The Challenges for Science. Education for the Twenty-First Century
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SCIENCE EDUCATION IN FRANCE: '*LA MAIN À LA PÂTE*'

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1. *Education in science, a new concept?*

In France, the issue of the scientific litteracy of the society is most often raised in terms of *culture scientifique et technique*. Several studies have recently been published, showing the coexistence, in the public opinion, of a high degree of interest for science and technology, associated with a great ignorance and many fears. Within the scientific community, there is a lasting consensus that this situation is not satisfactory and requires specific actions. In the last two decades indeed, numerous efforts have been made by the public authorities, the research institutions, the science community through its professional associations in order to bridge this gap and amplify the transfer of scientific results to the public.

Some of these efforts aim to improve the information of the public through the media (press, television), others to stimulate the creation of centers (*Centres de Culture scientifique et technique*) which mediate the knowledge towards a large public on a local basis, others to open the scientific or industrial laboratories to the public in a yearly national *Science Week* which has now twenty years of existence. Most scientific research institutions (CNRS, INSERM...) have developed in-house special offices dedicated to communication, with the aim to make known their activity to the press and the general public. The emergence of science and technology into society debates (genomics, procreation, climate, etc.) now leads to new forms of exchanges, which go beyond a pure scientific information: *cafés scientifiques*, *conférences de citoyens* (citizens debates), Internet forums, which are reflected in the press.

While this *information on science* (and technologies) tries to cope with the pace of discoveries, their impact on society and the political debates

they imply, another aspect began to emerge in the last decade, namely *education in science*. This is clearly an issue for the school system, which in France is strongly centralized, and deals with curriculum choices, teachers training, recruitment and evaluation. What should be the goals of a proper education in science, to be given to everyone during the school years, especially during the compulsory education, which in France lasts until the age of 16 and is in principle identical for everyone? does the change in the volume, the rapidity of development and the impact on society of science and technology force to reconsider the way science is taught in schools?

Education in science can be understood as the goal to share methods, history, values and results of the scientific and technological development. It is not to be conceived as a mere accumulation of facts, results, 'scoops' on discoveries, fragmentary knowledge, formulas or practical rules. It is a subtle access to this apparently miraculous ability of human intelligence, brain and hands together, senses and measuring artefacts together, to unveil the mysteries of nature and to become able to act on it, predict the future and develop new artefacts, in a cumulative process of development, specialization and cross-fertilization of disciplins. Achieving this *education* requires pedagogy, continuity, appropriate tools and methods, the partnership of a teacher and can not be confounded with *information*, which is needed but today appears as a volatile and often superficial product of the consumerist society. The ambition of education is to introduce everyone to this mixture of pure imagination and inflexible rationality leading to the scientific knowledge and subsequently to a power upon the natural world.

The transformation of the pace in science and technology evolution forces to reconsider entirely the ways through which the school system handles this challenge. The scientific community, the role of which has been essential in the development *of information on science* in the last two or three decades, as briefly discussed above, has to become involved also in this new issue, to a degree it ignored up to now. On top of its traditional *raison d'être* to create new knowledge and to disseminate it to the new generation to ensure a cumulative development, it bears a new responsability of *knowledge sharing*, which implies a more direct role and impact on the education system, and especially on teachers.

The central role of teachers for a good education in science is obvious. Yet, the community of science teachers (in *collège* and *lycée*), in the last two or three decades in France, became more and more separated from the mainstream of science and technology, became cut from active research and even organized in professional associations which have little or no rela-

tion with active scientists. One key issue is therefore to reinstall a kind of common interest and understanding between the two communities. An adequate place for this should be the pre-service and in-service training of teachers, since there is no hope for the science to remain the same during the several decades of duty a teacher will have.

2. *Evolutions in France*

It was progressively realized, by the mid-90s, that science was essentially absent from primary school education in France, as this education was instructed to focus on the so-called *fundamentals* requirements of reading, writing and counting. A movement called *La main à la pâte* was started in 1996 by Georges Charpak, Nobel Prize in Physics 1992, with the determinate support of the Académie des sciences, aiming at a rejuvenation of science teaching for children of ages 5 to 12. This movement is briefly described in the Appendix and its positive lessons are discussed below.

The lessons from *La main à la pâte* action and the worrisome recent decrease of science students in higher education leads now to a new question, i.e. the validity of the science/technology teaching achievements in the *collège*, namely the four years (12 to 16 in age) which end the compulsory school time in France. Since 1974, this *collège unique* is conceived on a uniform scheme for all pupils, no matter what their achievements, background and professional wishes or plans are. Although this formula has the merit to refuse former disparities, related to social classes, and to propose an equalitarian and uniform frame of learning for all children, it is more and more questionned in view of the problems encountered in classes.

The *collège* is today, certainly, the most difficult part of the French education system: teen-agers are in a difficult period of their personal development, teachers are submitted to strong but often contradictory pressures from the society and the parents, violence has irrupted in many classes, social integration of minorities is difficult. Science teaching is broken and parcellized in three independent disciplines (physics & chemistry, life & earth sciences, technology) which barely lead to a clear understanding of the nature of scientific knowledge and their role in society, not to speak of the relation of science with other disciplins such as language or history. Put in perspective with Gaston Bachelard's words *'For a scientific mind, every knowledge is an answer to a question. Nothing is obvious. Nothing is given. Everything is built up'*, our science teaching gives answers long before the teen-agers are driven to ask questions!

Nevertheless mathematics teaching, a traditional strong point in French schools, remains good, possibly for unsatisfactory reasons: proficiency in mathematics continues to be considered, by the parents but also by the system, as a *sesame* for almost any career.

After the *collège unique*, while a small fraction of each generation goes directly to work or keep some kind of apprenticeship, a larger and larger proportion (78% in 1999) continues the school, eventually reaching the *baccalauréat* or going beyond. In these three years which terminate the secondary cycle, for six students, three go to the *lycée général*, two to the *lycée technologique* and one to *the lycée professionnel*. Of the whole system, these three years are probably the ones where science/technology teaching is the best, where transformations are relatively easy and require relatively less attention.

Another concern recently emerged from the other extremity of the education system, namely from Universities and Engineering schools (Grandes Ecoles). From 1995 to 2001, although the number of students selecting sciences or science related technologies in the last years of secondary education has not decreased, the *post-baccalauréat* choices towards scientific fields and, to a lesser degree, technological fields, shows a trend of decrease, especially in physical and chemical sciences.

These various considerations, indeed specific to France, point out to a single phenomenon: science education is in a deep crisis. First, although the system more or less continues to produce the scientific and technical *elites* the country needs, science is taught more and more as a technical collection of efficient recipes to the detriment of creativity. Second, this education fails to give to the ones who will not become scientists, engineers or technicians a proper background to understand the evolutions and to participate to the choices in a democratic society.

3. *Some lessons from 'La main à la pâte'*

This is a brief summary of the development of action in French primary schools:

– 1995: Less than 5% of French *maternelle* schools (age 3 to 5) and primary (age 6 to 11) practice any natural science.
– 1996: Georges Charpak, the *Académie des sciences* and the *Ministère de l'éducation nationale* begin a small scale experimentation called *La main à la pâte* (344 classes).
– 1998: Publication by the *Académie* of the 'Ten Principles' as a simple guide and reference for teachers. A high-quality Internet Site is developed as a resource/exchange basis.

– 2000: The experimentation has expanded as a grass-root movement and rallied over 5000 classes, with *Académie des sciences*, public and private support.
– 2000-01: Along with *La main à la pâte* and inspired by it, a new Plan for quality science/technology teaching in all schools (350.000 classes) is established by the Ministry of national education.
– 1995-2001: international developments go in parallel, in French speaking country first, then in other countries, through the network of Academies.

The Ten Principles were elaborated in 1998 and broadly diffused as a simple reference for teachers, supervisors or trainers:

- Children observe and experiment with their senses on real and close objects or phenomena;
- They are encouraged to argue and reason, to share ideas, to build knowledge;
- Proposed activities are organized in sequences, leaving ample space for children autonomy;
- A minimum science time of 2 hours/week is spent on the same theme, for several weeks. Continuity must be ensured over the 5-6 years of elementary school;
- Children keep their Experiment Notebook to write, draw with their own words and schemes;
- The goal is an appropriation of scientific concepts/procedures with language (oral & written) acquisition;
- Family & neigbourhood are closely associated;
- Scientific partners (scientists, students, engineers) accompany the teacher, but not substitute;
- The teachers vocational schools (IUFM) are involved;
- An Internet site is developed for resources and exchanges (mutualization).

Learning by doing, *Hands-on learning*, *hands & brain*, *inquiry* are parallel designation of this approach of science which *La main à la pâte* aims to develop. It is not necessary here to detail principles which are well known. It may be more interesting to quote some of the conclusions reached after five years of work, dealing with the teachers, as they represent the only real possiblity for evolution.

A few remarks need to be made here, in order to understand the background of science teaching: in the French primary schools, the teacher is

polyvalent, namely he/she teaches, 26 hours a week, all the subjects, and children have only one teacher. Today, teachers are trained with 5 years after the baccalauréat, namely at the level of an engineer: their initial field may be science (a small proportion) or history, economics, litterature..., but beyond this, they all will have had two years of professional training, with barely some science (30 to 50 hours). Yet, older teachers may have had a much shorter initial training. Compulsory in-service training is limited to about 15 hours per year, while teachers are allowed to accumulate as much as 3 years of voluntary training over a 37 years career. Finally, 79% of the teachers are women. Here are a few of our conclusions:

– Teacher's attitude towards science itself is positive in principle, but often characterised by a great complex of ignorance;
– Teacher's attitude towards *teaching science* is very negative: fear, lack of knowledge, anxiety are often quoted as dissuasive obstacles;
– Teacher's are afraid, when questionned by a child, to be forced to say *I don't know*, while the child may have been exposed to scientific information on the media or in the family;
– Teacher's view on science is broken into narrow disciplines, without an integrated view of what is science and scientific behaviour. They completly ignore science history;
– Their attitude towards teaching technology is better, in the sense of 'building something which works', but they make little relation with an abstract content of the 'reasons why it works';
– They consider that science is made-up of formulas, and the mathematical expression of nature is considered as completly dissuasive of understanding what stands behind formulae;
– Best teaching sequences in science are clearly taught by teachers having no science background in their education. This is so often stated that it kills the common-sense opinion that, at this elementary level at least, science could only be taught by teachers having a strong scientific background;
– A thorough difference is observed when some kind of partnership is created and maintained between the teacher and a scientific partner (scientist, engineer, student). This partnership creates or increases teacher's self-confidence, solves difficulties about equipment or experimenting in the classroom, answers questions about scientific facts or phenomena (why is the sky blue? why is a bird flying and not falling? etc.).
– Main cognitive role of teachers is language education, as requested and easily evaluated by the parents and the system. Anything aside this

appears superfluous to the teachers. Therefore, connecting science education to language acquisition (especially the writing in the *Cahier d'expériences*, and the collective oral argumentation in discussing hypothesis or experiments) rehabilitates science as a mean, among others, to reach the language acquisition goals. Some teachers in difficult areas were quoting the fact that science writings were the longest texts children could produce!

– The number of teachers connected to Internet, either through the school or at home, is steadily increasing: developing a good site for teachers has proven to be a formidable tool for the development of science teaching. It allows exchanges of experiences, access to resources (the full 17 volumes of the *Insights* protocol, translated in French and free for dowloading, have been made available through this site). It allows also to question consultants from the scientific community or on pedagogy, and more recently cooperative work on specific subjects across the country or even worldwide (cf. the *Eratosthene* project on measuring the Earth's size with shadows). There are 350.000 teachers in French primary schools, and the *La main à la pâte* Internet site receives close to 50.000 connections per month; it handles more than 50 scientific consultants and has a forum discussion list of over 1000 teachers, while only 20% of the teachers population access Internet in 2001.
– Teachers appreciate, in very practical terms, universality of the questioning towards natural phenomena: science classes often prove to be the most efficient in giving the taste for knowledge to non-french born pupils or pupils with non-french mother tongue.
– Teachers are surprised to see that science can be taught in an integrated manner, not broken in disciplins which reminds them of their, often painful, secondary science education: dealing with *water* relates to physics, chemistry, meteorology, geology, biology of animals and plants.
– The best training of teachers is obtained, neither by giving them elaborate lectures on how to teach science, nor by step-by-step instructions which would eliminate their pedagogical initiative, but with a simple method: put them, in a collective manner, in the situation of the questioning, hypothetizing, experimenting, argumenting, writing child, and discuss with them their reactions, questions, a priori evidences, common sense, etc.
– Teacher's creativity can be trusted to enrich the initial material, draw on local resources (parents, museums, industries), improve by exchanges.

4. *Some conclusions*

The experiment started in France in 1996 is slowly progressing, and it is accepted that it may take more than one decade to seriously transform science education in primary schools. Generalization requires financial resources, a minimum equipment of 150 euros per class would lead to a total budget of 50 million euros, hundred times the 0.5 million euros spent to date in equipment. But even more, generalization requires to motivate and train the teachers. Experience shows that motivation is clearly obtained when scientific partnership breaks the teacher's isolation and fears: amplifying this partnership and finding ways to cope with the number of teachers (350 000 in France) is one of the main issues for the success. Initial training requires to thoroughly improve the academic context (vocational schools called IUFM or *Instituts universitaires de formation des maîtres*), which is not properly connected to the active science, and tends to substitute to this connection a discourse on didactics, valuable but too often cut from real and enjoyable science.

The involvement of the scientific community is also required to develop resources, create new themes based on contemporary science, relate learning to modern brain research and cognitive science (a growing field which has not been treated here, but should not be ignored), exploit the training and exchange capabilities of Internet: as a simple example the possibility to observe the night sky through a small telescope, during day time for a class, by remote observing (Hands-On Universe Project) offers entirely new perspectives to astronomy.

My conclusion is clear: improving science and technology education is in the hands of teachers, but teachers, even helped by manuals, can no longer cope alone with the pace of development. Leaving them behind means also one leaves behind whole generations of children. On the contrary, involvement of the science community and the Academies is demonstrated, through the modest effort carried in France, as a sure way to improve the situation.

APPENDIX

Note: *the following text is a short description, published mid 2001 by the French Académie des sciencies under Yves Quéré's supervision. It details the action undertaken by this Académie to rejuvenate science and technology teaching in French primary schools.*

LA MAIN À LA PÂTE (HANDS ON)

In 1995 Georges Charpak, joined shortly by Pierre Léna and Yves Quéré, launched the *La main à la pâte* (Hands-on) programme, intended to revitalize the teaching of the sciences in the primary school in France. This initiative received the unanimous support of the *Académie des sciences* in July 1996, which support has been unceasing since then.

In order to realize this objective, the Academicians have also the support of a team of around fifteen full time persons (Lamap team), of a *Scientific Council* composed of outstanding persons of research and education, and of a *Committee of partners* which is intended to give ideas and financial support to the action of the *Académie.*

What is 'La main à la pâte?'

The general idea of *La main à la pâte* is to cause children to participate in the discovery of natural objects and phenomena, to bring them into contact with the latter in their reality (outside of virtual reconstructions), directly through observation and experimentation, to stimulate their imagination, to broaden their mind and to improve their command of the language.

More precisely, here is a scenario of a typical *La main à la pâte* session.

A child has asked a question about his/her environment, inanimate or

living. Instead of replying immediately, the teacher throws the question back to the class, 'And you, what do you think about it?', eliciting the hypotheses of the children and thus firing their imagination.

A simple experiment (observation, manipulation, measurement..., what you will) is then begun. Led by the children in small groups, it must in principle provide the answer, doubtless making them return to the initial hypotheses, and giving rise to the dialectic of reasoning and experiment which lies at the very heart of all research work.

Finally, the children will be invited to express their thoughts (short statements, writing in an experiment book) on the little adventure they have just experienced together, being thereby obliged to enrich their vocabulary and refine their logic and, hence, their syntax.

Of course, this is an ideal scenario which, in many cases, may be severed from one of its elements. For example, experimentation on living things (or on astronomical objects) raises specific problems. The experiment may even fail, in which case the teacher will give the answer to the initial question ex cathedra. Nevertheless, the fact remains that a personal engagement by the child, appealing at the same time to both his/her senses and intelligence, tends to encourage an enjoyment of science and bring it to life for him/her.

Hands on (and the eye in the microscope) in a school of Montreuil (Seine-Saint-Denis).

Based on these general ideas, a number of partners were sought, actions were initiated and tools created. At the same time, stimulating relations have been established with foreign colleagues working in the same vein, thus

leading to collaborations and enriching comparisons. On all these points the *Académie* has contributed greatly to the progression of these ideas and to the facilitation of contacts between the partners in the operation.

The 'Académie's' partners

– The first of these has of course been the French national Ministry of Education. The launch of *La main à la pâte* in September 1996, was by Ministerial decision and involved 450 primary school teachers in five French *départements*. The number of teachers is currently more than 6,000.

Encouraged by the Department of School Education (*Direction de l'enseignement scolaire*, DESCO), the experiment led to the setting up by the Ministry, in June 2000, of a plan derived from *La main à la pâte* to revitalize the teaching of the sciences, in *all* French schools at *cycle 3* (final two years of primary school), the idea being to then extend it to all primary education, including preschools.

The *Instituts Universitaire de Formation des Maîtres* (IUFM) are essential partners because that is where the teachers are trained. The *Académie* has established excellent relations with the IUFM, concretized in the creation of a network of *La main à la pâte* 'corresponding members', with a presence in each Institute.

The *Institut National de Recherche Pédagogique* (INRP, national institute for educational research) has been involved from the beginning through research staff, IT support (see *The site*),...

The *Corps des Professeurs des écoles* (ensemble of schoolteachers) is a crucial interlocutor for the *Académie*. This dialogue is established at numerous sessions, conferences, education days..., when the promoters of *La main à la pâte*, invited to talk science, receive comments and ideas in exchange.

The *École Normale Supérieure* (ENS-Ulm) has thrown itself alongside the *Académie* in this approach, involving *agrégation* candidates (the highest competitive examination for teachers in France), and making offices available to the *Lamap* team.

– The Ministry of Foreign Affairs is an important partner of the *Académie* for the international part of the programme (see later).

– A number of the Grandes Écoles have joined the movement: l'*École des Mines de Nantes* , Director: R. Germinet, which is generating educational material, l'*École Polytechnique* some of whose students spend a few months in schools in difficult areas; l'*École de Physique et Chimie Industrielle de la*

ville de Paris, whose Director Pierre-Gilles de Gennes has encouraged it to be involved in scientific support of a number of schools in Paris.

– Various Bodies and Associations, both public and private, support *La main à la pâte* in diverse ways, every one very effective.

The Department of Technology (*Direction de la Technologie*, DT) of the Ministry of Research, and the Interministerial Commission on the Town (*Délégation Interministérielle à la Ville*, DIV) have contributed to the financing of some of the *Académie*'s activities.

The *Fondation des Treilles*, with its hosting of seminars, and through the publication of books, has been a partner from the beginning, together with the *Société Française de Physique*, *EDF*, *France-Télécom*,...

Many Institutions are striving towards the popularization of science among children. *La main à la pâte* has positive relations with *L'explor@dôme* (Paris), *Ébulliscience* (Vaulx-en-Velin), *Science en fête*, *Les petits débrouillards*... and, of course, *La cité des sciences et de l'Industrie* (La Villette) and *Le Palais de la Découverte* (Paris).

In a less institutional way, many laboratories and research centres..., together with engineers and researchers (both active and retired), lend a valuable support, generally involving actions in schools or on the Internet Site (see later).

The educational tools

– The *Académie* has undertaken, with INRP, to provide French schools with an Internet network, enabling the teachers involved in *La main à la pâte* to link up with one another, and also linking them to the world of research.

The site (http://www.inrp.fr/lamap), which has three sections (information, resources, exchanges) has several attached networks:

The *La main à la pâte* network: a national site and departmental sites display locally produced resources and general information.

The network of *scientific consultants*: researchers and engineers answer science questions raised by teachers.

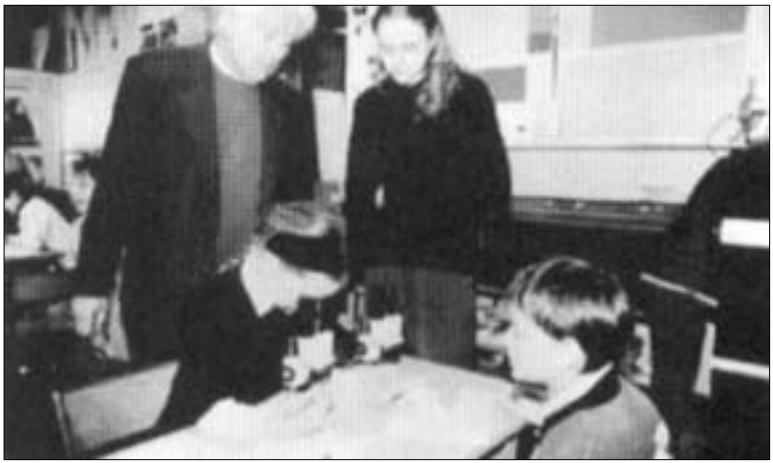
The network of *training officers/teaching specialists*: questions on teaching and education are dealt with here.

An international site in under elaboration

– Since, in the beginning, the availability of educational documents corresponding to the approach described here was only fragmentary, American *Hands on* texts have been translated and made available to teach-

ers on the Site. Then, the generation of texts, books, experimentation packs,... has been encouraged. A 'Seal of approval committee' has been created. Chaired by Marc Julia, it examines documents seeking to achieve the *La main à la pâte* seal, which guarantees their good scientific quality.

– An Autumn university has been founded, with the support of the *Fondation des Treilles*, which brings together schoolteachers and researchers. The reports of the latter are published in the *Graines de sciences* collection.



La main à la pâte prize giving in the *Académie.*

– *La main à la pâte* prizes are awarded annually by the *Académie* to classes for high-quality achieve-ments in science teaching and learning.

– A travelling exhibition on the *History of the teaching of the sciences in schools* is planned. It will tour France from 2002.

International implications

Numerous countries, including both some of the richest and some of the poorest are also facing the need to revitalize their system for teaching the sciences.

The *Académie* has established a large number of collaborations on this theme, all the more so because the IAP (*InterAcademy Panel for interna-*

tional issues, see *International relations* sheet) has made this one of its priority tasks. Among these collaborations, it is particularly pertinent to mention those established with Brazil, China, Columbia, Egypt, Israel, Morocco, Mexico, the United States, Vietnam..., and, more generally, with the ICSU (*International Council of Scientific Unions*) through the CCBS (*Committee on Capacity Building for Science*).

One sign of this broad opening up is that the book *La main à la pâte* (Flammarion, 1996) has been translated into Arabic, Chinese, Portuguese and Vietnamese (translations in Spanish, Hungarian and Romanian being in preparation).

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