xix).

Nickerson pointed out that researchers had not yet focused on students as authors of simulations:

> What has not yet received much attention from researchers is the possibility of having students develop simulations themselves as a way of

fostering a greater understanding of the processes they attempt to simulate (Nickerson, 1995, p. 16).

He follows arguing that "it is only difficult, not impossible, and the work that goes into the successful building of a microworld is likely to deepen one's understanding of whatever the microworld is intended to simulate" (Nickerson, 1995, p. 16). To build simulations, one can use programming languages, but these require technical knowledge and skill outside of the domain being simulated. This is the reason why Nickerson propose the development of specific tools that can be used by people without that knowledge:

> For student-developed simulations to be practical for educational purposes, it will probably be necessary to develop tools that are designated to facilitate the building of simulations by people without such language facility and programming experience (Nickerson, 1995, p. 16).

There are still two other important aspects that must be considered about cognitive artefacts such as computer tools, mentioned by Bruner in some of his recent writings. Bruner says that the computer reintroduced the capability to make routine work without human "servants". Bruner also points out that computers can be a kind of "intellectual mirrors", in the sense of Schwartz (1989):

> One last word and I am done. I have said nothing about computers, which seems strange in this day and age. I really have nothing to say about them, aside from the fact that I love them and my life would be much more tedious without them. They can be a boon to scientific consciousness and, besides, they have reintroduced the servant in an era when the sages all said we would forever more the servantless. Best of all, we can construct programs that can 'simulate' what we might with great cost and effort do in our heads or on paper, and, in so doing, making us aware of what it is that we must still do ourselves in our own heads (Bruner, 1992, p. 12).

Technological Change and Science Education

When I started using computers with students, in the early 80s, it was not clear how important and ubiquitous computers would be in our society. Now we know that "computers have pervaded all aspects of life in the developed world, changing working practices and leisure activities" (Ross, 1993, p. 69). Everybody now agrees that young people and adults must "become aware and unafraid of computers, just as they need to become literate and numerate" (Ross, 1993, p. 69). Most of this familiarization with computers is done, especially with young people, without any formal teaching—just learning with peers in informal settings, like resource centres and homes.

Ross also points out that it would be a waste of resources if we use computers just to develop computer literacy when we know that computers can help extend, improve and change the traditional curriculum significantly. And, more important, computers are now recognised as fundamental tools in the production of scientific knowledge:

> Scientific computation has become so much a part of everyday experience of scientific and engineering practice that it can be considered a third fundamental methodology of science—parallel to the more established

paradigms of experimental and theoretical science (National Research Council, 1989).

Then, why should we not use extensively computers in teaching?

Some authors, such as Cuban (Cuban, 1989), pointed out that computers, like all technological innovations in schools, tend to follow a cycle of four phases: high expectations; rhetoric about the need to innovate; oriented policy and finally limited use. This cycle is certainly true for innovations such as educational television but it is not true for other innovations such as radio or the teaching machines since for these there is a fifth phase: *no use at all*. It is also not true for computers, as Cuban himself seem to admit recently—see, e.g., the debate between Roy Pea, a strong advocate of the use of computers in education, and Larry Cuban (Pea & Cuban, 1998). Contrary to the other innovations, which declined very early after the first three initial phases mentioned by Cuban, computers are increasingly present in schools, as they are everywhere. For example, nowadays a school or university laboratory without data logging systems (computers, interfaces, sensors and software) is unthinkable. The same is true for school libraries: all have access to digital books, either off-line or on-line, at least in Portugal and in other European countries. Moreover, in the near future we will see an increase in the use of computers in education, at least in certain subjects such as mathematics and the physical sciences. For example, the Principles and standards for school mathematics (NCTM, 2000) now explicitly states the importance of technology in learning, considering the use of technology one of the six fundamental principles of teaching and learning:

> Technology principle: Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning (NCTM, 2000, p. 24).

But it is not only mathematics educators and curriculum developers who reinforce the importance of technology in learning. For example, the new Institute of Physics project Advancing Physics uses computer tools and the Internet as an integral part of the curriculum (Ogborn, 1997).

To understand the role of computers in education it is useful to use Pryluck's distinction between "inherent" and "imposed" characteristics of a medium (Pryluck, 1968, p. 372). The first, *inherent characteristics*, are "symbols and combinations thereof selected from the symbol system that was developed in connection with the specific technology of transmission." The second, *imposed characteristics*, are "situations of exposure (...), teachers' instructions, or even the didactic structure of the presentation. They are imposed simply because one could easily remove them, apply them differently, or apply them to another medium." Moreover, Pryluck reminds us that the imposed characteristics "at best correlates of the medium". Since computers are now normal tools in the production and communication of scientific knowledge, their inherent characteristics seem unquestionable. This leaves us only with the discussion about the imposed characteristics, that is, the discussion about using computers in physics education (and, probably, in most school subjects) should *not* be a *discussion about using computers* but a *discussion about how to use* them.

According to Collins (Collins, 1991), we can expect computers to help in the following eight shifts:

1. A shift from whole-class to small-group instruction.
2. A shift from lecture and recitation to coaching.

3. A shift from working with better students to working with weaker students.

4. A shift toward more engaged students.

5. A shift from assessment based on test performance to assessment based on products, progress, and effort.

6. A shift from a competitive to a co-operative social structure.

7. A shift from all students learning the same thing to different students learning different things.

8. A shift from the primacy of verbal thinking to the integration of visual and verbal thinking.

This list clearly relates to the "imposed" characteristics of computers in schools, not with the "inherent" ones. However, if we want technology to make a real difference, students must be in a state of 'mindfulness' for technology to work. Mindfulness, in this context, is the employment of non-automatic, effortful, and thus metacognitively guided processes (Salomon, Perkins, & Globerson, 1991).

According to Salomon, computers are more than add-on devices since "computer tools carry with them implicit assumptions about self-guided exploration and design, even playful activity, team collaboration, integrated curricula, mutual consultation, and teachers' orchestration of activities rather than teacher domination" (Salomon, 1992, p. 251). He follows alerting us that "to make computer use affect education it cannot just be introduced as an addition to otherwise unchanging classroom practices the way, for example, television could; with its proper introduction everything in the classroom, possibly in the school as a whole, changes."

This helps us understand why it seems so difficult to make computers become part of regular practice in schools, particularly in classrooms. Computers are not add-on tools like television. Their use implies profound cultural changes—changes in the teaching culture, in the learning culture, in the school culture—as well as changes in the school organisation. If the dominant cultures of teaching, despite their diversity and evolution, are still essentially individualist—"teachers' desire to be left to themselves" (Feiman-Nemser & Floden, 1986, p. 522)—and defensive, the constraints for the generalisation of computer use in classrooms become evident, particularly when another characteristic of the culture of teaching is the use of "little research-based technical knowledge" (Feiman-Nemser & Floden, 1986, p. 522).

But everything can change with time, social pressure and teacher involvement. It is also Feiman-Nemser and Floden who wrote that one particularly important change in progress in the culture of teaching is that the passive teacher moulded by the bureaucracy is being substituted by an "active agent, constructing perspectives and choosing actions" (Feiman-Nemser & Floden, 1986, p. 523). And the renovation of teaching and learning can only be done with teachers able to work in groups, open to learn continuously, open to learn and share difficulties with their students, open to criticism and improvement (Ponte, 1994).

Some critics, such as Apple (1991), introduce a different perspective when analysing the role of the computers in education:

> At root, my claim will be that the debate about the role of the new technology in society and in schools is not and must not be just about the technical correctness of what computers can and cannot do. These may be

the least important kinds of questions in fact. At the very core of the debate instead are the ideological and ethical issues concerning what schools should be about and whose interests they should serve (Apple, 1991, p. 61).

These critics fear, for example, that computers will support the "the creation of enhanced jobs for a relative few and deskilled and boring work for the majority" (Apple, 1991, p. 65). This is, undoubtedly, an important issue, but a more general than the ones I am analysing on this paper. All members of our societies must be aware of this danger, not only educational researchers and teachers. Apple also alerts us that computers can be extensively used to "rationalise and control the act of teaching" (Apple, 1991, p. 66). This is certainly true for computer uses such as computer-managed instruction, but not for exploratory environments and other computer tools. On the contrary, these tools give more control to teachers and can help them be more creative on the management of the curriculum. This can be exactly the *opposite* of what Apple fears, the "deskilling of teachers":

> Of the major effects of the current (over) emphasis on computers in the classroom one may be the deskilling and depowering of a considerable number of teachers (Apple, 1991, p. 67).

Apple is right when he says that new technologies embody a form of thinking, primarily technical thinking:

> The new technology is not just an assemblage of machines and their accompanying software. It embodies a *form of thinking* that orients a person to approach the world in a particular way. Computers involve ways of thinking that under current educational conditions are primarily *technical*. The more the new technology transforms the classroom into its own image, the more a technical logic will replace critical political and ethical understanding. The discourse of the classroom will center on technique, and less on substance. Once again 'how to' will replace 'why,' but this time at the level of the student. This situation requires what I shall call social, not technical, literacy for all students (Apple, 1991, p. 75).

But it is not linear that *technical* and *not technical* thinking are opposite ways of thinking. Most of the times, intelligent thinking is done with tools and it is not possible to separate intelligence from tools:

> Almost any form of human cognition requires one to deal productively and imaginatively with some technology. To attempt to characterise intelligence independently of those technologies seems to be a fundamental error (Olson, 1986, p. 356).

In a certain way, Apple recognises that sooner or later computers will be normal tools in schools. In this case, students should not only be technically proficient but also "have a serious understanding of the issues surrounding their larger social effects" (Apple, 1991, p. 75). Social literacy must have a considerable importance in the curriculum:

> Where are computers used? What are they used to do? What do people actually need to know in order to use them? Does the computer enhance anyone's life? Whose? Does it hurt anyone's life? Whose? Who decides when and where computers will be used? (Apple, 1991, p. 76).

Another point raised by Apple, teacher education and new technologies, must always have a clear goal: teacher education is about "*skilling*", not *deskilling*; about giving power to control technology, not giving technology to control teaching.

There have been many promises of radical change in education for educational technologists, researchers and computer enthusiasts. For example, one of the early advocates of computers in education, Patrick Suppes, wrote in 1966 that "in a few more years millions of school children will have access to what Philip of Macedon enjoyed as a royal prerogative: the personal service of a tutor well-informed and responsive as Aristotle" (quoted by De Corte, 1994, p. 206). We know now that is not feasible, at least in the foreseeable future. The enthusiasm with intelligent tutoring systems is something of the past. In the 1990s, a "clear transition has been initiated in educational computing in general (…) toward supportive systems that are less structured and less directive, that are more focussing on coaching and scaffolding" (De Corte, 1994, p. 116). Groups such as the group that worked with the Education Technology Center in Harvard between 1985 and 1995 have initiated this perspective. Their goals were, for the time, counter-current, but are now dominant. The Harvard perspective was based on four principles:

> Goals: Focus on key concepts and on the overall nature of knowledge, evidence, and inquiry in a discipline.

> Teaching Approaches: Help students develop a deep understanding of the subjects they study by taking into account their prior theories and by integrating teacher-directed instruction with opportunities and challenges for critical inquiry.

> Technology: Use technologies selectivity to make a distinct contribution to teaching and learning, for example, to present dynamic models of key ideas or to enable students to participate in disciplined inquiry.

> Implementation: Design technology-enhanced teaching modules and approaches that can be gradually and gracefully integrated into existing curriculum and practice (Harvard Educational Technology Center, 1988).

As we can see in these statements, *technology is not a goal in itself* but a selective contribution "to make a distinct contribution to teaching and learning". This contribution can, in many circumstances, be a "Trojan horse" to change education (Schwartz, 1993). But, as many authors point out, is the *teacher* that really can make the difference in creating powerful educational environments *with* technology. Or, as Hooper, one of the British pioneers of research in computers in education, stated in an interesting paper (*Computers and sacred cows*):

> (…) the teacher as human being is both the form and content of education, both means and end (Hooper, 1990, p. 4).

Compared with other institutions and areas of work, schools are less influenced by technologies. Cuban (1993) presents two reasons for that: one is what he calls "cultural beliefs" about what teaching is and how learning and teacher-student relationship occurs. He argues that popular views of proper schooling emphasise the role of the teacher, not the role of a machine. A second reason is the organisation of the age-graded school, with sequences of 50 minutes classes, that "has profoundly shaped what teachers do and do not do in classrooms". To Cuban, using computers in traditional organizational schools is an almost impossible task. Only a minority of "enthusiastic teachers" can do it. And, in present circumstances, he is probably right, even with

innovations such as using computers as data-logging tools, as Rogers & Wild pointed out:

> Despite the fact that the software and hardware tools for this type of activity are now refined and very easy to use, school science departments have been rather slow to adopt data-logging technology. The reasons for this reticence are often cited as a mixture of limited funds, limited time and limited training opportunities for science teachers. It t is also possible that limited awareness of the learning benefits has caused a failure to gain the professional commitment of teachers (1996, p. 130).

It can be difficult to "gain the professional commitment of teachers" when research shows that the effective use of Information Technologies (IT) needs *substantial demands on teachers and schools* as pointed out in a large scale evaluation in UK:

> Overall indications were that in particular circumstances the use of IT had a highly positive impact on children's achievement, but this was not without substantial demands on teachers and schools (Johnson, Cox, & Watson, 1994).

This high level of demand, this "high threshold of effort" (Wilson, 1997, p.24) for teachers and schools is recurrently considered as major obstacle for the regular use of computers.

But technological innovations in schools have always been very slow and not only due to teachers but also to cost. Computers are expensive commodities as paper was some centuries ago:

> The high cost of paper stimulated the use of substitutes—the wax tablet, the slate, the smooth wooden board, as well as the board painted black. Even these developments were slow. Brinsley mentions the blackboard in his *Ludus Literarium* of 1612, Comenius had pictured one in 1658, but we have no record of its use in schools until about 1800, and no mention is made of slates for individual pupils until about 1815. Again and again the records of the early schools disclose the complaints of the parents over the cost of each new innovation, and the introduction of student slates was the cause of public disturbances (Brooker, 1949, p. 12).

Other difficulties with the introduction of a proper use of computers can be related to the fact that empowering environments—such as Logo—have been replaced by more appealing multimedia presentations. According to Robertson (1998), this is due to the fact that investment on support for teachers and curriculum development based on educational research on computers has almost disappeared. Schools manage their own budgets and buy directly to publishers—the trend is buying what is more "attractive", not what can help explore the potentialities of the technology to help create powerful learning environments.

It seems reasonable to admit, with Joyce (1974, p. 411) that the "structure of the school is in many senses the medium of instruction—it facilitates certain kinds of learning modes and inhibits others". Joyce gives the example of programs such as "Sesame Street" that "would not have anywhere near the effect they are having if there were not television sets in most homes and if the parents were not delighted to have the children occupied before them". Would it be possible to change the structure of the school? A change in the direction of more active engagement of learners in their own learning, a change in the direction of the transformation of schools and classrooms in communities

of situated practice, in the sense given by Brown et al. (Brown, Collins, & Duguid, 1989)?

Computers are commonly associated to fun and enjoyment, including in learning environments. Learning can certainly be fun but, in most cases, is slow and difficult. If we want students and teachers to use computers as learning tools they must be aware that popular myths can be true for games and browsing through most of multimedia titles, but are certainly not true when reflection and hard work is needed (Stoll, 1995). Using computers as scientific tools is a demanding experience, as is all scientific work, both for students and teachers.

Recent research in innovation and knowledge dissemination tend to insist on "a social constructivist approach to dissemination and use of knowledge" (Hutchinson & Huberman, 1994, p. 43). Users are not passive recipients of novelties and it is not possible to transfer expertise and information as we transfer bits and data. As a matter of fact,

> (…) work on organizational life has shown clearly that, within any given social setting, there are a sufficient number of tensions, differences in perception, differences in influence or authority, etc., to preclude any straightforward communication of information or innovation. A constructivist view of knowledge use also shows us that users must transform inputs simply to apprehend them, even if they are as unaware of the process (…). When we look at outcomes, then, we must assume that users have reconfigured their understanding and use of a given practice simply to integrate it into their repertoire (Hutchinson & Huberman, 1994, p. 43).

No longer we need short-term programs that assume that innovation is granted because is has proven with the enthusiastic. We need programs that "encourage cumulative improvement over the long haul" (Holton, 1994), committed to ongoing slow but clear change. "Cumulative improvement" is, certainly, a more reasonable view to envision how computers tools will be assimilated and change learning and teaching. Our modern institutions are profoundly dependent on abstract systems, what Giddens calls "expert systems" (1991). Computers and computer networks are good examples of these expert abstract systems. Their potential and social impact is enormous and will increase as technology advances. But, as Papert pointed out twenty years ago, "there is a world of difference between what computers can do and what society will choose to do with them" (Papert, 1980, p. 5). In the near future, we all face the challenge to use technology to empower learning (and all other human activities), not to create any kind of Aldous Huxley *Brave New World*, where machines control everything, dehumanising schools and learning.

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