The Role of Thinking, Experimenting and Communicating in the Science Lab

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Summary

In this article, we discuss early childhood and primary science education supported by ICT. We propose an approach that incorporates thinking, experimenting and communicating as means to develop technical and scientific thought, in addition to encouraging pupils to control their learning outcomes and work together.

The research presented focuses on a number of important ways in which this type of pedagogy can take place. Importance is given to a teacher’s ability to respond to a pupils' inquisitiveness and their own interests, as well as their capacity to help pupils develop mental agility, or promote attitudes and values such as respect for others, independence, a critical mind and the ability to work in a team. Also crucial to developing technical and scientific thought is the emphasis placed on understanding the world around us, interacting with it and relating it to everyday life, in addition to the use of cognitive and linguistic skills, which are the building blocks of learning and communication.

Based on a socio-critical educational model, we are interested in improving science teaching's quality and fostering its critical potential. This includes, among other things, understanding the key role emotions have in the process of creating scientific knowledge.

Keywords: critical thinking, critical pedagogy, learning processes, student experience, early childhood and primary education, science education

Context

The importance of scientific and technical knowledge in today’s world stems from the fact that our perceptions of the world around us, our relationships with others and how we interact with our surroundings have all changed.

Technoscience appears to be driving the social transformation of our time and it is possibly technoscientific progress that has most changed our lifestyles, whilst also bringing about a climate of uncertainty and evanescence. Nevertheless, the extraordinary development of science has not necessarily resulted in better quality of life for the majority of the world’s population, which has inadequate access to drinking water and education.

This situation calls for knowledge, including scientific knowledge, to be democratised and extended to society at large, in addition to participation in decision-making in scientific politics, in light of the sociocultural reality and the danger of technocracy. If we must teach individuals to live in this world, scientific and technological education is essential (Pujol, 2003).
The problems of our time are complex and global and are evolving rapidly in time and space. They have multiple causes and their consequences entail uncertainty and unforeseeable events. In addition, they run into all areas of our lives, both individual and group. As such, they also have economic and political dimensions.

At the same time we are seeing hyperspecialisation, resulting in a loss of responsibility, individualism and scientific reductionism. We must now overcome the division between science and ethics, and the even greater division between science, ethics and politics.

In view of the challenge inherent in responding to these problems, a new style of strategic thinking in order to analyse, contextualise, relate, act, and incorporate uncertainty is required, along with new citizen action capable of bringing about change and a new ethic to underpin construction of a fairer and more sustainable society (Bonil et al., 2004).

Some argue that in this age group pupils are unable to learn to think with the theoretical tools that science has invented and that, on numerous occasions, teaching has merely sought to foster an interest in science and the acquisition of scientific vocabulary. Theoretical learning is put back until secondary school which means that the leap from one to the other is enormous. This is a waste of very significant years to develop interconnected strategies to EXPERIMENT, THINK AND TALK scientifically (Mans et al., 2005).

In accordance with the DELORS report recommendation to enable lifelong access to education, our challenge is to offer scientific education for this changing world, to children and young people in our society, in a school setting.

**Educational action dynamic**

The dynamic of any kind of educational action is based on the interaction between learning content, pupils and their receptive structures (previous ideas, habits, values, feelings, experiences, language, relationships) and teachers, with their wealth of knowledge, technical ability, skills as teachers, and global vision, or way of understanding the world. But what does scientific education actually comprise?

The answer to this question is somewhat elusive because it depends on how education and science are understood and what is considered to be the ideal educational methodology.
There are various conceptual guidelines on the educational perspective such as what we might call the “academic-culturalist”, based on the transmission of learning objects, the “personal-humanist”, targeting the learning subject, the “technicist”, prioritising learning processes and tools, and the “socio-critical”, based on education in responsible citizenship. Each of these puts the emphasis on different contents.

A spectrum of conceptions of the scientific perspective can also be identified. These include what we may term the “objectivist”, which sees science as a systematic knowledge of objective reality discovered by the wise and transmitted dogmatically, the “experimentalist”, in which each person must rediscover science through individual experimentation, and the “complex”, which stresses, among other things, the link between science and the economic, social, ideological, environmental and other interests of the community in which it develops. Varying educational contents can be selected from each of these conceptions.

Evidently, differing methodological conceptions emerge from these educational and scientific perspectives, ranging from those based on the “transmission” of all manner of contents, whether verbal or sensorial, to those that promote “discovery”, inductively or deductively, and to the "socio-constructivist".

**Learning science at nursery and primary school**

*Incorporating new “ways of seeing”*

The explanations given by science generally entail learning to look at objects and phenomena from angles that defy common thought. For example, what is surprising about the world is its diversity; however, in order to be able to answer the questions that arise upon observing it, we
need to identify its regularities, that is, the common denominators or similarities between apparently diverging phenomena (Mans et al., 2005).

Among other things, learning science involves conducting activities that enable us to:

a) *Observe objects, phenomena, changes and problems* from different viewpoints that allow pupils to recognise relationships that cannot be seen through direct observation. These spaces of “disciplinary dialogue”, which incorporate complexity and make it possible to structure knowledge of the different disciplines in the study of world facts, do not, a priori, exist. They must be created in the classroom by managing the teaching/learning processes. One option is to use good questions - “mediation questions” - which are both a starting point and a meeting point in the teaching/learning process. They are a starting point in that there is a clear vision that the phenomenon can only be understood when looked at in all its complexity, and a meeting point because having explored the phenomenon in greater depth scientifically, they make it possible to come back to the global dialogue space in order to construct a model that is more complex than the initial one.

b) *Bring into play each individual’s cognitive possibilities* as these enable us to “reason”, or in other words to categorise; group; find similarities and differences; classify; discover regular features; seek analogies; organise perceptions and ideas; establish relationships between things; recall, and so forth. The fact that from birth we live in a natural and a cultural environment, both of which are a source of cognitive experiences, must be borne in mind. This diversity of cognitive experiences can be used in order to build new personal and social knowledge. Science helps to structure and organise the world.

c) *Develop the capacity to communicate*, to talk about perceptions and ideas, feelings and doubts and apparent certainties. Language is the fundamental medium through which we define problems, exchange points of view, make group decisions, and so on. In order to explain our ideas we have to describe, narrate, explain, argue, draw, model and communicate with our bodies, and in doing so we define them, specify them and change them; in other words, we learn. Science makes us seek out and put a name to objects and whatever else we discover in order better to understand, consider and explain them. Words alone are meaningless; the meaning is attached by human action when it needs and seeks it. Communicating, listening, talking and writing about science can help us to understand the possibilities and limitations of all interpretation, as well as the different facets and dynamics of problems, thus enabling us to learn about science.

d) *Uncover new feelings and emotions, and new desires and pleasure*. The consumer society in which we live and the dynamics generated within only validate and promote certain determinates: it values the ephemeral, renewal, consumption, novelty, a specific kind of styling, swift success, the cult of the body, speed, and so forth. Changing values involves
realising that there are other ways of understanding quality of life and the relationships we have with our surroundings and other people. The dominant culture extols needs created above and beyond natural resources, equates progress to maximum ownership, and imposes production and consumption as a model that can provide a quality of life desired by and extendable to humanity as a whole. In this context, social groups that do not control current forms of production and management of resources are severely affected as they are economically and politically dependant upon the powers that be. As a result, it is difficult to reflect calmly, connect with one’s desires, limits and possibilities, and seek out personal paths.

e) Conceptualise new ideas, theories, structures and means that science has constructed in order to explain the phenomena observed: the ways we understand what a cycle, energy, change, balance, the human model and so on are have varied over time. The very concept of science education is evolving. We therefore need citizens who are trained in science and technology and are capable of interpreting, taking decisions and contributing ideas to takes us towards a world in which quality of life will be better for all. We may believe that learning - or building knowledge of any kind - is one of the results of human activity. But not all activities are translated into learning, and the same activity carried out by different people does not result in similar learning. One should not forget that teaching time and learning time do not always coincide.

The process of teaching and learning from a complex vantage point

Hence, learning science and building scientific knowledge entail laying down processes that make it possible to look at the world in a different light.

From the science of complexity, one among other suggestive dimensions is to work on the perspective that opposite elements or situations should not be considered as opposing but rather complementary in knowledge-building (diversity/regularity, change/conservation, etc.).

![Diagram of teaching-learning process](image-url)
Any specific activity carried out is underpinned by knowledge and previous values that determine the perspective from which it is observed, thereby conditioning the possible learning that will take place. This is why it is argued that learning is above all changing the way we look at, explain, assess and discuss phenomena (Sanmartí and Tarín, 1998).

**Thinking, experimenting and communicating**

We believe that children and young people can carry out this reconstructive process, particularly when interacting with teaching staff and classmates and evaluating for themselves the quality of their own ideas or activities by putting them to the test. This is a socio-constructivist methodology as it relates to aspects that we consider fundamental to science teaching and learning: self-assessment/control of reasoning, feelings and behaviour, and active participation in a social group in which learning takes place.

Methodological strategies must factor in pupils’ “dynamic qualities” if they are to teach them to be responsible, creative, independent and critical, both individually and as a group. This will help to bring about more diverse and imaginative responses to present and future questions (Tarin and Pujol, 2004).

![Diagram](image)

**Working with “models” in the classroom**

**School science models**

According to Jordi Martí (2006), “One of the most important contributions of teaching research has unquestionably been acknowledging the importance of children’s ideas in the science learning process.

Far from considering pupils to be a blank slate, we now know that they are able to build representations of objects and phenomena that they are invited to study, give explanations on how things work and put meaningful attributions to commonly used scientific terms and, in addition, we recognise the value of these ideas”.
Hence, when working in the classroom we should bear in mind that the term “model” has various possible interpretations: life model, house model, family model, aesthetic model and so forth. As such, it is necessary to reach a consensus upon what we understand by “scientific model”.

We know that pupils bring their own ideas to the classroom and organise, or shape them. Therefore, the differing models generated when attempting to explain observations are provisional representations that only explain certain aspects of reality. When new observations are made and new questions asked, they can gain awareness of how new phenomena can be explained with similar models, albeit with a few minor adjustments to the initial model.

For these stages, we believe that Gilbert’s definition of “model” is of interest.

**What is a scientific model?**

“A model is a simplified representation of a phenomenon, focusing attention on specific aspects. The model is used to provide explanations as an answer to a question”.

The OCDEC (2000) has already defined what science learning at school should comprise: “Developing pupils’ capacity to use scientific knowledge to identify questions and obtain conclusions based on facts, in order to make decisions about the natural world and the changes in it caused by human activity”.

In order to achieve this, pupils must be helped to develop their ideas - their personal explanatory models (M1, M2, M3, etc.) - about facts, objects and phenomena in their surroundings, to bring them closer to scientific ideas, or scientific explanatory models.
The diagram below shows the aspects that we believe are fundamental in the modelling process at school.

**Three fundamental aspects in the process**

- Questions aimed at fostering modelling
- Selecting, placing in a hierarchy, stimulating co-regulation...
- Handling of material
- Group-class interaction using different languages

**Example: the living being model**

What do we mean by the living being model? Pujol (2003) describes it as, “…studying living beings from a systematic perspective that identifies them as open and complex systems. They are open in the sense that in order to be, they are continually exchanging material, energy and information with their surrounding environment, and complex because they are made up of many interrelated elements, the whole of which is not the sum of its parts”. It is this complexity of views provided by a living being school model such as Rosa M. Pujol’s that enables ideas to develop throughout schooling.
We shall now turn once again to the process of building scientific knowledge based on differing “ways of seeing”, now specifically on the study of living beings.

Coming up with a model on living beings and their relationship to the environment necessarily entails no longer studying them as systems that stand alone in time and place. They must be taken in the complexity of their organisation and of the exchanges they create in a given environment (each living being lives in a specific habitat because of its specific nature). For Jiménez Alexandre (2003: 27) "If we take learning situations as communicative processes, it follows that there must be communication for learning to take place".

Thus, one way of helping and accompanying pupils in this task is through communication in the classroom: the conversation. This teacher-pupil or pupil-pupil conversation entails asking or answering questions, or showing divergences that allow pupils to reflect upon and incorporate new relationships between concepts, as a process of going back and forth between thought and language.

**TEACHING-LEARNING PROCESS**

It is necessary to foster new educational situations and create different learning settings in order to help build this living being model in nursery and primary education.

It is our opinion that these settings, which might include a fish tank, terrarium, window box, allotment, incubator, building a story, wall frieze, model, a simulation, a trip, the Sciences Classroom and more, are teaching mediators that must facilitate both observation and raising of good questions and communication, and representation of key aspects using different languages (oral, graphic, written, body, three-dimensional) (Gómez, Sanmartí y Pujol, 2005).

Creating these settings must allow us to talk about things that happen and things that we imagine happening, to show the interactions between the within and the without, to contextualise perceptions, and to identify and represent the parts of the organism and the medium.

This space of knowledge can only be managed by teachers able to accompany children in their ongoing development, with a view to obtaining rich and fascinating sources of learning, sources
of surprises and emotions, of uncertainties and questions, of doubts and of a thirst for knowledge.

An initial analysis of the proposal illustrates the importance of “questions” and in particular those known as “mediation questions” - questions that facilitate the learning process. This typology of questions will serve as the springboard to move from reproductive to productive answers, boosting pupils’ degree of independence and critical spirit by encouraging experimental work rather than merely describing facts or phenomena.

Hence, a core aspect to change in our working methodology are the questions we ask in order to assess the outcome of a learning process. It is through these questions that from a very early age children perceive what is important to learn. If the only questions we ask require them to cite objects or their parts, or to explain the same situations or phenomena that they have worked on in class, children will realise that all they need do is recall data and that striving to learn to use other thinking strategies is superfluous.

Examples of this type of question are suggested in the table below.

<table>
<thead>
<tr>
<th>WAYS OF LOOKING AT THE PHENOMENA THAT SURROUND US</th>
<th>QUESTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diversity / regularities</td>
<td>Are all living beings the same? Do they all behave in the same way? What do they have in common? (Confirm diversity but recognise points in common.)</td>
</tr>
<tr>
<td>Change / conservation</td>
<td>Can a living being change? How would it change? What will it change and what will it keep? What might make it change? (Observe interrelation with the environment.)</td>
</tr>
<tr>
<td>Within / without</td>
<td>What is it like on the outside? What on the outside does it use for what is on the inside? (Living beings are a system of interrelations that cannot be seen merely as “isolated”.)</td>
</tr>
<tr>
<td>Macro / micro</td>
<td>What are the miniscule parts that shape the object and that we cannot see like? (The link between what we see and what we do not see. It is important to learn to look-imagine-think in zoom.)</td>
</tr>
<tr>
<td>Continuity / discontinuity</td>
<td>Am I just a whole block? Or am I made up of parts? How does the seed that will grow into a plant know? (The living being is seen as a continuum and it is necessary to understand it right down to its smallest part and the importance of this.)</td>
</tr>
<tr>
<td>Past / present / future (time)</td>
<td>What were living beings in the past? What will they be in the future? Where have they come from? How will their story continue? (Idea of the cycle.)</td>
</tr>
<tr>
<td>Here / there (space)</td>
<td>Can all beings live anywhere? What does it depend on?</td>
</tr>
<tr>
<td>Elements (parts) / structure</td>
<td>What relationship does the plant have with the seed? What does the root do for the flower? (When we observe parts it is necessary to recognise the importance of each part to the whole.)</td>
</tr>
<tr>
<td>Experimentation / extension of models</td>
<td>Do all plants come from a seed? How can we find out? If we plant any part of the plant, will a new plant grow?</td>
</tr>
<tr>
<td>Uses / needs</td>
<td>Who eats the living being? What is it for? What does it need from the environment to stay alive?</td>
</tr>
</tbody>
</table>
Science Classroom scheme as a learning setting

A need and an opportunity

The Regional Government of Catalonia Department of Education launched the first “Science Classroom with ICT in Nursery and Primary Education” during the 2005-2006 academic year. There are now 350 schools equipped with this classroom.

The aim of this scheme is to provide a learning environment to facilitate scientific modernisation and science teaching in nursery and primary education. It consists of an array of material resources for use within and without the classroom, both those for everyday use and those that are specific to the laboratory and ICT tools.

This scheme arose from social and teaching requirements such as the following:

- Responding to modern society’s need for science education. IT tools such as data capturing sensors, simulators and computer-obtained images are now also used in science and it therefore stands to reason that pupil-adapted IT tools and software be used, in the same way we use the word processor of a computer to write texts and an image editor to work with images.

- Factoring in the concept of pupil-built learning to the Sciences. To date this notion has been less present in science than in other areas such as mathematics and languages. For instance, we can ascertain the various stages a pupil goes through when learning to write, we can identify them, work with them, and know a little about the interpretation children give to the phenomena that surround them and their mental images.

- Working on science from the standpoint that THINKING, EXPERIMENTING AND COMMUNICATING is pupils’ habitual metacognitive procedure, with a view to boosting their independence and critical spirit to the maximum.

The Science Classroom scheme aims to provide the opportunity to extend modernisation of science and teaching throughout Catalan schools.

It seeks to meet teachers’ training needs in knowledge of the psycho-educational foundations of the sciences, helping them to gain greater insight into their own practice and new methodological proposals, with a view to updating and improving the basic technoscientific skills that are so vital to the development of 21st-century children. To this end the scheme entails teacher training courses which are of course based on the theoretical framework described above.

The Science Classroom: a new space

When a school puts in a request for the Science Classroom scheme it commits to meeting a number of requisites. One of these is to provide a space in the school in which to locate the Classroom. This space must be assessed technically because it must enable one of the conditions arising from the teaching approach explained above. A space in which group communication is essential must be organised to this end. It must therefore allow for group work and, more specifically, the computers must be positioned so as to encourage this. The layout below shows one possibility.
An open space that enables communication with the environment and facilitates numerous contexts so as to accompany pupils in developing their ideas on facts and phenomena, taking them towards the notions of Science.

A space linked to scientific thinking, problem-solving, arousing curiosity, asking questions, investigating and so forth, which fosters global learning processes in the sense that these generate interrelationships between differing fields of work and which is equipped with an array of methodological resources.

A space where we can shift from doing experiments (knowing how to do things) to doing experimental work (knowing why they are done) and make this part of our everyday life.

A space in which to do school science, where both the most humdrum of materials and new technologies have a meaning, using each wherever and whenever most appropriate; where such technologies will afford the possibility of raising new questions, will broaden the way we see and the way we obtain and handle data and images, and foster exchange of experiences.

A space where creativity can also find a place.

The Science Classroom: materials

The scheme’s material resources are varied, highly versatile and can be put to different uses. They have been devised to work on technoscientific skills in contextualised situations. There are four types of material, each with its own cupboards and boxes to be organised and stored.

- Everyday use of materials.
- Laboratory-specific materials.
- Materials for trips and the natural environment.
- ICT instruments and tools: 4 cameras, 2 binocular microscopes, 2 video cameras that can be linked up to the binocular microscopes, 4 flat screen computers, 1 42-inch projection monitor and 6 briefcases with 6 sensors to capture temperature, sound and light data.
Conclusions

From an educational standpoint, we believe it is necessary to take a “socio-critical” stance since in our view it is now no longer about developing science teaching by improving its dissemination, but by enhancing its quality and critical potential. We are in agreement with Paulo Freire when he stated (1996):

“Discussing problems with courage, understanding difficulties, in order to set out from our own conscience, having the valour and strength to ‘fight’, instead of being dragged into a loss of self...this is only possible through education that promotes ongoing dialogue, constant appraisals of our own thoughts, critical analyses of discoveries made, the quest for changes in the reality we discover”.

With regard to the scientific perspective, we attach great significance to the input of a science of complexity that among other features incorporates the central role of emotions in constructing scientific knowledge and builds bridges to many other fields of discipline. We concur with Edgar Morin (2001) in seeing scientific know-how as:

“Know-how that trusts more in the path that is built than in reaching the finish line, know-how that knows about uncertainties and stumbling blocks. It is perhaps a type of know-how that is more in line with a vision of life as an adventure with all its question marks, doubts and risks.”

From the methodological standpoint we see learning as an interaction between the pupil’s personal structure or initial model on the one hand, and on the other, the events, information and new ways of acting that s/he experiences. Notwithstanding, this learning is not simply about integrating new knowledge based on experience nor adding new concepts to those that already exist, but about rebuilding the way pupils think and act with a new scale of values. Therefore, we can not solely use a methodology of discovery or of oral and written transmission, but a socio-constructivist approach that fosters social interactions in the classroom by utilising differing types of language.

Many factors are interrelated in science learning: interests; observation and experimentation; reasoning strategies; the way ideas are organised; the way ideas are communicated; values, to name but a few. As stated by the European Commission Working Group on Lifelong Learning Policy Development (2004):

“one of the main objectives of school science is to develop, especially key competences in science and technology; another is to contribute to the development of other key competences through science such those related to: communication, learning to learn, interpersonal, intercultural, social, civic and entrepreneurial skills”.

The quantity of material means available must not be a barrier to taking on new challenges that arise: the greatest strength of this teaching approach that we propose is fundamentally the role of the teaching staff and the role that pupils play.

Professional challenges must serve for us to give deeper consideration to the role that we consciously want to carve out both in the classroom and in our relations with our pupils, the educational community and our environment. We have a long path ahead of us on which to enjoy our profession.

We can enjoy accompanying our pupils in their process of building learning. We can enjoy observing their representations of the facts and phenomena in the world around us, discovering their internal logic.

We can enjoy their arguments, their discussion, what they defend, what they discover, their new questions, their queries, their interests...
We can enjoy learning to measure our intervention as we see them grow to be more independent, as we improve on our questions and when we have rightly remained silent on certain occasions..., seeing ourselves in an ongoing process. As Maria Arcà (2004) has argued:

“It is not true to say that children and young people only have knowledge of fragments of the world whilst waiting for adults to reorder them: there is always something at work, a gargantuan effort to build networks, and this effort to relate and understand and explain is just as intense as their will to live.”

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