The Fibonacci Project

DISSEMINATING INQUIRY-BASED SCIENCE AND MATHEMATICS EDUCATION IN EUROPE

Starting Package

Scientific background

by the Fibonacci scientific committee

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WITH THE SUPPORT OF

EUROPEAN COMMISSION

SEVENTH FRAMEWORK PROGRAMME

Preamble

In the Fibonacci project, the overall scientific coordination is split between two partners, members by right of the Scientific committee and chairmen of the same :

- *La main à la pâte* - Ecole normale supérieure : David Jasmin.
- University of Bayreuth : Peter Baptist.

The scientific coordination also receives advice and orientation from a Scientific committee composed of the following European experts (January 2010) :

- Michèle Artigue (FR)
- Justin Dillon (UK)
- Wynne Harlen (UK)
- Pierre Léna (FR)

See short biographies at the end of this booklet.

General objectives of the scientific committee

- ensure the quality of the pedagogical approach recommended in the project.
- ensure homogeneity between different approaches according to specific contexts.
- ensure convergence between mathematics and natural sciences inquiry.
- provide scientific support to the European coordination, Reference centres and Twin centres through written statements and documents.
- provide scientific support for preparation and realisation of the international conferences.
- develop strategies for dissemination and exploitation of project results on a European level and in the long term.
- advertise Fibonacci activities in the research and scientific fields and provide connexion with other networks.
- review documents and reports.

Contents of this booklet :

1 - Rationale 3
2 - Inquiry-based education in science 5
3 - Inquiry-based education in mathematics 8
4 - Design, Technology and Engineering 9
5 - ICT and inquiry based learning in mathematics and sciences 10
6 - Cross disciplinary approaches 12
7 - Boundary between primary and secondary 13
General conclusion 15
Some references to go further 15

Fibonacci Starting Package : Scientific background.

1-Rationale

Why inquiry?

The reason for emphasising inquiry-based education[1] in the Fibonacci project is that, carried out effectively, it facilitates understanding. Learning with understanding is different from remembering facts such as the names of the planets in the solar system or which particular objects float or sink or multiplication tables in mathematics. We are not saying that facts are not important but rather that they are insufficient for developing understanding alone. Information needs to be organised to be useful with isolated pieces brought together to form principles and concepts which can be used in making sense of new events and phenomena. The important thing is for students to understand why things do or don't float, not just what does or doesn't float. But principles and concepts cannot be directly transmitted to learners, unless as meaningless words which have to be learned by rote; they have to be (re)created and appropriated by the learner's own thinking. For this reason we need to consider how learning with understanding - be it in science, mathematics or any subject - may take place.

Learning through inquiry

There is plenty of research evidence that shows that when students encounter something new to them, they attempt to make sense of it using ideas formed from earlier experiences. These ideas become modified as students use them in trying to explain new experiences. In this process an idea can be used to make a prediction and then tested by seeing if the evidence from the new experience agrees with what was predicted. If it does, then the idea becomes just a little 'bigger' because it then explains a wider range of phenomena. Even if it doesn't 'work' – and an alternative idea has to be tried – the experience has helped to refine the idea. Through these processes there is a change, not only in the range of events and phenomena that can be understood, but there is also a qualitative change in the nature and the scope of the ideas. Scientific ideas that are widely applicable are necessarily context-independent, as, for example, the idea of what makes things float that can be used for all objects and all fluids. To move from an idea of why a particular object floats in water to the big idea of floating is a large step which involves making connections between observations in very different situations. Similarly, ideas of how to solve particular types of mathematical problems, e.g. involving fractions or negative numbers, are built up through bringing together experiences of tackling a range of related problems. Such ideas are only understood if they make sense to the learner because they are products of their own thinking.

This view of learning argues for students to have experiences which enable them to work out for themselves how to make sense of different aspects of the world. First-hand experiences are important, particularly for younger children, but all learners need to develop the skills used in testing ideas – questioning, predicting, observing, interpreting, communicating and reflecting.

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[1] In this document, we use the IBSME acronym to refer to Inquiry-Based Science and Mathematics Education. IBSE will then only refer to natural sciences, and IBME to mathematics education.

If these skills are not used rigorously, then the ideas to which they lead may be inadequate. Learners also need access to ideas other than their own in order to find the best way to explain new experiences. Alternative ideas may come from various sources such as books, the internet, a teacher or other adults, but most importantly, through discussion and debate with other students. Talking with others about how they understand particular phenomena and presenting arguments to support different views brings a realisation of alternative ideas to their own and a willingness to try a range of ideas to see which best fits the evidence.

Although the ideas that students have at any one time will probably have to change as they encounter new events, it is the ideas that they have worked out for themselves that make sense to them at that time. The opportunity to reflect on how they arrived at these ideas and why and how they have changed begins the process of learning how to learn.

What students need to learn

Inquiry-based learning is important not only because it is consistent with how students learn most effectively, but because of the kind of learning to which it leads. It is widely acknowledged that the world in which we now live is rapidly changing and the pace of change will only increase throughout the life-time of today's school students. To prepare for change, students need to know how to deal with new experiences and problems, and to appreciate the 'big', widely applicable ideas that enable new phenomena to be understood. Further, with easy access to information, there is no need to accumulate large amounts of factual knowledge, but it is important to know how to access, select and interpret information. Inquiry-based learning has the potential to enable students to develop the important skills through which they can develop widely applicable ideas and the capability of continuing to learn throughout life.

Developing inquiry-based teaching

Inquiry-based education requires teaching skills and classroom relationship that vary considerably from those associated with traditional teaching. What is noted in the IAP report of the Working Group on Science Education (2009) is relevant to all learning:

> "The aims of modern education and of inquiry-based education in particular require students to become more independent learners. This means teachers developing new relationships with students and having the confidence to allow students to develop their own ideas."

Most teachers will require a considerable time to adopt the roles, beliefs and practices that are required in inquiry-based teaching. Moreover the views of learning of the school management and of parents may need to change to support a different conception of learning. As well as time, such changes depend on teachers' understanding the nature of inquiry, which is best achieved through experiencing it for themselves as part of professional development. Teachers need to learn actively just as do students. The need to allow for this to happen has implications for the role of evaluation in the Fibonacci project.

Evaluation and assessment of students in the Fibonacci project

There is an understandable desire to want answers to questions about the impact of inquiry-based education on students' achievement and in particular whether spreading this approach to schools in the Fibonacci project will lead to the improvements in learning that are claimed. But before any attempts are made to assess any impact on students' learning it is first important to ensure that they are indeed experiencing inquiry-based education. As just noted, considerable changes in teaching are generally needed and, until these have become embedded, any evaluation based on student outcomes is likely to give misleading data about the impact of inquiry. Instead, evaluation is best directed at the classroom processes and used to improve implementation of learning through inquiry. In the same way the assessment of students' ideas and skills is best used to feedback into teaching to help learning. Indeed this formative use of assessment is an essential part of inquiry-based teaching. The information about students' learning is gathered by teachers observing, questioning and studying the products of students' work as part of regular interactions, rather than from formal tests which often tend to assess memorised facts.

2- Inquiry-based education in science

Introduction

> "Inquiry-based science education is an approach to teaching and learning science that comes from an understanding of how students learn, the nature of science inquiry, and a focus on basic content to be learned"[2]

Inquiry-based science education (IBSE) is increasingly seen as important in developing young people's scientific literacy in terms of their understanding of scientific concepts and their appreciation of how science works. While there is growing evidence that traditional approaches to science education have failed to ignite the enthusiasm of many students, particularly in more economically-developed countries, IBSE appears to offer outstanding opportunities for effective and enjoyable teaching and learning. IBSE's three pillars – learning theories, the nature of science inquiry, and science content – provide strong foundations for a pedagogy for science education for the 21st Century.

IBSE and students' learning

The IBSE movement can be traced back many years although it has attracted strong interest worldwide since the mid-1990s. We know now that learners often have strongly-held erroneous views about science phenomena which they are reluctant to let go. IBSE, taught well, provides opportunities for students to see how well their ideas work in authentic situations rather than in abstract discussions. Students build knowledge through testing ideas, discussing their understanding with teachers and their peers, and through interacting with scientific phenomena. Practical activity, involving a direct contact with reality, is an essential ingredient of IBSE, as the hands-on approach can often lead to a 'minds-on' engagement which helps to develop better comprehension of scientific concepts.

IBSE and the nature of scientific inquiry

IBSE also allows students to appreciate how science works. Scientists use a wide range of methods and approaches to building new knowledge but underpinning them all is a desire for reliable and valid data about phenomena in the natural world that can be tested and reproduced by peers. IBSE encourages students to develop their scientific skills, independently or in collaboration, in such a way that they can appreciate the processes that scientists use in their everyday lives. Students come to appreciate that scientific knowledge is tentative and that doing science doesn't simply involve a set of linear steps towards an end goal. Science inquiry can be fuelled by inquisitiveness as well as necessity and can bring out the best of a person's creativity and inspiration while rewarding patient endeavour.

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[2] Worth, K., Duque, M. and Saltiel, E. (2009), *Designing and implementing inquiry –based science units for primary education*, the Pollen project (www.pollen-europa.net).

IBSE and the teaching of science content

The teachers' role in IBSE includes the selection and matching of the student's task with the nature of the scientific knowledge to be learned.

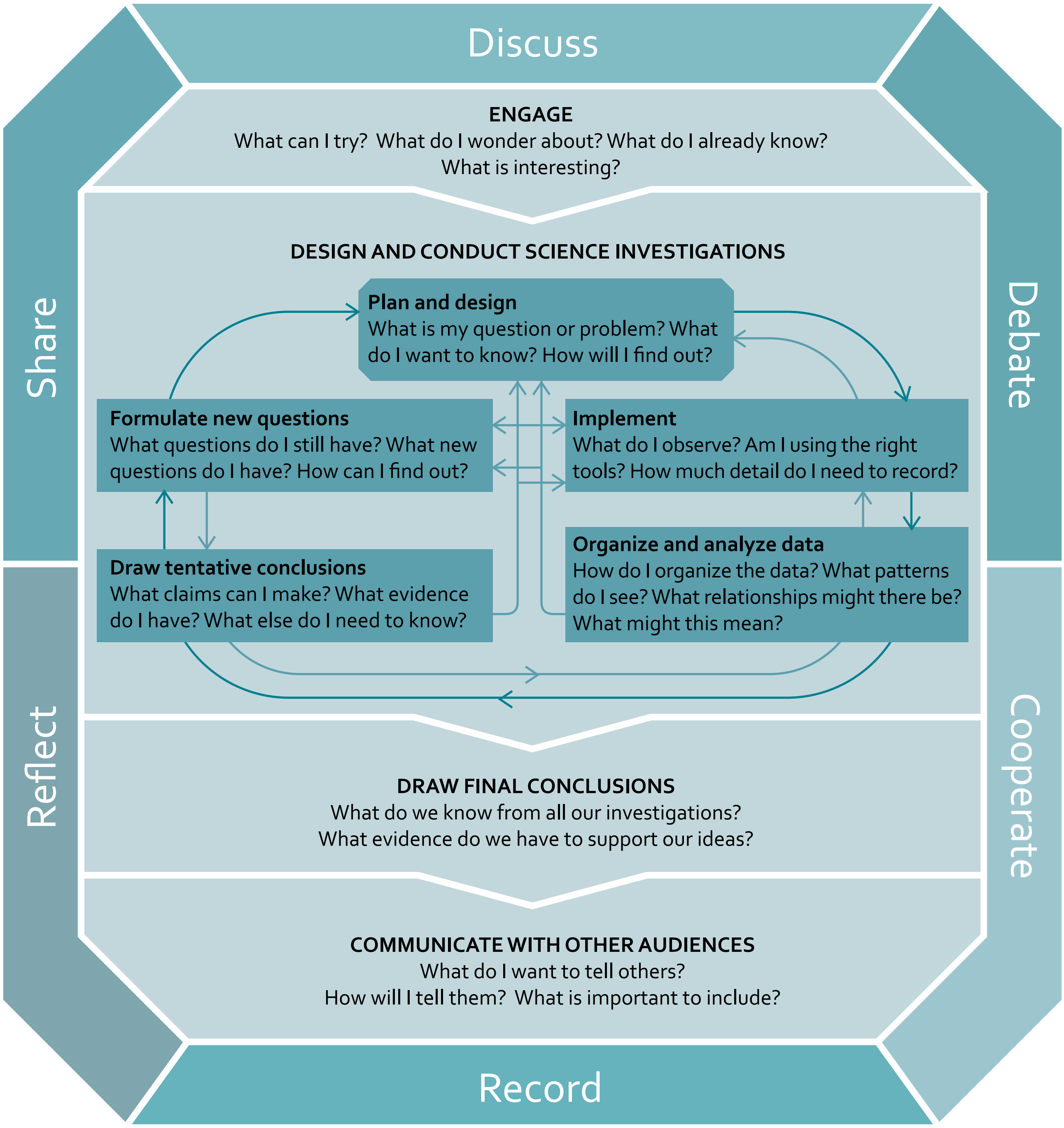
> "IBSE will look quite different in different classrooms. There is a great deal of room for individual teachers to adapt and innovate, working from their own knowledge, skills, and interests as well as from those of their students. But there are some important principles that are followed in all inquiry-based programmes."[3]

The teacher's choice of topic and activity will depend on a range of factors including the local or national curriculum that they are following, the resources available to them, and the interests and abilities of their students. Many teachers have not experienced this approach to science education themselves to any great depth and will need opportunities to develop their pedagogy through professional development.

A framework for science inquiry

During the Pollen European project (2006-2009, www.pollen-europa.net), an attempt was made to conceptualise a framework for scientific inquiry. The diagram below is a representation of that framework. The diagram shows six key processes that underpin the inquiry process: co-operating, discussion, debate, sharing, reflecting and recording. A 4-stage model of IBSE begins with some engagement with a topic such as floating and sinking. The teacher can elicit the students' ideas and then move onto encouraging reflection on what questions can be investigated. The planning and doing stage is the core of IBSE and involves various processes which are carried out in an iterative rather than a linear manner. When the investigation has been carried out and the data collected and analysed, the students can move on to draw some conclusions, to see if they can answer their original questions. Once the conclusions have been made and agreed, the students can think about ways to communicate their findings to others in the same class or in classes in different schools in the same country or in other countries. The framework is meant to be flexible and open to adaptation. It is not meant to represent the only way to do IBSE.

3 Worth, K., Duque, M. and Saltiel, E. (2009), Designing and implementing inquiry –based science units for primary education, the Pollen project (www.pollen-europa.net).



A unit or part of a unit may include several investigations before reaching the Draw Final Conclusions stage.

One session or lesson in a unit rarely, if ever, includes all of the parts of the Design and Construct Science Investigations stage of this diagram. One session or lesson never includes all stages of the diagram.

3- Inquiry-based education in mathematics

In the Fibonacci project, we consider that inquiry-based education is an appropriate concept not only for the learning and teaching of the natural sciences but also for the learning and teaching of mathematics. Here we point out the similarities and some differences between the characteristics of inquiry-based education in mathematics and science.

As is the case in natural science, inquiry-based mathematics education (IBME) refers to an education which does not present mathematics to pupils and students as a ready-built structure to appropriate. Rather it offers them the opportunity to experience:

- how mathematical knowledge is developed through personal and collective attempts at answering questions emerging in a diversity of fields, from observation of nature as well as the mathematics field itself,
- how mathematical structures can emerge from the organization of the resulting constructions, and then be exploited for answering new and challenging problems.

Inquiry-based practices in mathematics involve diverse forms of activity: articulating or elaborating questions in order to make them accessible to some mathematical work; modeling and mathematizing; exploring and experimenting; conjecturing; testing, explaining, reasoning, arguing and proving; defining and structuring; connecting, representing and communicating. IBME must engage students in these forms of activity and foster the development of associated competences.

It is expected that the inquiry-based approach will improve students' mathematical understanding which will result in their mathematical knowledge becoming more robust and functional in a diversity of contexts beyond that of the usual school tasks. It will help students develop mathematical and scientific curiosity and creativity as well as their potential for critical reflection, reasoning and analysis, and their autonomy as learners. It will also help them develop a more accurate vision of mathematics as a human enterprise, consider mathematics as a fundamental component of our cultural heritage, and appreciate the crucial role it plays in the development of our societies.

If it is to be more than a slogan, IBME requires the development of appropriate educational strategies. These strategies must acknowledge the experimental dimension of mathematics and the new opportunities that digital technologies offer for supporting it. The history of mathematics shows that such an experimental dimension is not new, but in the last decades technological evolution has dramatically changed its means, economy, and also made it more visible and shared by the mathematical community. Compared with experimental practices in natural science, one must however be aware that the terrain of experience for mathematics learning is not limited to what is usually called the "real world". As they become familiar, mathematical objects also become the terrain for mathematics experimentation. Numbers, for instance, have been used for centuries and are still an incredible context for mathematics experiments, and the same can be said of geometrical forms. Digital technologies also offer new and powerful tools for supporting investigation and experimentation in these mathematical domains. IBME must, therefore, not just rely on situations and questions arising from real world phenomena, even if the consideration of these is of course very important, but use the diversity of contexts which can nurture investigative practices in mathematics.

Mathematics has a cumulative dimension to a greater extent than the natural sciences. Mathematical tools developed for solving particular problems need to build on each other to become methods and techniques which can be productively used for solving classes of problems, eventually leading to new mathematical ideas and even theories, and new fields of applications. Moreover, connections between domains play a fundamental role in the development of mathematics. Thus it is important in implementing IBME that students do not deal only with isolated problems, however challenging they may be, since this may not enable them to develop the over-arching (or more generally applicable) mathematical concepts.

Selecting appropriate questions and tasks for promoting IBME thus requires the consideration of their potential according to a diversity of criteria, and the building of a coherent organization and progression among these, having in mind the characteristics of mathematics as a scientific discipline and the ambition of such education of emphasizing the interaction between mathematics and other scientific disciplines, between mathematics and the real world.

A further crucial point is that, even when they emerge from real world situations, mathematical ideas are not directly accessible to our physical senses, and are thus worked out through a rich diversity of semiotic systems: standard systems of representation such as graphs, tables, figures, symbolic systems, computer representations, etc., but also gestures and discourse in ordinary language. IBME must be sensitive to this semiotic dimension of mathematical learning and to the progressive development of associated competences, without forgetting the evolution in semiotic potential and needs resulting from technological advances.

Modern technological tools have an impact on inquiry-based education through the immediate access given to a huge diversity of information, whatever the topic. This situation means that the "milieux" with which students can interact in investigative practices are potentially much richer than those usually used for developing investigative practices in mathematics. However, the necessity of selection and the critical use of such information create new demands that IBME must take into account.

4- Design, Technology and Engineering

The emergence of technology

Through science, humankind aims at understanding the natural world and developing knowledge about it, but we have always tried to develop tools in order to act and increase our control over a range of processes and materials. For centuries, techniques were empirically developed, leading to impressive savoir-faire of the craftsmen. But the Industrial Revolution brought another era, where techniques used scientific knowledge to progress, while science was more and more dependent on elaborated instruments to advance: thermodynamics and the steam-engine are a good illustration of this new relationship. Much later, a new word was coined, the word 'technology', proposing a formal approach to technical advances, from their principles and conception to their production and evaluation. This domain progressively covered many facets of human activities, from the use of elaborated artefacts by individuals to large-scale production in industry. They required a wealth of specialized education activities, from training technicians to highly multidisciplinary engineers. As the amount of knowledge integrated in a complex technical achievement – an integrated electronic circuit as well as a bridge or a fish farm - continuously increases, technology and science are more and more becoming twins, sometimes to the point that they become hard to distinguish in their daily practice: this is today the case with nanosciences and nanotechnologies, dealing with matter at the atomic scale.

Diverse names for a single concept?

Today, the word technology often appears to have the broadest meaning, being an umbrella to cover a wide range of activities. Other words are also in use: 'design' is used to cover the conceptual phase where a technical object is thought of, created and made visible. 'Design' is used as well by architects, by engineers for an aircraft or a circuit and by the fashion or advertising industries. It has kept a connotation of aesthetics, which technology does not have – especially appealing to some students. 'Engineering' may be used in a broad sense, almost equivalent to technology, but often refers to a specific phase of the elaboration of a technical object, i.e. its fabrication, operation or eventually industrial mass production. But some would regard engineering as the process and technology as the product. Eventually the handling of information, with computers and related electronic tools, acquires the title 'informatics' or 'ICT', as it is pervading so many facets of everyday human activities and productions.

Technology in the curriculum

Dealing with science education in primary and secondary schools, should one include technology or not? If one considers the increasingly intrinsic connection between science and technology and the fertile use of inquiry in both cases, it is tempting to treat them together and to stress at every occasion the connections between them. On the other hand, curricula differ widely in whether and how they consider technology. At the primary school level, some curricula ignore it completely, while in others it is merged explicitly with science. In secondary education, technology may appear as a separate subject, often more developed for early vocational training, or not appear at all. At these levels, technology curricula are often less precise and less defined in their goals than the science ones.

The choice of Fibonacci

Facing this diversity of situations, the Fibonacci project has chosen to focus on science education, whilst accepting that science and technology cannot always be separated, especially in primary education. Indeed, the application of some, even elementary, scientific knowledge to achieve a technical product is of high pedagogical value, as in making a simple instrument to explore a scientific issue, such as constructing a simple liquid thermometer.

5- ICT and inquiry based learning in mathematics and sciences

Information and communication technologies provide today powerful tools for supporting inquiry based education in mathematics and sciences. These tools are quite diverse:

- specific educational interfaces developed for supporting the collection and analysis of experimental data in a diversity of scientific domains;
- microworlds attached to specific scientific or mathematical domains, as are in mathematics the various software tools for algebra and calculus and geometry;
- simulation tools such as Net-Logo which make possible the exploration of the behavior of complex systems, and the identification of regularities often not easily accessible through pure analytic work;
- more general tools such as spreadsheets, statistic software, tools for numeric and symbolic computations, for graphical representations, not necessarily designed for education but converted then into educational tools.

Most of these ICT tools, implemented in handled technology or computers, have been present in the educational area for two decades at least. Their potential for supporting experimental practices and inquiry-based learning in sciences and mathematics has been investigated by educational researchers and attested in experimental settings. However, their influence at large on mathematics and sciences education has remained quite limited. But the situation is getting better as EU projects (e.g. Intergeo and InnoMathEd) and national projects (e.g. in the Netherlands and Germany) show.

In the last decade, Internet technology has substantially moved this educational landscape:

- making many of these technologies accessible online, and leading to new forms of educational objects, such as so-called applets (small interactive software components that can be accessed through an Internet browser);
- giving easy access to a huge amount of information, whatever be the question at stake, and to professional data bases;
- leading to an exponential increase in the number of resources produced both for students and teachers, by individuals, collectives or institutions, and changing the usual patterns of production and dissemination;
- supporting the development of collaborative practices both on the side of students and teachers, and the development of networks.

Dynamic worksheets are an appropriate way to foster inquiry based learning in mathematics and sciences. Following the idea of a traditional worksheet, a dynamic worksheet is a document written in HTML that includes applets to be viewed at the computer screen. This technical basis enables the integration of texts, graphics and dynamic configurations. The learning arrangement combines experiments on the computer screen with traditional paper and pen work because the students have to put down notes and sketches in their study journals.

The potential offered by ICT technology for supporting inquiry based practices in mathematics and sciences education, for moving from local to global influences and successes, is thus substantially transformed, and in Fibonacci we will use ICT technology to improve inquiry based education.

This being said, we would like to stress some important points.

ICT technology offers evident potential for supporting inquiry based learning in mathematics and sciences. This does not mean that ICT tools must be given a predominant role. Experimental work can and must also develop with more classical objects and technologies. Virtual experiments should not replace real experiments. These are especially important for approaching new fields, new domains of experience. For instance, an adequate development of spatial and geometrical knowledge with young students cannot just be achieved by using a Dynamic Geometry Software (DGS), whatever is the quality of this use. It also requires working with objects and models in different spaces, not just in the micro-space of the sheet of paper or the computer screen.

ICT technology offers evident potential but actualizing this potential requires appropriate tasks and guidance of the teacher. As shown by research developed in that area, real creativity must be developed in terms of tasks, and not just adaptation to the ICT environment of tasks which have proved to be effective in more standard environments. This makes the collective elaboration and exchange of resources in Fibonacci especially important. The same can be said regarding teachers' practices. Benefitting from the learning potential of ICT technology requires from the teachers new forms of orchestration and guidance whose requirements have been underestimated until recently.

In summary, ICT technology creates today a new ecology for inquiry based education in mathematics and science education, that the Fibonacci project must take into consideration, without underestimating what a productive use of ICT technology requires in terms of design and teacher expertise.

6- Cross disciplinary approaches

Primary schools usually employ generalist teachers, teaching all subjects, although in some countries some specialization may exist. This has great advantages for science education, since mathematics and natural science lessons can be embedded in a global cognitive development of the child. Quite naturally, the essential and necessary connection between science and language acquisition can develop, with the use of a science or experiment notebook, evolving from free expression of the child to the choice of a progressively more accurate vocabulary, the organisation of thought into sentences of adequate construction, a proper use of tenses (e.g. implying causality), etc. Other logical ways of information coding may also develop, such as graphs, schemas and diagrams, drawings, etc. Expressing scientific observations, reasoning and conclusions with clear formulations in everyday's language is a prerequisite, too often bypassed in secondary school by an excessive use of formulas learned by heart. This connection of science with the acquisition of the written and oral mastery of the mother tongue has proven extremely fruitful in many IBSME pilot projects.

Beyond the direct connection with language, history offers numerous and pedagogically fruitful opportunities to establish links with science. From its very beginning, the development of science has been an extraordinary human adventure, which easily arouses the interest of children and youngsters. Narratives describing people, attempts and errors, failures and success, controversies and proofs can be fascinating, especially when placed in the cultural and technological background of the times. Conversely, it might be fruitful to compare causality in the case of a scientific observation – e.g. the Sun rising in the morning, or a volcano erupting – and in the case of an historical event – e.g. the causes of World War I.

Art is another subject which is often proposed for connecting with sciences and mathematics, a connection which may take many forms : from aesthetics (e.g. in geometry) to the discovery of natural shapes and symmetries, from the choice of materials or pigments to the rules of construction in architectural design. Yet, some care should be exercised to avoid confusion between the objective nature of science and the subjective feelings in art – even if both attitudes may meet at some point.

The list of linked subjects could continue with geography, sport, health education : in each case, IBSME sequences can be constructed while intimately mixing these subjects with mathematics or natural sciences.

In middle school, the presence of specialized teachers renders the links more difficult to implement in practice, although they could be even more fertile than in primary school because of the deeper knowledge teachers have of their own discipline. Obstacles here are not of a different nature from the ones mentioned above between scientific disciplines, but the culture of a language, sport or art teacher may introduce more distance from science, and vice-versa, than cultural differences inside scientific disciplines. To exploit the rich potential of interdisciplinarity in secondary school, more efforts seem to be needed.

7- Boundary between primary and secondary

The boundary between primary and secondary education is somewhat variable among countries. Most of them have pre-school, then a primary school beginning at age of 5 or 6 (grade 1) and lasting 5 or 6 years. In rare cases, primary extends to grade 8 or 9 (Chile). Secondary school may be separated into two levels, junior high school (post-primary school) up to grade 9, followed by the high school (grades 10 to 12) and leading to the end of secondary education. Primary education is compulsory worldwide – although with only a fraction of children finishing it in some countries (in Africa for instance) –, but many countries have extended the schooling obligation to the age of 16, or grade 9. In some countries, all children attend the same kind of secondary school, while in others there is an orientation process at the end of primary, some pupils going then to more vocational schools (such as in Germany).

Relevant differences regarding science and mathematics education

Despite this relative diversity of systems, in relation to science and mathematics education there are generally three factors shared when children move from primary to post-primary school.

First, teaching in primary school is often carried out by a single teacher, often having no particular specialization and able to teach all subjects, including science and mathematics. The training of these teachers is usually focused on pedagogy, child development, language acquisition and health more than on a specific academic discipline. By contrast, teachers in post-primary schools have most often been trained in a particular discipline (e.g. life sciences) or a combination of two closely related ones (e.g. physics and maths, or physics and chemistry), and have a higher academic degree (bachelor and often masters). Thus there is often a significant difference in science and mathematics knowledge, understanding and approach between the two populations of teachers.

Second, pupils in primary school are children, while in secondary school they rapidly become teenagers, entering into an age of considerable changes (puberty, affective and social relations, etc.). In addition to the cognitive and affective changes, the horizon of secondary school is also marked, for a significant fraction of pupils and their parents by the career decisions to be made around age 16.

Third, the pressure of curriculum becomes more intense in secondary school. Although many countries have recently introduced high stakes pupil assessment in primary school, with mixed results, the pressure becomes greater post-primary. Assessment is usually focused on knowledge, facts and problem solving, and rarely includes the competences IBSME is aiming at: creativity, critical thinking, language abilities, experimental skills. Teachers are under the pressure of completing the curriculum and are led to "teach to the test", something which may have a more positive impact if the tests were built to measure valuable attainments and not facts learned by heart.

Consequences for IBSME in secondary education

Most of the pilot projects, carried in the last decade and promoting IBSME pedagogy, have been done in primary schools. The single teacher configuration, with an holistic concern for the child's cognitive and personal development, has in fact been advantageous to the introduction of IBSME. Even the lack of scientific knowledge is not necessarily a disadvantage as the teacher – if properly trained and coached – shares the discovery path of the student. By contrast, secondary school science teachers seem to be less amenable to IBSME: trained in science, their focus is more on the content of the subjects rather than the process of learning. In addition, adolescents often do not see the point of much of what they are intended to learn; they need to find their work interesting and relevant to their lives. Finally, the time required to succeed with IBSME sequences is not easily accommodated in the curriculum and is not compatible with the assessment pressure.

Since research and studies show that IBSE pedagogy can also be recommended for secondary education, its implementation needs precise answers and strategies to overcome these serious obstacles. Some suggestions are made here in this respect:

- There are advantages in engaging teachers who have a good science background. But in many countries, with the traditional pedagogy that teachers are used to, often they would rather conduct an experiment as a demonstration for the whole class, rather than having groups performing and discussing it in parallel. The laboratory work would often be prescribed by a detailed protocol, allowing minimal engagement from the student. Changing from a whole class to a more group-based pedagogy is often difficult, and something which needs professional development and concrete examples.
- The specialization in separate subjects (e.g. physics, Earth sciences, etc.) often comes too early in secondary education. In accord with the science for all objective which today underpins science education, the most important aspect for the students is to understand the basics of science as a process, rather than accumulating a more or less heterogeneous collection of facts and knowledge. The unity of science, possibly including technology, is difficult for students to grasp, when their own teachers are prisoners of disciplines separated by walls, each of them with specific methods and specialized languages. Students with social difficulties or poor cultural environment are the first to suffer from these useless (at this stage) academic subtleties. What would help here is to define some big ideas in science, to be addressed in a completely interdisciplinary manner. This strategy does not necessarily mean that teachers are to be trained as generalists, equipped only with a vague science content. On the other hand, their excellence in a scientific field, properly validated by their training, is a guarantee of their ability to explore and learn related fields, in order to teach interdisciplinary science at the secondary level. In some experimental programmes (France), one observes that teachers progressively accept that they can say "I do not know" faced with a student's hypothesis or questions, and complete this answer by "but I will search and tell you more next time!"
- The more children have seen their curiosity fed and their autonomy aroused in primary school, the more they will accept IBSE in secondary school, the more the teachers will be able to use this lively curiosity and autonomy to organize IBSE sessions and groups with success. It is noticeable that in such classes, both boys and girls react positively to the challenges of an IBSE lesson.

Despite the science qualification of secondary school teachers, and precisely because of these real obstacles to IBSE implementation, it is essential to properly organize this transition between primary and secondary schools. Expert primary school teachers and trainers can contribute to a dialogue with specialized secondary school teachers. Classroom activities, prepared for the end of primary school, can usefully be adapted for early secondary school. Teacher professional development and new IBSE resources, available locally or on-line, are absolutely necessary to change the pedagogy.

As a long-term goal, a continuous progression from early primary to the end of compulsory education, focusing on the big ideas in science and acquisition of competencies, could be the aim of an integrated IBSE curriculum.

General conclusion

The Fibonacci project is exploring the nature and practice of inquiry-based education in a number of different contexts: in primary and secondary schools and in relation to science, mathematics, technology and engineering. In the case of science and mathematics in primary schools, inquiry has been developed through many pilot projects in the past decade. As a result, resources for teachers, training approaches and even assessment tools have been developed and are available for implementation, adaptation, improvement or research. Inquiry is equally important in secondary schools, especially for pupil ages 12 to 16, but its implementation in the significantly different content of secondary schools has to date not been explored with such thoroughness and creativity, either in sciences or mathematics. Fortunately, a number of the Fibonacci partners are among those, across the world, who have the most significant experience, although as yet limited, to deal with these new issues.

This background paper has briefly discussed some of the main issues in IBSME in primary and secondary education: the nature of inquiry-based learning in these contexts, the development of teaching, student assessment, the relationship with technology, design and engineering, the role of ICT, primary to secondary transfer and cross-curricular work. It is hoped that the short description of these issues will clarify and help the exchanges within the Fibonacci community, taking account of both the expertise of the more advanced groups and the strong will and enthusiasm of the new ones.

Some references to go further

- Harlen, W. and Allende, J. (2009), *Report of the working group on teacher professional development in pre-secondary inquiry-based science education (IBSE)*. Interacademy Panel on International Issues.
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www.lezard-graphique.net - 2010

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