Choosing ICT: a matter of learning about learning Science

Pintó R.
Centre de Recerca per a l'Educació Científica i Matemàtica (CRECIM)
University Autònoma de Barcelona (Spain), roser.pinto@uab.cat

From the last two decades and with an increasing and continuous presence, we have new resources for Science teaching: the information and communication tools (ICT). There is a proliferation of ICT and, nowadays, our job is to choose the one that best suit our interest in each moment. It is necessary to think about the process of learning and in the intended goals of the school at each level to decide which is the best ICT to be used to achieve such goals. It is appropriate to do some reflection about the possibilities and limits of each ICT and do not take for granted that using them good achievements can be obtained

Within different international spheres increasingly acknowledged is the relevance of science education because, as we already know, it is considered that in many situations, problems encountered by individuals in their daily lives require some understanding of science and technology before these problems can be fully appreciated, understood or addressed. It is also considered that a good scientific education leads to more and better scientists and technicians for a society in which technology is seen as a source of economic progress and the base for social welfare. Therefore, science needs to be learnt and used lifelong by all; everybody needs some scientific literacy.

Nowadays, the community of science educators have a diversity of proposals for improving the learning of science, coming from the analysis of different aspects: teachers' discourse, teachers' beliefs, students' understanding, students' interactions, class resources, materials, equipment, and so forth. Particular resources for science teaching have been the information and communication technologies (ICTs) with a continuous presence over the last two decades.

There is a general consensus among science educators that ICT can radically improve the possibilities for meaningful learning. However, in many studies, we continuously evidence a scarce use of ICTs in most school courses and, in fact, the process of using them needs some reflections (Osborne & Hennessy, 2003).

In a presentation to introduce about any ICT for teaching use, we usually can hear the multiple possibilities it offers but, very rarely do we hear how to make an efficient use of it in order for students to learn something specific with it. It seems that educational technologists assume that a well designed lesson using ICT, when shown to students, will generate automatic learning. It is taken for granted that using it for teaching, students will learn. Unfortunately, this is not the real situation. Our assumption, coincident with Jonassen's (2006) view, is that students don't learn from technologies, they learn from thinking. The considerations about the benefits for the students or for the teachers using the introduced ICT do not appear as the most relevant in such presentations. The use of ICT in teaching is usually well seen in families, where the fashionable aura associated with these technologies seems to justify their usefulness. However, the real obstacles for the implementation in classes are usually ignored. What is evident is the disregard of the big gap between the teacher's action of teaching and the students' process of learning.

The European Commission (2005) proclaimed that ICTs have to enable learning *anywhere*, *anytime* and *anyhow*. However, very little is said about whether what is intended to be taught is actually meaningfully learnt or not. It is not generally the case, either, to establish what can be learnt from each technology. To reflect on the benefits that we can obtain from the use of each ICT can give us criteria to select the most appropriate ICT for each learning situation. This requires us to think about what we want our students to learn and what it means to learn.

Then, the first step is to answer the following questions:

- What do we mean by learning? When can we say that students have learnt?
- What is intended to be taught in school? Which kind of contents are the targets in the school?

What do we mean by learning? When can we say that students have learnt?

To answer these questions, it is necessary to have a model or mental representation of learning, that is, a model of the process leading to learning. After knowing the answers to both questions, we can decide on which kind of ICT is useful for what to be learnt.

At present, many researchers agree that a meaningful learning supposes learning with understanding (Bransford, Brown, & Cocking, 1999). Meaningful learning requires that a learner put new information into an existing cognitive structure in a nonverbatim or non-rote manner, thereby allowing better use and retention of the knowledge. In contrast, rote learning is arbitrary, verbatim, and not related to experience with events or objects, and lacks affective commitment on the part of the learner to relate to new and prior knowledge (Chin & Brown, 2000).

Agreeing with the National Research Council (2005), we assume the three fundamental and well-established principles of learning as follows:

1. Students come to the classroom with *preconceptions* about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom. The understandings that children bri*ng into the cl*assroom, even before the start of formal schooling, will significantly shape how they make sense of what they are taught.
2. To develop competence in an area of inquiry, students must (a) have a deep *foundation* of factual knowledge, (b) understand facts and ideas in the context of a *conceptual framework*, and (c) *organize knowledge* in ways that facilitate its retrieval and applications. Information stored in memory, if organized around core concepts, can be much more effectively retrieved and applied than isolated pieces of information. The reason that experts in a field remember more than do novices is that the former see information as organized sets of ideas and novices see it as separate pieces. The experience of learning topics as isolated chunks of knowledge is less useful, more difficult and a lot less inspiring than a learning experience that reflects the conceptual integration that characterizes science (Taber, 2008).
3. A "*metacognitive*" approach to instruction can help students learn to take *control of* their own learning by defining learning goals and monitoring their *progress in achieving them*. *Metacognition* refers to people's knowledge about themselves as information processors. This includes knowledge about what we need to do in order to learn and remember information and, the ability to monitor our current understanding to make sure we understand the information. It is said that some teachers introduce the idea of metacognition to their students by saying, "You are the owners and operators of your own brain, but it came without an instruction book" (National Research Council, 2005, p. 11). The concept of metacognition includes thus an awareness of the need to ask how new knowledge relates to or challenges what one *already knows.*

We will not develop such principles in-depth. However, we find it appropriate in the present context to take especially into account the second principle when considering the selection of ICTs. Which kind of ICT will facilitate students' learning to develop their competence in an area of inquiry that they need:

2. to have a deep *foundation* of factual knowledge?
3. to understand facts and ideas in the context of a *conceptual framework*?
4. to rely on the new concepts in a conceptual core of concepts?
5. to organize information?.

Research has evidenced that when students are taught according to such three principles, they are able to transfer new knowledge to new contexts, different from that which has been taught (Snyder, 2000). If a new concept is learnt, then it is organized/structured in the individual's mind and linked to other concepts, and also individuals identify easily other elements of knowledge that can be related to it. As a consequence, teachers should promote strategies or use resources having the goal to scaffold students to abstract general principles that lead to such flexible transfer.

We know that some students are more successful than others in learning science and this can be interpreted to be due to differences in the way they learn (Chin & Brown, 2000) "*When students use a deep approach to learning science, they venture their ideas more spontaneously; give more elaborate explanations which describe mechanisms and cause – effect relationships; ask questions which focused on explanations and causes, on predictions..*"*(p. 109).* On the contrary, students using a surface approach give explanations that are reformulations of the questions, a "black box" variety which does not refer to a mechanism, or macroscopic descriptions which refer only to what is visible. Their questions only refer to more basic factual or procedural information. This is not what we commonly expect in students' achievements and hence we will have to choose strategies and resources for a deep approach of learning. Adequate activities and strategies will be oriented to encourage students to ask questions, to make predictions, or to give consistent explanations.

Such views should be applied when we have to select the appropriate ICT for whatever learning situations.

Selecting an ICT for some purpose

When presented any ICT addressed to teaching, at first look, we can easily recognize an underlying conception of learning. Which ICT to choose in order to favour a deep approach of learning? We can go through different kinds of ICT and analyse their underlying ideas about learning.

ICT and associations

There are ICTs whose purpose is that students associate an answer with a question. In some cases, the association to be done is to guess a rule, to match a couple of words, to fill in some gaps, to order some sentences, and so on. Being able to rightly make associations of some words do not mean any gains in knowledge. Similarly, being able to use the right definitions of a concept does not mean to understand the concept or to have learnt it. Research has not evidenced that a deep learning has occurred when such behaviour of rightly associating answers to questions has been successful.

In such cases, the use of the ICT cannot be considered to have as its goal to promote students' deep learning of some scientific content, but merely to match some names, to link some images to some words, to associate some sentences to be repeated, and so on. Within this sort of teaching approach, learning by rote can be expected from the users of this type of ICT.

ICTs as organizing tools

In the assumed paradigm, helping students structuring information is a way to help their understanding and learning. There are good tools to help students to organize information, tools that allow putting each piece of information into categories and hierarchies. The linear texts could show to students how the written information is organized. However it is not done and the organizing principles are not explicit, Only some teachers intend to help students to be aware of the knowledge structure by proposing the realisation of charts or any kind of diagrams to highlight the organisation of the information of the text.

Especially helpful for students in restructuring knowledge are the applications for making concept maps and organisation charts. If people have an available core of information where the new concepts can be hooked to the previously learnt ones, all the pieces of information can be effectively learnt throughout their life, irrespective of their age.

ICT and visualizing

A big information processing step was given by the tools designed to show moving pictures on the screen, representing a variety of processes and objects as happen in animations, simulations, applets and many internet resources: the dynamic visual representations. They can be valuable tools for exploring physical (even virtual) worlds, adding to the classical methods of experimenting and doing exercises. But, what could be the role of these tools in school?

It is a rather common belief that observing a process or visualizing a phenomenon results in images that are created remaining strongly in our memory so that the process or phenomenon is understood and learnt. For graphic or animation designers, such vision is very frequent. The old Chinese saying “a picture is worth a thousand words” is only right if the information that the picture conveys can be “read” by the learner. Njoo and Yong (1993) found that learners have problems in making sense of information from computer simulations, such as discerning relevant variables or interpreting the results of experiments. Many researchers have evidenced that images are not ‘transparent’, and that the meaning of an image is structured through quite complex and subtle organizations (Kress & van Leeuwen, 1996; Halkia & Theodoridis, 2001; Pinto & Ametller, 2002; Stylianidou, 2002).

Observing the dynamism of virtual images on the screen is generally amusing but, obviously, it does not mean learning. We already know well that after having observed a phenomenon or process (observed the reality), it is necessary to find an adequate explanation of it, to construct a conceptual model giving reason for such phenomenon or to apply an existent model to justify what has been observed. Therefore, we should take into account that visualizing is not explaining: visualizing is not building nor applying any conceptual model.

Furthermore, when we visualize or observe a phenomenon or a process we are already interpreting it and this can only be done through our “own lens”. From research, we know that our observation is always guided by our prior knowledge and so, the observed images will be read through such lens. We can only perceive what we have enough theoretical background that makes possible its perception, since any observation is impregnated with theory (Glynn & Duit, 1995). This should be the first warning when talking about the use of dynamic visual representations as a resource for teaching

Moreover, sometimes, the opportunity offered from most ICT tools of visualizing images of processes or phenomena seems to have revived the pedagogically poor idea of “learning by observing or by visualizing” (a fashionable idea in the 1930s). As it was believed that “more coloured attractive pictures, more powerful tools for learning”, therefore, pieces of different coloured chalks were used to write on the blackboards. Again, more recently, some of the commercial presentations about new digital class blackboards seem to support such a view and it should be taken into account.

When can dynamic visual representations support learning?

Seeing does not mean understanding; however, research tells us that the realistic images that simulations, animations, applets and so forth offer can help students "*to understand facts and ideas in the context of a conceptual framework"* if teachers make the efforts for students to decode the information that images convey and interpret them. The meaning of images (their context and elements) and the meaning of the represented process (its parallelism or analogy to a real situation) should be interpreted.

Some research studies have evidenced (Monaghan & Clement, 1999, Evagorou et al.2009) that simulations could be useful tools to assist students in their process of building mental representations of scientific phenomena. Being able to build a right mental representation−of the way a phenomenon is developed, a system behaves or a model runs−seems to be a necessary step for students' understanding and learning. Simulations or animations can provide this support to students so that these tools become meaningful when used by students, especially for those without high mathematical skills. Forming a visual model as a representation that is more general than single examples, but not as abstract as mathematical formalism is considered by many to be central in the thinking of practising scientists. And now, there is growing evidence that such visual model may also be central for understanding within science students (Monaghan & Clement, 1999).

When students are able to understand the meaning conveyed by images of a simulation, it can be adequate to display such meaning through the multiple representation of the same phenomenon or the same system. It is frequent to find applications that employ in the same screen a variety of representations (pictures, animation, graphs, vectors and numerical data displays) of a process. However, we can wonder if the multi-representationality of a single fact makes any sense for learning or if it is simply an exhibition of the technical possibility of the application. The answer is not firmly round but we can make mention of our framework of learning: something (concept, theory, phenomenon) is learnt when individuals are able to transfer such knowledge to a different context. Being able to interpret different representations corresponding to a single phenomenon as a mere change of language, means being able to integrate different pieces of information. Then, a degree of agility is necessary for such transfer: observing and describing a single fact using different lenses and languages would be analogous to observing and describing it using different models. So, the multi-representationality can be seen as another potentiality of simulations, of which we can take advantage in supporting student learning. In such situations they could help students in understanding the underlying concepts, relationships and processes.

Nevertheless, even though a simulation can be designed for the purpose of showing simultaneously different representations of a particular process by means of vectorial representations, different graphical representations, numerical representations, pictures and so on, the integration of the different representations is not obvious (Saez & Pintó, 2005, 2007).

What scientific literacy should students learn?

We can explore more the potentialities of the ICTs taking into account the contents to be learnt in school.In the previous paragraphs we have clarified what we understand by learning and the different sorts of learning in which some Information and Communication Technologies can engage the user. However, nothing has been said about what should be learnt/taught for real scientific literacy.

There is a general consensus that students at school should develop *scientific literacy,* which, according to Programme for International Student Assessment (PISA, 2006), is the ability to use scientific knowledge and processes, not only to understand the natural world but also to participate in decisions that affect it.

1. To use *scientific knowledge or concepts* needs a foundation of knowledge facts and a conceptual framework for understanding and interpreting them.
2. To use *scientific processes* requires the ability to obtain, interpret and act upon evidence through
    1. describing, explaining and predicting scientific phenomena
    2. understanding scientific investigation, and
    3. interpreting scientific evidence and conclusion

Acquiring scientific processes

More specifically, when referring to *simulations or applets* the process that is expected from students is to be able to interact with them modifying certain parameters. A simulation can lead students to questions of *"what if...?"* That is, students can be engaged in an inquiry process. The use of sliders can allow students to explore the role of each of the parameters. This is a relevant scientific process to be able to identify and control variables affecting a phenomenon: the interaction student-application can encourage mastering it. However, it is not easy that students systematically use the sliders or controllers and, on the contrary students often have a tendency to run simulations by trial and error without reflection.

In fact, we observed (Pinto & Garcia 2004) relevant two main problems in using simulations. First, the discovery role assigned to the simulations. Some teachers envisage "again" (as in the 1960s) that teaching by discovery leads to real learning. Sometimes when students manipulate the computer they assign values to certain parameters, and they conclude that they have tested some law. This, of course, could never happen since students are "exploring a world" through the simulation with the rules introduced by its designer. These rules contain the mathematical models of physics, chemistry or biology (e.g., energy conservation is not evidenced using any simulation). Nothing extra is created when running a simulation. Only the issues contemplated by the designer can be visualized! The same can be said for any application where students can interact with the computer.

In the second place, the substitute role assigned to the simulations. Simulations allow students to show and sometimes to investigate phenomena which are difficult to experience or to analyse in depth in a classroom or a laboratory due to extreme complexity, technical difficulty or a risk of danger, or due to its rapid, time-consuming or expensive nature. They allow imitating experiments, which can be used to get quantitative results with a computer under idealized conditions. Such "virtual experiments", in contrast with real laboratory experiments, have the particularity that all disturbing influences are eliminated from the beginning and that laboratory conditions are both fixed to suitability and stability. However, this idealised settings are not idyllic for teaching and learning: there is the risk, evidenced in the following teacher's comment: *Many* *students in my lab group appear to be easily frustrated if they take time to build a circuit to test an idea and it does not work as expected. In contrast, the students in the simulation group appear excited, perhaps because it takes relatively less time to test new ideas and concepts and they receive immediate accurate feedback* (Pinto et al., 2007*).* Not doing experimental work, that is, working only in ideal situations as simulations do, could tend to disguise the reality. Students might confuse reality with virtual reality.

ICT and real experimental work

Other specific ICT tools are addressed to analyse real phenomena capturing data with great accuracy. Datalogging or microcomputer-based laboratory (MBL) become especially interesting for promoting the students' gains in acquiring scientific processes such as interpreting graphics, thinking critically, or linking real phenomena with their graphical representations. Sensors and interfaces connected to a computer can provide measuring data to analyse processes developing in time. They offer real-time data and different modalities of representation with minimum effort. This display of representations enables students to visualize the course of the experiments where changes of temperature, level of sound, intensity of light, pressure, force and so forth take place. We benefit from the computer facilities to process data taken along the time and to analyse digital data, converted through an interface from analogical measurements. Such technologies offer very accurate data from phenomena that happen very quickly and otherwise can not be taken. Measuring becomes an easy, quick and precise exercise. And, what is most relevant is that the time for practical work can be mostly devoted to analysing results of measurements and to discussing about them, instead of to spending a long period for taking data as in traditional labwork.

Due to these different possibilities of allocating class time, it is plausible to give a pedagogical direction to the labwork with MBL that favours a deep approach of learning scientific content. Thus, MBL can be a very useful technology to promote both the learning of scientific knowledge and learning of scientific processes (Russell et al., 2004).

However, it is necessary to be aware of some epistemological problems that may rise often in the use of MBL. During the rapid process of capturing data many particulars can occur and the graphs obtained can be very different from the expected ones (mathematical functions of the ideal models). The causes of the unexpected graphics can be an erroneous configuration of the software (i.e., capturing too high number of data per second), an inadequate arrangement of the experimental equipment with respect of the sensor**,** certain hardware problems (i.e., wrong calibration of sensors) and so on. However the most common cause is the high sensitivity of the sensors capturing real data. In front of such "distorted" graphs, different solutions usually are adopted for the teachers. We could observe (Pintó, 2007) different behaviours: to ask students to repeat the data gathering until they obtain a "neat" graph, to provide an electronic file with a "correct graph" to the students or to eliminate the parts of the graphs not having the expected shape. When the graphs are adjusted to smooth their "disturbances", in fact we are forcing the graphs to show an idealized pattern of the phenomenon analysed**.** We subconsciously intend to make a real phenomenon appear as a simple mathematical function even though the reality is usually very much more complex. This epistemological precaution should be taken. In a research study (Pintó, 2007), when observing many classes of students using MBL, we could not find any situation where the shape of graphs was analysed and discussed taking into account their distortions. In fact, the results were very embarrassing for teachers to manage and make understandable the causes of the distorted shape of complex graphs that appeared on the computer screen. However, as we have said, if working with simulations has the risk of giving the impression of working with natural phenomena, MBLs have the risk of provoking confusions between the reality and the ideal.

Undertaking real-time experiments with MBL technology is supposed to be able to overcome hardware problems of calibration or robustness (connexions, battery, etc.) and software problems. Therefore, teachers should be always ready to surmount surprises that can arise in any moment and so, the inexperienced teachers easily felt uncertain (Sassi et al., 2005). Moreover, the time constraints and the pressure sensation to cover a lot of topics influence the ways of teaching proceedings. Another important constraint is the space in the lab. In most of the lab sessions we have observed, teachers organised students in groups of 4-5 students. In the research study carried out in 2006-07, a high range of classes with teachers having a strong or low control of students work was also observed. We could evidence that a teacher's style and his/her experience with MBL played an important role in teaching. In the firmly controlled groups, teachers discussed the results and conclusions with the whole class. On the contrary, teachers with a meagre control did not hold general discussion of the results. The extreme situation was seen in the case of a teacher not even allowing students to use the MBL equipment.

Modelling as a process of learning and modelling as a software

As previously mentioned, an important task for a scientist after having observed a phenomenon or process is to find its adequate explanation by either constructing a model or applying an existent model to justify what has been observed (Clement 2000). The model will be more powerful if it has predictive possibilities for explaining more phenomena. Much of the success of physics lies in its power to predict the behaviour of increasingly more complex material systems by constructing models.

The teaching of models and modelling has become a frequent theme in science education research (Lijnse, 2006). It has been proposed reiteratively that students need a better understanding about the process of modelling and the role of models in science to understand the nature of science (e.g., Gilbert & Boulter, 1998).

The relevance of building models as a way to understand the production of scientific models has led to produce more and more specific computer tools. Using these computer tools, learners can understand the structure of models, even though some tools have their mathematical formalism hidden. Ogborn (2002) suggested that pupils since primary school can make models using objects and events to express their own representations of their world. In the first steps, pupils can construct environments where objects obey some rules (i.e., through *Worldmaker*, *Stage Cast*, etc.). Later they could build models with relationships among them (*VnR*). The more complex computing modelling software packages are those where students can use calculus and algebra to design iterative computational models. Such kind of applications run according to the rules, relationships or mathematical equations imposed (mathematical modelling). Students construct the model writing the relationships or mathematical equations that objects or images should "obey". After it, students verify its correctness running the model and proving that it behaves as the modellised phenomena would do in the real world. In this stepped introduction of building models, the ability of modelling will be enhanced from the first stages. Science education approaches based on enhancing the modelling process have been found to be efficient procedures of teaching; and there has also been much evidenced that building models of subject content using technology-based modelling tools facilitates the process of learning.

With modelling software, students can construct a model, while using the simulations they run a model constructed by the designer. In both cases, during teaching students are usually impelled to reflect on possible scenarios: *what would happen if…, I am wondering what results will be like if I change…* However, the cognitive demand on students when designing a model for a process or phenomenon consists on analysing all the components of a system, the rules of relationships among them and also expressing them through a computer application. While, using a simulation requires decoding some images and relating its dynamism to some known scientific rules, laws, or principles. Therefore, the cognitive demand on students when using a simulation, due having an already designed model, is lower than in the former case when they have to construct their own model.

Conclusions and implications

With ICT tools we can encourage students to develop skills, some of them highly recognised, such as: capacity of decision-making, capacity of gathering and analysing data, capacity of presenting information and so on. With the use of ICTs we can also extend the "learning community" beyond the classroom or school walls. In this sense, what is really interesting is to use the ICTs as catalysts to promote students' acquisition and development of higher order cognitive skills, and not only as fashionable tools for implementing the curriculum.

We have also seen that there are ICTs whose role in facilitating learning, particularly in higher order learning skills or in learning science, is very minor or negligible. This has made us wonder if their use in the science classroom is justified.

Obviously, the use of new technologies cannot guarantee more successful and interesting teaching, in the same way that a new game does not guarantee users better game playing. The most brilliant resources do not necessarily improve learning *per se* in our classes. The key element are the pedagogical approaches followed when using the ICTs. First, it is necessary to select the ICT and clarify the goals that are intended to achieve by taking into account its potentials and limits. In the second place, it is essential to decide the approach that favours the sort of intended learning. These are the irreplaceable responsibilities of teachers using ICTs in the classroom.

In a knowledge–based society, for citizens to be able to use all kind of technological tools is indispensable. In order to introduce these tools in schools, the critical point is that teachers should be able to select the most appropriate one for each learning situation and to use it competently for any real learning of their students. Teachers are pushed to achieve better student learning outcomes using ICTs but as well they should be provided with more time and consistent access to resources, encouragement and support. Moreover, they should also receive specific guidance to adopt a constructivist view of teaching since this is essential for more effective and deeper learning.

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