

Early science education and astronomy

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¹*La main à la pâte*

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Abstract. Inquiry-based science education is currently receiving a consensus as a pedagogy to teach science at primary and middle school levels, with the goal to reach all children and youngsters, no matter what their future professional choices will be. By the same token, it also greatly increases the fraction of the school population in which future technicians, engineers and sciences could be recruited for further training. *La main à la pâte* is the name of the action undertaken by the French Académie des Sciences to develop inquiry in France, and then in many collaborating countries. The focus is on science as a whole, and not on particular disciplines such as physics, biology, and so on, since it is the understanding of scientific method and use of evidence which is at the heart of inquiry. Yet, astronomy is offering so many opportunities to demonstrate the scientific method that *La main à la pâte* has developed a number of inquiry activities in this field, which are presented here, such as Measuring the Earth, Calendars and cultures, the use of One Laptop per Child for Moon observations, etc.

Keywords. Inquiry, science education, Eratosthenes, calendars, Main à la pâte

1. Introduction

Interest in active methods for learning science at an elementary level has always been advocated, even as earlier as comments made by Comenius (1592-1670) or Henri Bergson (1859-1941), not to speak of the many great scientists, from Albert Einstein to Leon Lederman, who expressed their sorrow when looking at the way science is often being taught. Facing the profound changes induced by the impact of science and technology on modern societies and cultures, our times have become more sensitive to the issue of science education for all students, beginning at an early age and no matter their future professional choices may be. It is in this context that science academies, governments, research bodies, national or international institutions have produced, during the last decade, a large body of reports, recommendations or efforts to introduce new goals and policies in science education. Although *science* does not here refer to any scientific discipline in particular, astronomy is one of the subjects, if not *the* subject which has most attractivity, content and potential relations with most of the others. No wonder that many astronomers and physicists play an active and often leading rôle in this contemporary movement.

By its very nature, science is universal. On the other hand, children are born and raised in a specific culture, within which their identity expresses itself and their personality develops. In an increasingly globalised world, one of the challenges of science education is to conjugate universality and singularity, in order for the children to perceive the beauty of the former without losing the latter, rooted in the diversity of cultures (Sánchez Sorondo, Malinvaud & Léna 2007; Klein 2009). Figures 1 and 2 illustrate this challenge, as experienced by young girls in Afghanistan and Egypt. It is interesting to analyse how the recent efforts in science education are able to cope with this issue.



Figure 1. Young Afghan girls in a *La main à la pâte* class in Kabul, experimenting by themselves. Given the sad situation in which girls are in some Afghan classes today, their faces have been blurred. ©*La main à la pâte*.

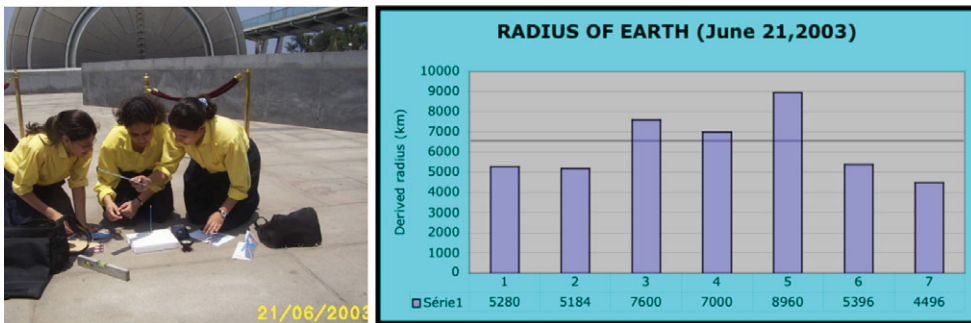


Figure 2. (Left) Young Egyptian girls measuring the length of shadows on the Summer solstice day, in front of the *Bibliotheca Alexandrina* in Alexandria (Egypt), exactly where Eratosthenes measured the Earth's circumference for the first time 25 centuries before. Connected by telephone to similar groups in Assuan, they jointly derived the values given in the graph (right). ©*La main à la pâte*.

In this short review, we recall in § 2 some of the most significant works recently carried on the subject, at various national or international levels, and their main conclusions. In § 3 we focus on a specific, large-scale project of elementary science education, named *La main à la pâte*, initiated in France in 1996 and expanding into many European and non-European countries today, under the leadership of the French *Académie des sciences*. In § 4, some realisations of this program directly related to astronomy and to the International Year of Astronomy 2009 are presented.

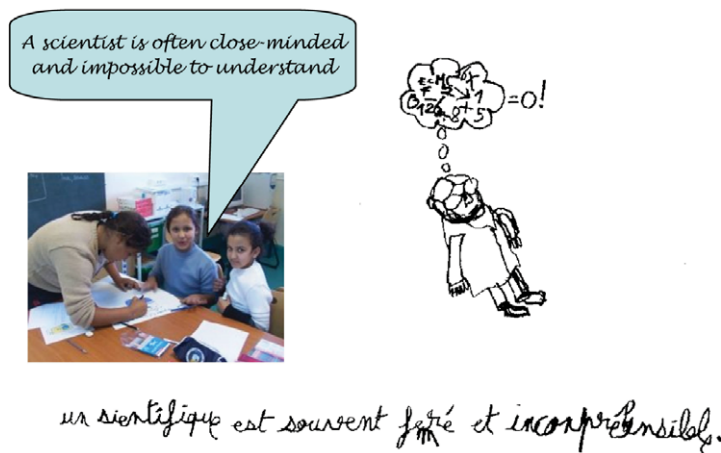


Figure 3. Children (grade 4 or 5) from French primary schools are requested to draw and write their vision of a scientist. Thousand of drawings are analysed, and correlated with the existence, or not, of science classes of *La main à la pâte* type (Lafosse-Marin 2007).

2. Science, children and students

Observing the reactions of children and youngsters to the word *science* is puzzling: while a number of studies and polls point out the genuine interest they have for scientific achievements in general, as they may know them through the media, their spontaneous vision of a *scientist* (Fig. 3) or their own interest for science and/or technology in classrooms (Fig. 4) is much more negative. In the latter case, it is remarkable to observe the clear anti-correlation between the level of economic development of a country and the perception of science among its children, with an increasing gap between girls and boys when GNP increases. The thorough studies of the ROSE group from Oslo (*Relevance Of Science Education*) are quite instructive on this point and similar to other ones †.

These results are in complete opposition with the observations made on children *once* they have participated to a program of science education, inspired by the principles of Inquiry learning (summarised in Harlen & Allende 2006, 2009; National Research Council 1996)‡. Then, the natural curiosity of children can develop and blossom, leading to a questioning attitude and offering to properly trained teachers any number of opportunities to communicate expertise and knowledge, to build competencies and increase involvement of children and parents in school activities (Fig. 5). We like to designate the age between 5 and 12 *the golden age of curiosity*, even if the exact cognitive development and function of curiosity has not yet been well elucidated (Kreitler, Zigler and Kreitler 1975; Litman 2008).

INQUIRY

Inquiry [...] involves: making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. National Research Council (1996)

It thus appears an apparent contradiction between the eagerness of children for discovery and understanding on the one hand, and the poor vision of science by youngsters on

† <http://www.ils.uio.no/english/rose>

‡ See also <http://www.interacademies.net/CMS/Programmes/3123.aspx>

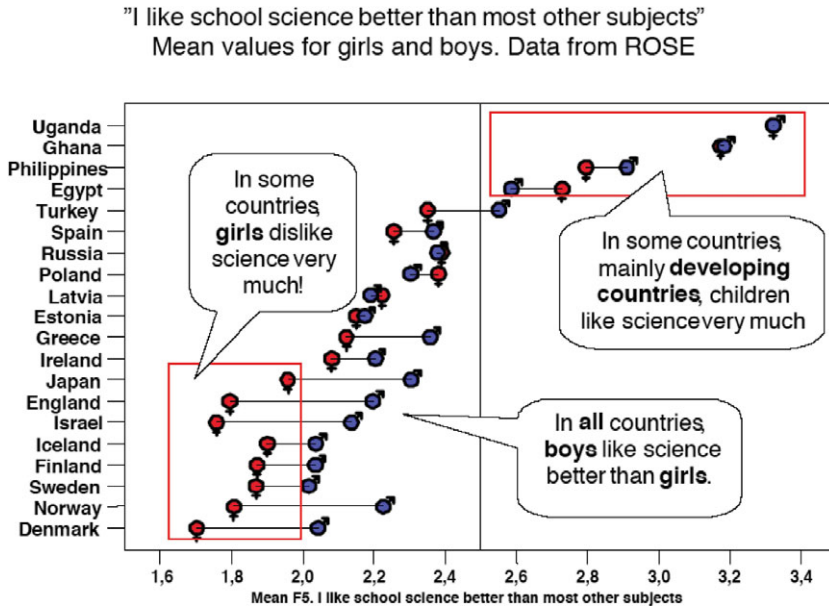


Figure 4. An extract from the ROSE studies. The sentence on top has been submitted to youngsters, age 15, in various countries, ordered by GNP/person in ordinate, and their average answers are presented. Abcissa scale : 1.6 = total disagreement, 3.4 = total agreement.

the other. This contradiction is especially perceived in developed countries, where indeed the exposure of youngsters to science is more developed (school, media, museum, families, etc.) and the request for scientific and technical skills is higher. In the last decade, the pace of scientific development in the world, the many cultural, political, ethical, ecological issues related to the impact of technologies, the competition for leadership in research and innovation have led numerous bodies to examine in great detail two fundamental questions, at a degree of investigation which never had such a depth and scope in the past (Léna 2008). A recent (2008) OECD report, *Encouraging Students Interest in Science and Technology Studies* (OECD 2008), gives a deep analysis of the current situation and numerous references to other reports. Among these, two deserve special quotation for their impacts. Michel Rocard, former Prime minister of France, gathered a study group and reported to the European Commission in 2007 on *Science education now : a renewed pedagogy for the future of Europe* (Rocard 2007), while two British researchers addressed the same issue with their 2008 report *Science Education in Europe : Critical Reflections* (Osborne & Dillon 2008). These reports put a special accent on the role of education in the school. While a decade or two earlier, the accent was put on *informal* education, leading to the development of scientific museums, centers, etc., the new accent is now placed on what happens in schools, since research establishes that the image and approach of science is mainly structured by what is experienced during the school years. On the longer term indeed, both ways should complement each other and concur to the final goal.

These analysis enumerate the variety of arguments which underline the necessary development of science education and scientific literacy for all. To be brief, these arguments are : *a/* modern economies requires new skills, lifelong learning, understanding of basic principles of science and technology as to provide a broad basis for development ; *b/* citizens must be prepared to understand the contemporary issues on energy, health, climate,



Figure 5. The golden age of curiosity : science begins by happily learning to observe: here shadows versus the time of the day. ©*La main à la pâte*.

population, etc. where decisions have a profound impact on everyday's life, as well as on broad issues of global concern and possibly even peace or war ; *c/* ability to use properly reason, developing a critical mind, is a necessary protection against fundamentalisms, while the nature of science - which never produces absolute truth - has to be understood, including in its own limitations ; *d/* science, being one of the most remarkable achievements of human culture, is to be shared with all, especially when extreme specializations of scientific disciplines and complexity of their results seem to hopelessly increase the gap between science and the average person. Admiration, interest, motivation for knowledge can be driven by the beauty of science.

In policy statements, a mix of these arguments is often found, each one giving a different flavor to the implementation of a science education policy. Astronomy education can easily refer to all of them, especially the two latter ones.

The convergence of these reports is impressive, based on their analysis of successful experimental programs in a number of countries : they all underline a similar set of requirements for the quality of science education. *a/* Education at school should begin very early (age 5 or so), accompanying and developing the curiosity of children; *b/ inquiry* principles should be followed in the classroom; *c/* to achieve this, proper teacher training is the key requirement.

3. *La main à la pâte*, a French and international project

In 1996, the French Nobel laureate Georges Charpak and the Académie des sciences in France launched a program to totally renovate science education in French primary schools. They had analysed the status of natural sciences in these schools, and discovered that, contrary to mathematics (i.e. mostly arithmetics and calculus), natural science had practically disappeared in pre-school (*école maternelle*) and grades 1 to 5 beyond. The program, named *La main à la pâte*, had a slow and careful experimental start, then progressively expanded to the whole of France, where *inquiry* teaching became recommended to teachers by official instructions in 2002, 2005, 2008. The story of *La main à la pâte* is described by Charpak, Léna & Quéré (2005), and Sarmant, Saltiel and Léna (2009) and its many activities described and available on its website †.

To briefly describe a wealth of activities, let mention the existence, in France, of 15 selected pilot centers (approx. 3000 classes) where *inquiry* principles are carefully implemented and of 40 experimental middle schools since 2006 (grades 6 and 7). A broad impact on primary school teachers is obtained over France through the website (distance training) and its numerous teaching resources, while a special set-up, called ASTEP (*Accompagnement de science et de technologie à l'école primaire*‡) is organising the contribution of the scientific community to improve the understanding and inquiry pedagogy of science by teachers.

The French program has found worldwide a number of counterparts and partnerships in the education efforts carried by the InterAcademy Panel (IAP) since a decade. IAP is the worldwide association of science Academies, and has developed a special interest of science education at elementary levels (primary schools, then recently middle schools, Harlen & Allende (2006, 2009)). The French program has developed European large scale actions funded by the European Commission in the wake of the Rocard Report (*op.cit.*), such as the *Pollen* (2006-2008) and the *Fibonacci* (2010-2012) projects, the latter associating 21 European countries. It also has collaborated to the implementation of inquiry pedagogy in Latin America as well as in China, especially through training sessions and tools for the classroom.

4. *La main à la pâte* and astronomy

4.1. *In primary schools*

There are numerous subjects in natural sciences which can be considered to be at the level of cognitive understanding by children of ages 5 to 12. They are therefore included in many science curricula, and are indeed part of the *La main à la pâte* goals and contents. But astronomy clearly deserves a special place for the extraordinary interest it raises among children, even at pre-school ages. In addition, astronomy is connected to many topics in natural sciences, and such connections are of great pedagogical value. It offers a golden opportunity to familiarise pupils with scientific observation, questioning and experimentation, and for this reason deserves an important place in *La main à la pâte* strategy. We give here some illustrations of class sequences, teacher's resources and training, which have proven to be highly successful, among children as well as teachers.

In practical terms, how to teach astronomy with a *inquiry* pedagogy? Let us consider one example: the Moon phases. Initially, students can observe the shape of the Moon in the school yard and make drawings during several weeks. The mere fact that one can see the Moon during the day is by itself a surprise for many children. After clarifying the

† <http://www.lamap.fr>

‡ <http://www.astep.fr>



Figure 6. The development of inquiry pedagogy in China, under the leadership of Prof. Wei Yu and the center *Learning by doing* in Nanjing (see <http://www.handsbrain.org>). Circles : the early pilot centers (beginning 2003). Stars : the further expansion (2008).

vocabulary (full Moon, new Moon, quarter, crescent, gibbous Moon ...), the class will try to explain this succession of phases. The assumptions of children are often surprising. Thus, it is not uncommon that the Moon is qualified as an “alive” entity (“*the Moon grows, dies, and is born again*” or “*the Moon breaks into pieces and then rebuilds itself*”). But for most students, the phases of the Moon are caused by the shadow of the Earth, so there is a confusion between phase and eclipse. With balls and flashlights, pupils will experiment and find it impossible to create a gibbous Moon with the Earth’s shadow. Step by step, they realise that the phenomenon of lunation is due to the relative position of the Sun, the Moon, and the observer. Rôle-plays can then help students to feel with their bodies the positions and movements.

The *La main à la pâte* website proposes dozens of teaching sequences within astronomy, allowing primary schools to study the seasons, sundials, Moon phases, eclipses †. These resources, created by teachers and tested in classrooms over the years, are validated for scientific content and enriched by scientists and teacher trainers.

La main à la pâte launched also more ambitious projects, like the one called “*Following the footsteps of Eratosthenes*”. During a set of sequences involving astronomy, history, geography and mathematics, pupils measure the circumference of the Earth (Fig. 2). This project is especially innovative as it can create a true collaborative work between schools from different countries. The achievement is indeed possible only by gathering several measurements taken at different latitudes. This requires classes to communicate and exchange their individual pieces of work on a website, which we made available in 7 languages (Farges et al. 2002) ‡. Since 2001, hundreds of primary school classes from France, Egypt, Europe, U.S., etc. have collaborated in measuring the circumference of the Earth.

Another project, called “*The climate, my planet... and me!*” was launched in 2008 and deals with climate change (Wilgenbus, Bois-Masson & Chomat 2008) ¶. It includes

† <http://www.lamap.fr>

‡ see also www.lamap.fr/eratos

¶ see also <http://www.leclimatmaplaneteetmoi.fr>

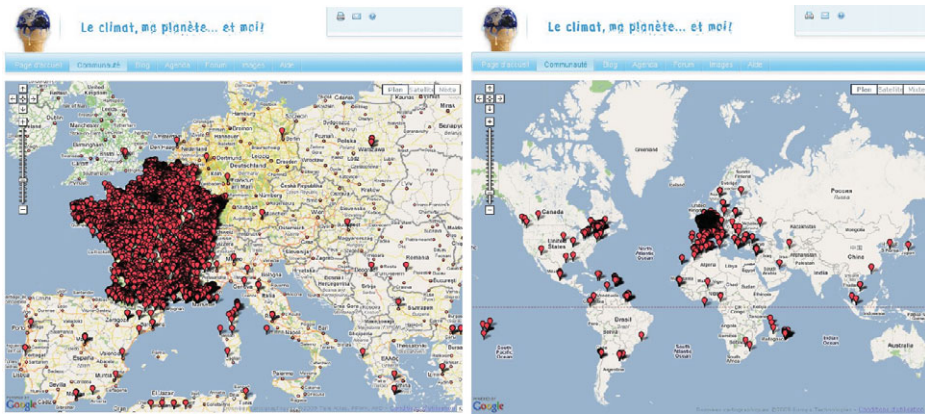


Figure 7. Geographical distribution of the 10,000 classes included in the project *The climate, my planet... and me !*

several sessions of astronomy based on the multidisciplinary approach described above. This recent project distinguishes itself by the large number of classes involved: 10,000 classes within 18 months, all over the world (Fig. 7). This impressive success can be explained by the fact that all resources (teacher's guide, multimedia animations for pupils and assistance) are freely available to teachers and schools. In addition, there is a specific support offered to teachers by *La main à la pâte*, and this additional help is often necessary to overcome the fear of teachers, when they consider to get involved in an inquiry pedagogy. In less than 2 years and in France alone, this single project led to dozens of conferences and training sessions, reaching over 3,000 teachers, trainers, and primary school inspectors.

Following the same principles, *La main à la pâte* has set up a new pedagogical project for the International Year of Astronomy 2009, under the name "*Calendars: mirrors of the sky and cultures*" (Wilgenbus et al. 2009). Through the universal theme of time keeping and calendars, this project enables classes to study the measurement of time, its history and impact on past and present societies, while discovering numerous methods of astronomical science (Fig. 8). Pupils study the path of the Sun in the sky, the cycles of day and night, the seasons and phases of the Moon, all phenomena which punctuate and shape our daily lives. The study of Gregorian, Muslim, Hebrew and Chinese calendars, as well as those of the ancient Mayans, Gauls, Romans, is used to firmly link astronomy to the heart of history and cultures. Compliant with the official curriculum content, the project highlights an investigative scientific approach connected to history, geography, languages, information technologies, mathematics and education of the citizen. Accessible to both novice and expert teachers, completed in 6 weeks, the project "*Calendars: mirrors of the sky and cultures*" does not require any a priori scientific knowledge by the teacher and uses simple materials. The teacher's guide is a complete teaching module, offering a turnkey solution made up of 11 core sessions and 9 optional sessions. The website <http://www.calendriers-miroirs-des-cultures.fr>, available in French and English and accessible free of charge to anyone, provides support for classes during the entire project. It offers multimedia animations on astronomical phenomena, scientific and pedagogical resources for teachers, as well as numerous tools (forum, blog, interactive maps) designed to promote exchanges between classes and contacts with experts.

The stated objective of this project is to bring astronomy into the classrooms where this science is usually absent. The cultural and historical dimensions appear to be seductive

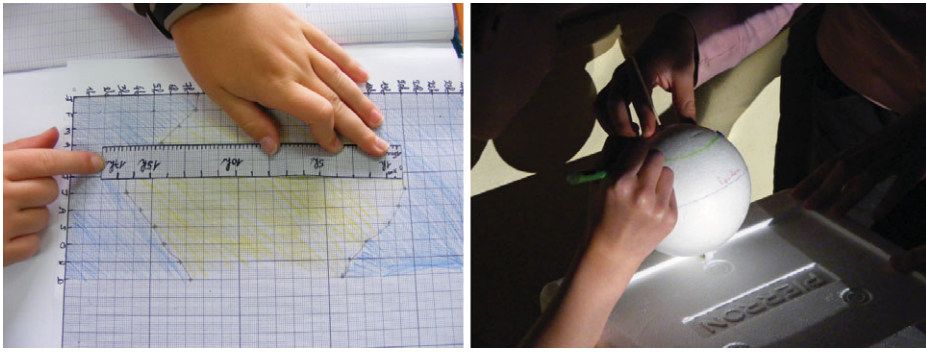


Figure 8. *Left:* Discovering the change in day length during the year. *Right:* The next session is devoted to searching for the explanation of this phenomenon.



Figure 9. The homepage of the project *Calendars: mirrors of the sky and cultures* (<http://www.leclimatplaneteetmoi.fr>).

for primary school teachers, since over 3,000 classrooms have registered for the project within a few months.

4.2. Science and health education of children

In France and many other countries, primary school teachers as well as education authorities are concerned with health education, often much more than with science education. We believe that the former can greatly benefit from being connected to the latter, in the sense that a child who understands the rationals of health prescriptions (e.g. *wash your hands*) will respect them better and more than in the opposite case. Can such a health-science education have an astronomical content? The project called “*Living with the Sun*” was launched in 2005 in partnership with the association *Sécurité Solaire*. Designed to be used in primary schools, it aims at preventing risks of overexposure to the Sun† (Wilgenbus, Cesarini & Bense 2004).

† <http://www.soleil.info/ecole>

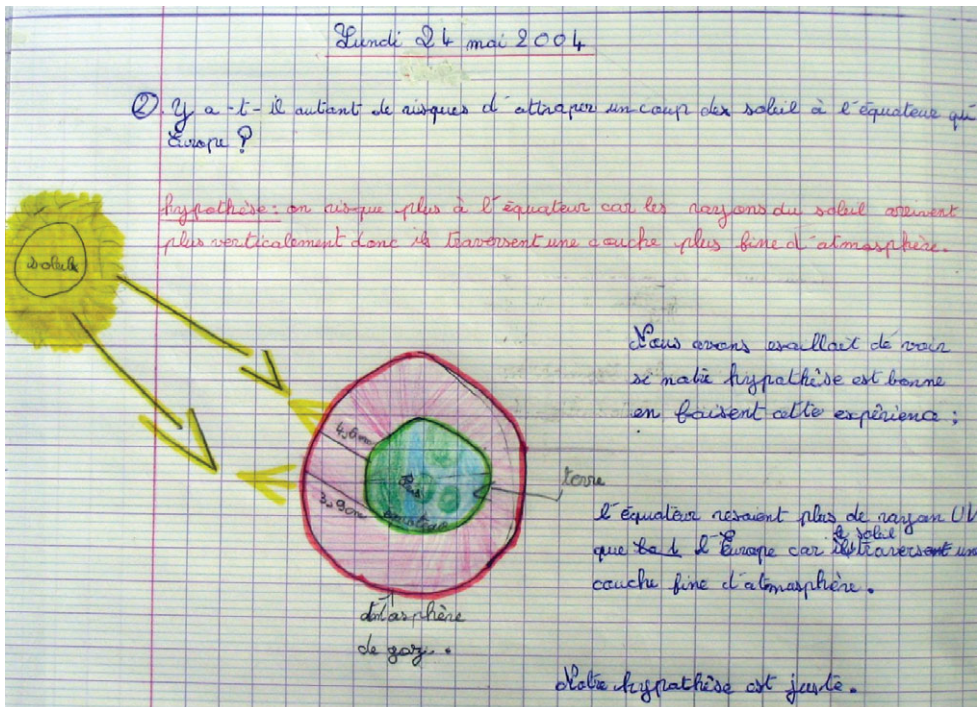


Figure 10. A 10 years old student shows, with his own words and drawing, that sunlight passes through a thicker atmosphere in France than near the equator, which explains that exposure to UV is lower in France, since there UV rays are more filtered by the atmosphere (Wilgenbus, Cesarini & Bense 2004).

Indeed, in developed countries at least, the recent boom in the travel industry and the development of outdoor activities have strongly increased exposures of unprepared children to sunlight. As overexposures during childhood are responsible of melanoma in adulthood, the World Health Organisation recommends the development of prevention programs targeting young children. ‘Solar education’ is a bit uncommon in the field of health education. Unlike other health topics such as tobacco or alcohol, the Sun has also beneficial effects: discussing and understanding these effects, without condemning the Sun, helps the study of hazards. Moreover, the Sun is an object of fascination, dream, and imagination, and offers opportunities for science education.

During the project “*Living with the Sun*”, the children study the decomposition of white light in colours and discover the existence of the ultraviolet rays, using a reactive paper that gradually changes colour when exposed to UV rays. Thanks to this simple and cheap material, pupils can investigate the variations of UV rays reaching them over time, season, latitude, altitude or weather (Fig. 10). They model the atmosphere and the ozone layer as a filter whose thickness controls the intensity of UV radiation passing through it (optical thickness of the atmosphere is hinted at, but indeed not formalised).

Understanding why some situations are more risky than others, students can then find out and test strategies to protect their skin and eyes from sunlight. The project “*Living with the Sun*” has been a growing success with 300 classes enrolled in 2005 and 10,000 in 2009. Since 2008, the project is officially labelled by French Ministries (Health and Education).

4.3. In middle school

The French Académie des sciences is extending its education activities, *La main à la pâte* oriented, to middle school (grades 6 and 7) since 2006, promoting an integrated teaching of science and technology. This is a profound change with the traditional French disciplinary teaching (physics-chemistry, life and Earth sciences, technology) beginning at the first year of middle school. Without entering here into the rationale of this experimental program, presented in detail elsewhere†, let us simply mention that the proposed curriculum is focusing on *Matter and materials* in grade 6 and on *Energy and energies* on grade 7. The experimental sequences deal with numerous aspects of astronomy, such as *How does one know the composition of celestial bodies without visiting them ?*, and *How can energy from the Sun reach the Earth ?* This integrated science teaching is based on the quality of teachers, who are specialized in the above-quoted disciplines but who make the effort to integrate their own subject, in which they excel, into a broader and more unified scientific vision. The project is currently (mid-2009) under assessment for a possible extension over France, but it has already received an extremely favorable evaluation from the pedagogical authorities of the Ministry of education.

4.4. One Laptop per Child

It is worth mentioning here a potential development, on which we are working in a collaboration with the group *One Laptop Per Child*‡. This non-profit enterprise provides children in various countries, at nominal cost, with a special kind of laptop (called XO), designed to be used by children in adverse conditions of energy supply, weather, etc, and allowing cooperative work. Uruguay is one of the first country to have moved in this direction by ordering and delivering to *all* children aged 6 to 10 this laptop (Fig. 11). Over 800,000 such computers have been already distributed in 31 countries. They could represent a very interesting education tool, if teachers were provided with suitable interfaces and instructions. We are working on a hand-held small telescope, which could use the laptop camera to image the Moon and provide teachers and children with images taken by themselves. These images would allow all kinds of measurements, hypothesis and archiving. We therefore are also preparing teaching sequences for the classroom, using this instrument and the special possibilities of cooperative work offered by the XO laptop. We hope to test on a large scale, with teachers, this equipment in Uruguay in 2010. It is worth mentioning that the XO laptop could accept USB connections with all kinds of sensors, including better telescopes or other measuring instruments.

5. Conclusion

We hope to have shown here how important the role of astronomical concepts, experiments and observations can be in a more global science education program for students in primary and middle school. Since over a decade and in many countries, the constant experience of *La main à la pâte* has been as follows. Teachers are willing, and even enthusiastic, to enter inquiry based sequences of teaching, often quite difficult for them at the beginning, as long as they are accompanied, locally and/or at distance, with proper aids and resources. Therefore, as many others, we have dedicated energy and funding to create such accompanying tools, always on an international basis, even if the starting point of our activities is in French schools.

† <http://science-techno-college.net>
‡ <http://laptop.org/en>



Figure 11. Children in Uruguay proudly show their XO laptop (Picture courtesy of Antonio Battro).

Within the broad diversity of the tools we offer, a number of them is related to astronomy, and meets great success. It is interesting to note that their implementation brings the teachers to understand the principles of modern science, based on experimentation and observation, as introduced by Galileo who we celebrate in this World Year of Astronomy. Although they often deal with apparently simple phenomena, such as day and night, or seasons, we often discover that the amount of misconceptions on these may be considerable. There is no need to exploit complex phenomena to introduce teachers to an authentic scientific attitude. Moreover, quite often scientists themselves discover, while helping these teachers, that they clarify their own views, an unexpected but real bonus.

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