Συνέδρια της Ελληνικής Επιστημονικής Ένωσης Τεχνολογιών Πληροφορίας & Επικοινωνιών στην Εκπαίδευση

Τόμ. 1 (2002)

3ο Συνέδριο ΕΤΠΕ «Οι ΤΠΕ στην Εκπαίδευση»

Embedded Technologies in the Curriculum: A Framework and Some Examples in Science and Mathematics Education

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SUMMARY

Probably, one of the most relevant challenges we face now in education is to embed computers the regular of classrooms. It took centuries to use books as classrooms tools and there were strong opponents to the idea. Computer based technologies are now so common in everyday life that it is becoming difficult to find opponents to the idea of using computers in education, with reasonable arguments. But education is not "a rocket science", it is much more complex and educational systems take a long time and effort to change. Using computers as a classroom tool, as ubiquitous as books, is an enormous challenge and probably it will take some generations. In this paper, I make some proposals and I give examples on how this has been done recently.

KEYWORDS: *curriculum development and computers.*

INTRODUCTION

More than thirty years ago, Oettinger (chairman of the Harvard University Program on Information Resources Policy), writing about the mythology of innovation, concluded that **the user, more than the tool, is the key factor in innovation**:

> In short, computers are capable of profoundly affecting science by stretching human reason and intuition, much as telescopes or microscopes extend human vision. I suspect that the ultimate effects of this stretching will be as far-reaching as the effects of the invention of writing. Whether the product is truth or nonsense, however, will depend more on the user than on the tool (Oettinger, 1969).

The "user versus the tool" is a recurring theme in the use of computers in education, and other areas, with most of, if not all, analysts of innovation. And all seem to agree that **tools can empower users**, but that **is not an inevitable consequence** of the use of tools.

Educational innovation is a difficult enterprise. Constraints for change come from many sources. Typical classrooms are still very similar to classrooms in the beginning of the massification of schools, in early 1900s. Leon Lederman, a Nobel physics laureate, is probably right when says that "classrooms of today all too often appear and function as they did 100 years ago" (Lederman, 1998). Central and local governments, as well as supranational authorities like the European Community, spent millions of euros in promoting the use of new technologies in schools but **common classroom practices are still based on lecturing, questioning and recitation**, at least in some countries.. For example, a recent study on Portuguese schools concluded that the "most common practice in classrooms deals with solving exercises, expositive transmission of knowledge, demonstrations accompanied by questions and correcting tests and homework" (Martins, 2002).

The "complexity of the real world (…) is extremely difficult" (Edelson, 1998). It is not an easy task to overcome the complexities and difficulties schools and teachers have to change their practices. Policy documents and implementation projects, from governments and supranational authorities like the European Union, stress the importance of the use of computers in the curriculum. The E-Europe initiative, according to the E-Learning Action Plan, target a ratio of 15 pupils per on-line computer for educational purposes in EU schools by the end of 2003 and supports the evolution of school curricula with the aim of integrating new learning methods based on information and communication technologies by the end of 2002. The recognition that computer skills are a key component of literacy is widespread.

Some policy analysts, such as Ernst (1997), consider that "computer use offers an example of technology (largely because of cost and limited useful life) not yet 'ripe' for mass use in early education". But, as Ernst also recognizes, this situation is "bound to change" in the next years. However, improving education can never be strictly related only with disseminating computers in schools. Visionaries, like the well known Bill Gates, in his book *The road ahead* (1995) tried to show that "technology will be pivotal in the future role of teachers". But he also modestly recognize that technology "won't replace or devalue any of the human educational talent needed for the changes ahead: committed teachers, creative administrators, involved parents, and, of course, diligent students".

For decades "reformers" of different origins have argued that technology of one sort or another were about to revolutionize teaching and learning (Cuban, 2001). However, as Cuban argues, the fact is that **teaching and learning are intensely personal activities, and at best technology helps to facilitate the interaction between teacher and learner**. On the other hand, it's important to say that the most important problems of education (engaged learners, teachers and communities; adequate funding; professional development of teachers and other staff; accountability; resource management; parental and societal involvement in school communities; democratic participation; etc.) have little to do with more technology in schools, as Cuban also points out. Naïve conceptions of educational change assume that educational change depends on the change of independent variables, such as the teaching method, the teaching tools and materials, the school environment, etc. But, according to Salomon (1992), decades of educational thinking and practice show that there are no independent variables. All variables are mutually dependent when we think of learning environments. To think that computers can change education is an expectation that can block out educational change.

In the past, educators (and educational researchers…) had high expectations about new educational technologies. Cuban (1986), 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. But they don't do what they were initially envisioned to do—see, e.g., what George Leonard wrote on his book, *Education and Ecstasy* (1968): the "goals of education are fully realized through computer technology. (...). At the heart of this school is the computer system, offering individualized education to each student”.

Figure 1: Skinner Machine for teaching arithmetic (1954). One of the many “educational innovations” that raised high expectations… [http://americanhistory.si.edu/teachingmath]

THREE TENETS FOR A POLICY

Even “simple” innovations can take a long time to be widely adopted. For example, it took hundreds of years to use books as personal objects in schools. It seems clear now that computers have an undeniable ubiquitous role in almost all human activities. But as a “complex” innovation, which requires knowledge and skills, as well as policy and organizational measures, it will probably take one or more generations until they could be as common as schoolbooks are now. And, as schoolbooks did, they will transform education. But this transformation will probably be slower and longer that we can think now. **The transformation will be more related with access to information and to ways of producing and communicating knowledge and less related with any major change in the process of teaching**, were personal interactions are a key factor, even with adults, as Brown and Duguid had shown (2000).

A policy for embedding computers in education must recognize that the efforts to reach that goal cannot be considered independent from other much more important goals. Education is complex endeavour and using technology is in most cases a minor component of this endeavour. The major components are **organization and accountability**, **curriculum development**, and **professional development**.

Schools as learning organizations

The concept of organization that learn has been applied recently to schools (see, e.g., Senge, 2000). A *learning organization* is one in which people, at all levels, individually and collectively, are continually increasing their capacity to learn and produce better results they really care about.

A policy for embedding computers in education must have **a clear concept of what a school is**: learning communities in which teachers pursue clear, shared purposes for student learning, engage in collaborative activities to achieve their purposes, and take personal and collective responsibility for student learning. Students work, discuss, listen, present their views and ideas, and support other students, particularly those who are having difficulties. Teachers are frequent learners and they are able to learn from their students, from other people in the school, and from sources outside the school. Teachers are particularly interested in monitoring and support students with learning problems. Didactic instruction and hands-on activities are balanced. Scientific inquiry (getting evidence, testing ideas and models, supporting conclusions, etc.) is normal practice. And tools, particular computer tools, are used to support inquiry, to search and get information, and to communicate and share knowledge.

Such a policy should:

- Be part of a global policy to improve the quality of education, valuing democratic and participatory principles and recognizing change as an internal process, focusing on a sense of ownership of innovation by those who are in the front line of the educational enterprise.
- Promote curriculum and professional development as participatory activities, guided by practical problems but grounded on relevant educational research and theory.
- Promote schools as supportive and rich environments, where committed teachers can teach and manage learning environments with support from other professional staff.

Organisational aspects and resource management in schools play a determinant role on how and how often computers are used in schools (Becker, 2000; Cuban, 1989; Cuban, 2001). For Tinker (1996) the school organizational inertia is the most important factor that explains the limited implementation of computers in school science. Usually, governments tend to make investments in equipment but investments in resource management and maintenance are not considered. In a typical school, we can now easily find 50 or more computers, in laboratories, in resource centres, in libraries, etc. Schools need professional staff to manage and maintain equipments and support its educational use. If we want schools of the XXI century different from the XIX century schools, technical personnel for resources management must be considered as essential as teachers are now.

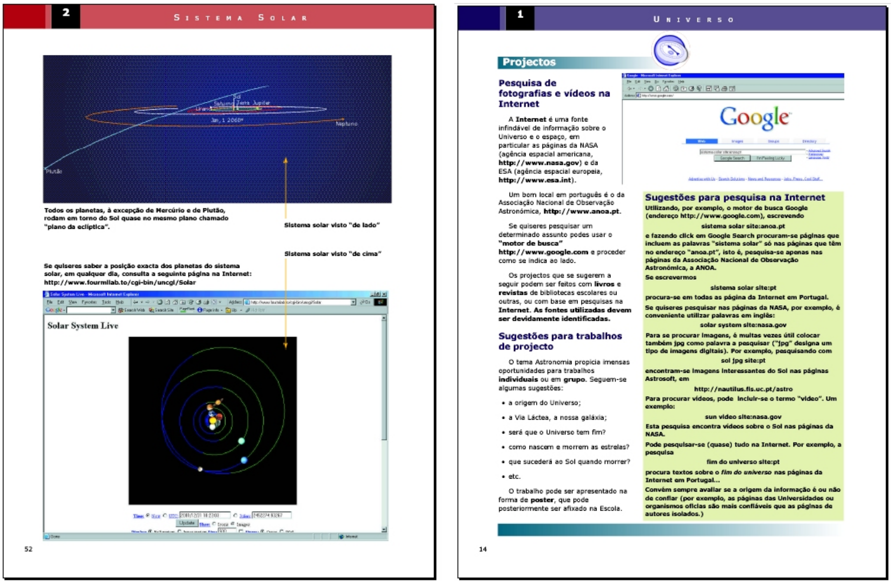
Embedding computers in education, in schools and colleges, must be an explicit goal of the educational policy. The use of computers in most human activities are now so widespread that it is difficult, if not impossible, to argue that computers should not be used in education, particularly in certain subjects such as science and mathematics. Technologies, old and new, helped to change the way people see the world, communicate, learn, and build identities. With the current stage in technology dissemination, education cannot discuss about “use or not to use” computers. The discussion can only be about “best practices” and “bad practices”, about “empowering users” or “deskilling users”.

As with all educational innovations, it is not possible or desirable to define a universal “algorithm” that can guarantee a successful process to embed computers in education. But research in policy and in education can suggest some useful elements to define and implement such a process. For example, the classic RD&D model (Research, Develop & Disseminate) based on techno-rationality, has **serious limitations and is insensitive to school and teachers cultures**, as Lieberman (1998) concludes, in the introduction to the 1998 *International Handbook of Educational Change*.

Curriculum development

Curriculum materials that make use of computers can be developed as *add-on materials*. We all know lots of these types of curriculum materials… that have never been used by any “real teacher”. Most national projects in Europe supported the development of such materials. In Portugal, I know more than one hundred books, collections of worksheets, etc., available for teacher use… but that teachers don't know—and, when they know, they say they cannot use it because they are too complex, they don't have time, they don't fit on the official curriculum, etc.

One of the most common problems with innovative curriculum materials is that they demand a lot of from teachers, and teachers are "intimidated by the time, content and preparation demands of hands-on learning" (Tressel, 1994). As a consequence, only more motivated teachers, with better resources, are able to implement and maintain the interest in the new curricula.



2 SISTEMA SOLAR

Todos os planetas, à excepção de Mercúrio e de Plutão, rodam em torno do Sol quase no mesmo plano chamado "plano da eclíptica".

Sistema solar visto "de lado"

Sistema solar visto "de cima"

Se quiseres saber a posição exacta dos planetas do sistema solar, em qualquer dia, consulta a seguinte página na Internet: http://www.fourmilab.to/cgi-bin/uncgi/Solar

Solar System Live

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1 UNIVERSO

Projectos

Pesquisa de fotografias e vídeos na Internet

A **Internet** é uma fonte infindável de informação sobre o Universo e o espaço, em particular as páginas da NASA (agência espacial americana, **http://www.nasa.gov**) e da ESA (agência espacial europeia, **http://www.esa.int**).

Um bom local em português é o da Associação Nacional de Observação Astronómica, **http://www.anoa.pt**.

Se quiseres pesquisar um determinado assunto podes usar o **"motor de busca" http://www.google.com** e proceder como se indica ao lado.

Os projectos que se sugerem a seguir podem ser feitos com **livros** e **revistas** de bibliotecas escolares ou outras, ou com base em pesquisas na **Internet. As fontes utilizadas devem ser devidamente identificadas.**

Sugestões para trabalhos de projecto

O tema Astronomia propicia imensas oportunidades para trabalhos **individuais** ou em **grupo**. Seguem-se algumas sugestões:

- a origem do Universo;
- a Via Láctea, a nossa galáxia;
- será que o Universo tem fim?
- como nascem e morrem as estrelas?
- que sucederá ao Sol quando morrer?
- etc.

O trabalho pode ser apresentado na forma de **poster**, que pode posteriormente ser afixado na Escola.

Sugestões para pesquisa na Internet

Utilizando, por exemplo, o motor de busca Google (endereço http://www.google.com), escrevendo

sistema solar site:anoa.pt

e fazendo click em Google Search procuram-se páginas que incluem as palavras "sistema solar" só nas páginas que têm no endereço "anoa.pt", isto é, pesquisa-se apenas nas páginas da Associação Nacional de Observação Astronómica, a ANOA.

Se escrevermos

sistema solar site:pt

procura-se em todas as página da Internet em Portugal.

Se quiseres pesquisar nas páginas da NASA, por exemplo, é conveniente utilizar palavras em inglês:

solar system site:nasa.gov

Para se procurar imagens, é muitas vezes útil colocar também jpg como palavra a pesquisar ("jpg" designa um tipo de imagens digitais). Por exemplo, pesquisando com

sol jpg site:pt

encontram-se imagens interessantes do Sol nas páginas Astrosoft, em

http://nautilus.fis.uc.pt/astro

Para procurar vídeos, pode incluir-se o termo "video". Um exemplo:

sun video site:nasa.gov

Esta pesquisa encontra vídeos sobre o Sol nas páginas da NASA.

Pode pesquisar-se (quase) tudo na Internet. Por exemplo, a pesquisa

fim do universo site:pt

procura textos sobre o *fim do universo* nas páginas da Internet em Portugal...

Convém sempre avaliar se a origem da informação é ou não de confiar (por exemplo, as páginas das Universidades ou organismos oficias são mais confiáveis que as páginas de autores isolados.)

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Figure 2: Two pages of a schoolbook for 7th graders, written by the author and colleagues. On the left page, students are asked to run a simulation on a web page to find the exact position of the planets on a certain day. Students will use this information to make a model at scale of the solar system. On the right page, students have suggestions on how to do a written project about the Universe, using images, video and other documents from the web, located with Google, a search machine.

Curriculum development is crucial for using technology in schools. And, since schoolbooks are used by teachers in most countries as the main source to define what is taught and how it is taught, we must use schoolbooks as the main support to trivialise the use of computers as learning tools. **The policy should be clear on the importance schoolbooks must give to embed computers as learning tools**, without demanding too much from the teacher and the student. An example of such approach is given by the *Advancing Physics* project, developed in the UK (Ogborn & Whitehouse, 2000, 2001) by the Institute of Physics. Student and teacher materials include a book and a CD-ROM (and a website), with a lot of complementary written material (for students and teachers), digital images, files to be used with common scientific software such as Excel, and software for modelling and simulation, with hundreds of examples. Where necessary, the use of the software is integrated with the flow of ideas on the textbook. Certain chapters can only be studied effectively with software explorations. Another example is a schoolbook I and other four colleagues published recently in Portugal for 7th graders (Figure 2 shows two pages of this book, which is accompanied by a CD for teachers). In this case, since it directed to younger students, the use of computers is limited to the use of simulations available on web pages, simple graphs on a spreadsheet, simulations recorded as digital video files, web search for materials to use on students' projects, and web readings.

Professional development of teachers

In the first wave of curriculum development, forty years ago, "educating the teachers" to use new curricula had reduced importance. Developers aimed to make "teacher proof curriculum materials" but, more recently, teachers are recognized as playing a relevant role both in development and implementation and there is plenty of evidence that teachers change the ideas when they teach them (Korthagen, 2001). **The sense of ownership is probably the most crucial question in curriculum innovation**:

> One of the strongest conclusions to come out of decades of studies of the success and failure of a wide variety of curriculum innovations is that innovations succeed when teachers feel a sense of ownership of the innovation: that it belongs to them and is not simply imposed on them (Ogborn, 2002).

A policy for introducing computers in education must be grounded on a **new vision of "ownership" of innovation**, a vision that recognizes teachers, particularly experienced teachers, as essential to create, define and assess the goodness of innovative ideas and approaches. This doesn't mean that scientists, educational researchers and curriculum developers had any relevant role. As established institutions, schools have a great inertial organization and must interact with other systems that can help change. But outside institutions don't change schools: change is an internal commitment, not an external intention.

According to Korthagen (2001), "the problem of educational change, and particularly of teacher education, is first of all a problem of dealing with the natural emotional reactions of human beings to the threat of losing certainty, predictability or stability. This affective dimension is too much neglected in the technical-rationality approach." He purposes the following basic tenets of what should be **a realistic approach of professional development of teachers**:

- The starting points are **concrete practical problems** and the concerns experienced by teachers **in real contexts**.
- It promotes the **systematic reflection** of teachers on their own and their students' wanting, feeling, thinking and acting, on the role of context, and on the relationships between those aspects.
- It builds on the **personal interaction** between the teacher educator and the teacher and on the interaction amongst the teachers.
- It takes gestalts of teacher as the starting point for professional learning, **using theory not as a reduction or simplification of formal academic knowledge**, but as perceptual knowledge, personally relevant and closely linked to concrete contexts.
- It has a **strongly integrated character** (integration of theory and practice and integration of several disciplines.)

USING COMPUTERS IN EDUCATION: SOME “REASONABLE” EXAMPLES AND TRENDS

I’ve argued above that **schoolbooks are essential to promote the use of computers in education**. When using schoolbooks, students should naturally have information about how to locate documents on the Internet, on hands-on activities that use computers, on how to share and discuss ideas on electronic forums, on how to use critically the data from electronic sources, etc., etc.—without giving too much technical details since computer user interfaces are now standardized and most users are familiar with them.

For certain subjects, the use of computers is mainly for information location, access and exchange, but, for other subjects, like science and mathematics, it is also a way of “making ideas come real” (Ogborn, 1999) focusing on the meaning of knowledge and not on mechanical and repetitive computations. Some software tools have so powerful concepts (and extensive use out of schools) that they can change deeply how people learn. A good example is the spreadsheet. It is significatively different, from traditional paper and pencil methods, to learn mathematics, science, economy, geography, technology with a spreadsheet. With a spreadsheet, learners can **focus on meaning, make things real and put formal knowledge into action** (Figure 3). Software tools are “tools-to-think-with”, as Papert wrote in *Mindstorms* (1980). Having examples and activities with spreadsheets in schoolbooks of certain subjects, particularly for the final years of secondary school, should be a common thing in the near future.

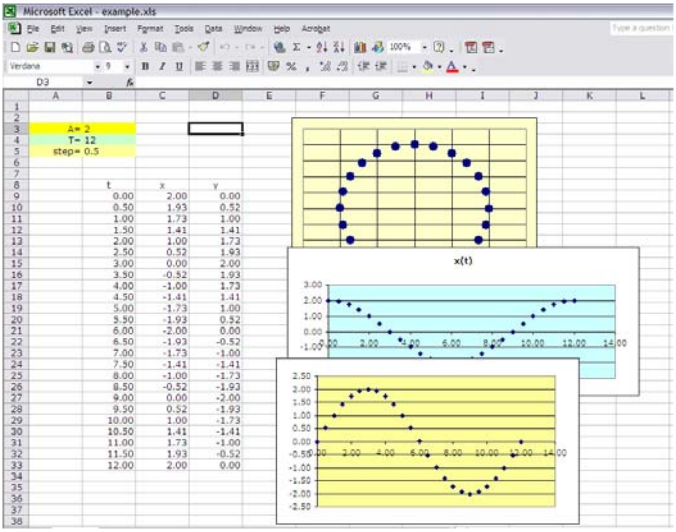

Figure 3: Making things real and putting formal knowledge into action: a spreadsheet file to study parametric equations of a circle created by an 11th grade student.

Other good examples of **powerful software concepts** for science and mathematics education are data logging, dynamic geometry environments, modelling environments, computer algebra systems, image analysis, and simulation tools. These types of software are **now common in scientific practice**, and they will also be **common in all schools in years to come**. But this, I suspect, can only be true if schoolbooks make regular use of them… Probably not with the software professional scientists and engineers use but tools with the same “software concept”, less features and simply user interfaces. Just an example: professional circuit designers use *Pspice* (http://www.pspice.com) and secondary school students can use *Crocodile Technology* software (http://www.crocodile-clips.com/croctech).

General purposed thinking tools, like tools for creating **concept maps**, have interesting features that can have a wide use in learning, particularly if students use *webfolios* (a *webfolio* is a portfolio that the student creates on its own homepages, as my students do since 1997). A good example of such a tool is CMap (Figure 4). CMap also illustrates a very important trend in educational software: files can be saved in a local disk or on a public or restricted server. It can also generate files that can be read on a browser—all software will most probably have this feature in a very near future!

An interesting recent trend on the development of learning environments is **the linking between digital texts and exploratory and simulation software** (e.g., Absorb Mathematics, http://www.crocodile-clips.com/absorb/math). Its impact is still limited in schools but it has some potentialities for the future in certain contexts, such as remediation and self-learning oriented by teachers. They could even be used as schoolbooks on the future … but the technical demands of these digital materials are so high that it is difficult to predict how successful they will be. From a pedagogical point of view, they have relevant characteristics: personal feedback, personalisation of options and learning routes, integrated assessment, multimedia environments, interactive explorations, etc. But, *if all students have their own personal computer notebook… with wireless network access, things will be completely different!*

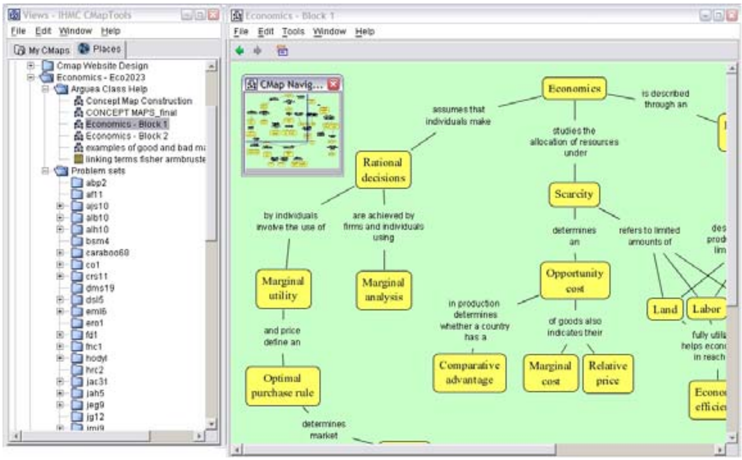

Figure 4: A concept map done with CMap software (http://cmap.coginst.uwf.edu)

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