The Fibonacci Project

DISSEMINATING INQUIRY-BASED SCIENCE AND MATHEMATICS EDUCATION IN EUROPE

THE LEGACY OF THE FIBONACCI PROJECT TO SCIENCE AND MATHEMATICS EDUCATION

A SYSTEMIC APPROACH FOR SUSTAINABLE IMPLEMENTATION AND DISSEMINATION OF INQUIRY PEDAGOGY, TESTED IN PRIMARY AND SECONDARY SCHOOLS THROUGHOUT EUROPE (2010-2013)

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SEVENTH FRAMEWORK PROGRAMME

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1) Many partners provided ideas and data through internal reports or through written contributions. Whenever reference is made to the work of a particular partner, the centre is mentioned accompanied by its country's flag for quick identification. The names of the 37 Fibonacci centres are provided in the text in Fig. 1.
2) Many of the ideas that structure this book are taken from the Fibonacci Project's Resources for Implementing Inquiry in Science and Mathematics at School, which were written by groups of partners.

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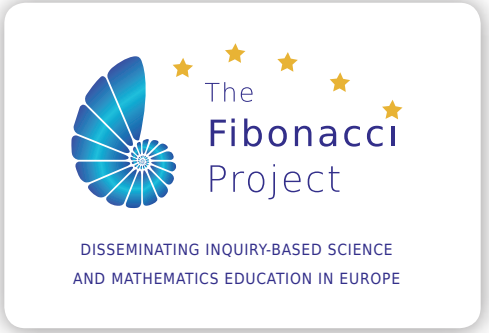

THE LEGACY OF THE FIBONACCI PROJECT TO SCIENCE AND MATHEMATICS EDUCATION

A systemic approach for sustainable implementation and dissemination of inquiry pedagogy, tested in primary and secondary schools throughout Europe (2010-2013)

Foreword

The collaboration that led to this book, among other products, originated in 2008 when the contributors developed the Fibonacci Project. During its period of implementation (2009-2013), 21 European countries were involved at the start and 30 at the end, with some 63 cooperating centres or institutions taking part. This book tells the story of the events leading to the birth of the project, what was involved in its implementation, its outcomes, and the challenges that remain ahead.

Fibonacci was ambitious, possibly overambitious, in attempting to tackle the decline in science and mathematics education in European primary, middle and secondary schools shown by many indicators, since the 1990s. Because modern science was born in Europe and had recovered remarkably from the disasters of the second world war, and because European schools had been of high repute in the not-so-distant past, there was no reason to accept such decline, especially when the economic future of the region was at stake and all citizens need some understanding of scientific ideas and the nature of science. For the first time, Fibonacci tried to bring together two different areas of science learning: mathematics, with its long pedagogical tradition, and natural science. This was attempted under the common banner of inquiry learning, which although not a new approach was nevertheless unknown in most classrooms. Defining, designing and testing the implementation of this common approach was not easy. But it was worth the effort, since many students discovered the joy of doing science and many teachers developed their confidence in their ability to practice inquiry, to do experiments in the classroom, and to collaborate with others, including distinguished scientists as well as education researchers.

The Fibonacci Project was evaluated throughout its three years and the results are presented in this book, with examples taken from all over Europe. A fair criticism is that this assessment lacks sufficient quality criteria, or that it is excessively based on teachers' self-reporting, rather than on more objective measures. This is true and should be improved in future projects. Yet, for any attempted change in science education worldwide, there is always a considerable gap between a 'pure' set of ideal learning patterns, and what can be put in place in the reality of the classroom, whatever the support in place to improve teaching. Such a pessimistic perception of reality could deter efforts to improve how science and mathematics are taught. However, the Fibonacci Project initiators, its scientific committee, and the leaders within the sixty centres we progressively established, did not accept the alternative to do nothing where perfection is not possible. Their modest hope is to have paved some pathways to improvement, and to have done their best to make them available to others.

We address this book to policy-makers concerned with and about education, to education authorities, scientists and industrialists, and indeed to school systems actors in general. We hope the Fibonacci Project, although far from being free of criticism, will demonstrate to them that in Europe powerful forces for changing science mathematics and science education exist through the simple means of collaborations among stakeholders within and outside classrooms.

The Editors

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▶ TABLES provide quantitative data.

▶ FIGURES provide visual information.

1 The birth of the Fibonacci Project

1. Some historical and political background

Scientific literacy: the alarm bells

The launch of Sputnik 1 by the USSR in 1957 shocked the leaders of the United States and other Western countries. It served only to underline the realisation by scientists, science educators and industry leaders that post-war science education was seriously out-of-date. The response in the USA and UK was a wave of innovative programmes and resources – produced in the USA by institutions such as Berkeley, Harvard and MIT, and in the UK by groups of science educators initially funded by the Nuffield Foundation and by the Schools Council for the Curriculum and Examinations, set up in 1964. In both countries the first projects aimed to renew the secondary science curriculum, followed by development in the 1960s of primary/elementary school science projects. The response in France, Germany and other European nations was not so strong.

For the next 25 years or so these pioneering projects were revised and new ones were developed, but it became clear that the process of change was slow and difficult. Studies of their implementation found that the impact of the curriculum projects was not as widespread as expected. In the 1980s major reports on the state of science education in both the US and the UK indicated that there was cause for concern. For example, in the USA the 1983 report *A Nation at Risk* revealed that less than one percent of school districts had effective science education programmes. One response to this finding was the creation, by the Smithsonian Institution and the National Academies, of the National Science Resources Centre (NSRC) in 1985. A key aim of the NSRC was to produce programmes and support for science teaching based on research into how to bring about change in schools as well as how to develop students' conceptual understanding. The NSRC initiated a project known as Science and Technology Concepts (STC) for elementary and secondary schools, with supporting classroom and professional development materials and equipment kits.

Despite the efforts of a few individual researchers, France, Germany, and some other European countries were lagging behind in terms of curriculum innovation in science. In the process of construction of the European Union (EU), the Maastricht Treaty (1992) established that primary and secondary education should remain in the hands of member states. Meanwhile, due to their role in conducting research as well as in teaching, universities became, at least in part, subject to a common policy (the 'Bologna process'). Initially, the support of the European Commission at the pre-university level was for informal education (museums or science centres), a strategy which was a convenient way to avoid interfering with national education policies while stimulating and funding new

ways of communicating science. Through hands-on science centres that were set up in many countries, visitors could experience a more participatory vision of science.

However, this approach was not a solution to the problem of mainstream school science education. In particular it was becoming widely recognised that school science had to serve the education of the whole population, not just those who would become scientists or technologists. All citizens in a world that is increasingly dependent on science and technology applications need to understand key science concepts and the nature of scientific activity, and be able to use evidence in making decisions. These needs were encapsulated in the notion of scientific literacy – 'an appreciation of the nature, aims, and general limitations of science, coupled with some understanding of the more important scientific ideas'.[1] Moreover, it was recognised that such literacy will be better achieved if it begins early, in primary school.

Science academies become involved

International scientific organisations such as ICSU (International Council for Science) were active in stimulating the renewal of science education worldwide from the 1960s. It was not long before primary school science education was included in their concerns. This was in recognition of the importance from the early grades of enabling students to learn science with understanding and to experience authentic scientific activity, embodied in the concept of learning through inquiry. The involvement of the academies of science in primary education was an entirely new development. It was the start of new developments supported and in some cases spearheaded by academicians using their expertise and influence to bring about change in primary as well as secondary school science.

For example, in 1996, with the support of the French Ministry of Education, and as a result of the involvement of French Nobel physics laureate Georges Charpak, the French *Académie des sciences* embarked on a large-scale project for the renewal and expansion of primary science education known as *La main à la pâte.*[2] Charpak was inspired by the work initiated by another Nobel Laureate, Leon Lederman, in Chicago. At about the same time, the Swedish Royal Academy of Science, in cooperation with municipalities throughout Sweden, launched the Natural Science and Technology for All (NTA) project in 1997. Other science Academies followed.[3]

1 Jenkins, E. W. (1994). Scientific literacy. In T. Husen & T. N. Postlethwaite, (Eds.), *The international encyclopaedia of education* (Volume 9, 2nd ed., pp. 5345–5350). Oxford, UK: Pergamon Press.
2 http://www.fondation-lamap.org/
3 Allende, J. (2008) Academies active in education, *Science*, **321**, 1133

Towards inquiry in mathematics education

Unlike natural science, mathematics has always been a fundamental component of primary education everywhere in the world. Mathematicians have thus been actively involved in thinking about the teaching and learning of mathematics for a much longer time than have physicists, biologists or other scientists. As early as 1908, at the fifth International Congress of Mathematicians at the *Accademia dei Lincei* in Rome, mathematicians decided to create an International Commission on Mathematical Instruction (ICMI) for promoting international collaboration and exchange in this area worldwide. At that time, its first president, the famous mathematician Felix Klein, was himself very active in promoting modern views of mathematics education in Germany. In France, Emile Borel pleaded for the creation of mathematics laboratories in high schools. Since then, mathematicians have been collaborating steadily with teachers, teacher educators and mathematics education researchers to improve the teaching and learning of mathematics. European countries have played an important and often leading role in this process.

As was the case in science education, the fifties and sixties were a period of intense reflexion and activity for mathematics education. During that period the 'New Math' movement emerged, with the main ambition of reducing the gap between mathematics taught at school and modern mathematics, the idea being that this would make mathematics learning more accessible, interesting and powerful. During that period, mathematics education began to develop as a genuine field of research whose scope was to promote and accompany the desired renovation of mathematics education at school. With time it became evident to mathematics education researchers that in many cases, the New Math movement had degenerated into formal teaching which was contrary to the spirit of the reform. Understanding why this was the case and avoiding the repetition of similar errors became a research priority.

In Europe, institutions such as the IREMs (*Instituts de Recherche sur l'Enseignement des Mathématiques*) in France, the Freudenthal Institute in the Netherlands, and the Nuffield Foundation in England, to mention just a few, allowed mathematics education research to develop in close contact with teachers and classrooms. This led to the development of approaches to teaching and learning which today provide a solid foundation for inquiry-based education in mathematics. Indeed, throughout the last fifty years, one of the main ambitions of innovation and research in the field of mathematics education has been to promote mathematical learning with understanding and to help pupils experience authentic mathematical activity from the early grades.

Although 'inquiry-based mathematics education' is a term of recent use in the field, in contrast with science education, the idea of learning through inquiry has been there for decades, embedded in a diversity of pedagogical approaches for which problem-solving is the core of mathematical learning and

teaching. However, despite the unquestionable advances of research in mathematics education and the accumulation of results and positive experiences in a diversity of contexts, the question of how to up-scale successful local initiatives remained a problem which had hardly begun to be convincingly addressed.

Europe begins to fund inquiry in science and mathematics education

In the early 2000s, through the advocacy of Georges Charpak and other leading figures, the European Commission (EC) became convinced of the need to invest significant funding to support change in science education in Europe towards inquiry-based pedagogy that promotes scientific understanding. The subsidiarity principle was clearly an obstacle to institutional involvement by the EC, despite the growing perception in the scientific community that action was becoming urgent. Nonetheless, the EC heard the message and began to provide limited support through the Sixth Framework Programme for Research and Technological Development, under the theme *Science and Society*.

From this opportunity was born one of the grandparents of the Fibonacci Project: ScienceEduc (2004-2006) led by the *La main à la pâte* group in France and including only six partner countries. ScienceEduc's main aim was to promote the dissemination of methods and good practices in science teaching and to directly support teachers' educational practices. So began a movement that gradually spread throughout Europe. The follow-up project, Pollen (2006-2009), gathered 12 partners, still with modest funding, but demonstrating that a joint EU approach was fruitful.

In the meantime, TIMSS and PISA results increasingly revealed poor performances of students in many EU countries, both in science and mathematics. In Germany, the 2000 results provoked a shock reaction in public opinion: they were far from reflecting the quality that had been attributed to German schools before that time. The Bund-Laender Commission for Educational Planning and Research Promotion (BLK) set up an expert commission to find ways of improving mathematics and science instruction. On the basis of the commission's diagnosis and recommendations, the Increasing Efficiency in Mathematics and Science Education (SINUS) project (1998-2003) was launched. The project involved 180 German schools from 15 different states and approximately 1,000 teachers, and promoted problem-based learning both in mathematics and in science.

As result of a very positive evaluation, the follow-up project SINUS-Transfer was launched in 2003 to bring the SINUS approach to a greater number of German schools and teachers. SINUS-Transfer involved about 1,800 schools and more than 10,000 teachers. It was the largest and most successful school development project ever to have been carried out in Germany.

Both in science and in mathematics education, the scene was set for a decisive move.

Inquiry pedagogy in science and mathematics becomes a headline European concern

Several research studies in the 2000s alerted European policy makers to the decline of young people's interest for science and mathematics[4] studies in many European countries.[5] In response the EC asked Michel Rocard (Prime Minister of France from 1988 to 1991) to lead a small team of European experts in preparing a report on science education. The report was published in 2007 under the somewhat provocative title *Science Education Now: A Renewed Pedagogy for the Future of Europe*[6] and became widely referred to as the 'Rocard Report'. Shortly afterwards, the Nuffield Foundation funded two seminars involving science educators from nine European countries. The result was also a report, published under the title *Science Education in Europe: critical reflections*,[7] in early 2008.

Both reports made strong recommendations about action to be taken to increase the quality of science education[8] and expressed support for the view that profound changes were needed in pedagogy. It was argued that inquiry-based methods of teaching and learning would increase students' interest in science, particularly that of girls, and levels of attainment.

The 'Rocard Report' also referred to the projects Pollen and Sinus-Transfer as successful initiatives at the European level and asked for immediate investment of €60m for inquiry-based actions in science and mathematics to be implemented in schools. The message had a strong impact and was acted upon without delay. Under the FP7 Science in Society programme (2007-2013), the EC issued a new call for inquiry-based science and mathematics education projects: it was a unique opportunity to develop inquiry-based education in Europe and to reinforce existing networks among the key players in science and mathematics education. The French *La main à la pâte* team – which had led Pollen – and a team from the University of Bayreuth – which had led SINUS and SINUS-Transfer – jointly responded to this call as project coordinators, with 22 other European countries as partners. Their project, called Fibonacci, was selected along with three other projects, to begin in 2009.

4 In this book 'science' refers to experimental and observational sciences, such as physics, chemistry, geology, biology, etc., which may also be designated as 'science of natural phenomena' or simply 'natural science'. Mathematics is distinct, but indeed is considered as a science throughout the book.

5 See for example: *Evolution of Student Interest in Science and Technology Studies – Policy Report*; Global Science Forum, OECD, May 2006.

6 Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H. and Hemmo, V. (2007). *Science Education Now: A Renewed Pedagogy for the Future of Europe*. Brussels, Directorate General for Research, Science, Economy and Society.

7 Osborne, J. and Dillon, J. (2008). *Science Education in Europe: critical reflections.* London: Nuffield Foundation.

8 In the 'Rocard Report', the term 'science' was defined as encompassing both the natural sciences and mathematics.

The Rocard Report was fundamentally a political text, putting forth propositions in response to an important issue for Europe, but not entering into detailed analysis of inquiry pedagogy or difficulties related to its implementation. Nor did it discuss the differences in pedagogy which could apply to natural science on one hand, mathematics on the other, or the different historical paths, recalled above, that these two domains had followed. But this historic Report, leading to Fibonacci and other European supported projects, marked a turning point in the will of Europe, as a Union, to deal with science education in the schools of each country.

2. Starting points

What the two reports on science and mathematics education in Europe and the subsequent FP7 call were asking for was by no means a small task. It implied two major challenges: 1) defining a common pedagogical framework for teaching science and mathematics through inquiry; 2) dissemination of this development to schools, other educational institutions and teachers on a massive scale. As a response to these challenges, the ambition of the Fibonacci Project (January 2010 – February 2013) was to design, implement and test a strategy of large-scale dissemination in Europe of inquiry-based teaching in mathematics and natural science in primary and secondary schools, taking account of national and/or local specificities. Following the recommendations of the 'Rocard Report', the project would not start from scratch, but instead take advantage of the networks of partners and expertise built up during the Pollen and SINUS projects. It is important to note, therefore, that the project was built on the implicit assumption that it could deal simultaneously with natural science and mathematics, based on a similar pedagogy, despite the differences mentioned above. After all, mathematics, physics, chemistry, geology and biology are all *sciences*.

A model for dissemination: the Fibonacci sequence

Local initiatives for supporting teachers in the implementation of inquiry pedagogy were at the heart of the Fibonacci project. The problem to solve was how to start from a few experienced pilot centres, and disseminate new practice from them without losing the quality and spirit of the change. Each Fibonacci Project centre established a network of schools in its region. A group of teachers from each school took part directly in the project. These regional networks of schools and teachers provided the basic focus for the activity of the centre.

The strategy consisted in a dissemination process from 12 centres selected from the Pollen and SINUS networks for their extensive school coverage and capacities for dissemination of inquiry-based education. These were called

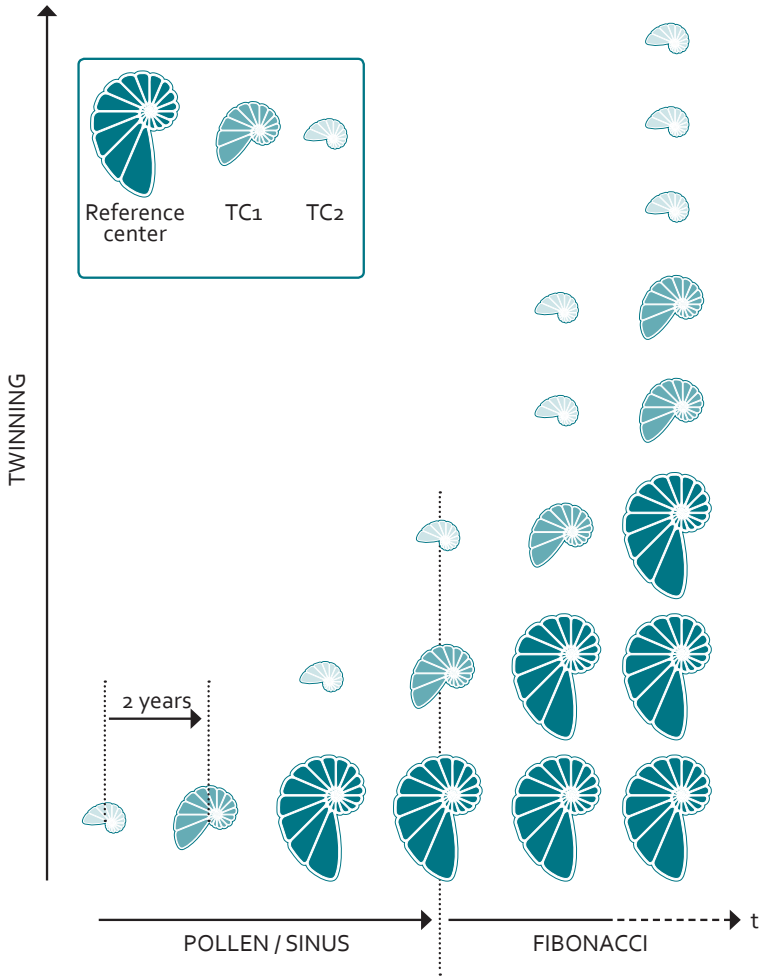
Reference Centres (RCs) and were intended to be the centres from which changed practice spread, first to 25 other centres, described as Twin Centres (TCs). Twelve of these (called Twin Centres 1 (TC1)) were selected based on their existing experience in inquiry-based science and/or mathematics education projects, and willingness to start their own initiative based the Fibonacci Project principles. Thirteen Twin Centres 2 (TC2), which had no experience in inquiry-based science or mathematics education projects, were selected on the basis of their potential for dissemination of inquiry-based practices at a local or national level (i.e. official links with key national or regional institutions, involvement of educational or scientific authorities in the project). TCs were considered to be RCs in progress.

By the end of the project, the TC1s were expected have acquired the necessary expertise to become RCs, and the TC2s were expected to have become TC1s. A new group of 24 TC3s, selected by the RCs using the same criteria as the TC2s, was to join the project at the end, and visit an RC (which could be a previous TC1) at least once.

This was, of course, designed as a model dissemination scheme which then had to be adapted to real actors and situations. Although the differences between the RCs, TC1s and TC2s were not always clear-cut from the start, this three-level structure was useful for organising systematic peer-mentoring between centres so that people with different levels of expertise could share knowledge. The Fibonacci sequence, described in **Box 1**, inspired the name of the project.

Box 1. Why "*Fibonacci*"?

Leonardo of Pisa (c.1170–c.1250), also known as Fibonacci, is often considered the most talented mathematician of the Middle Ages. In his book, *Liber Abaci*, he posed and solved a problem involving the growth of a hypothetical population of rabbits based on idealised assumptions. The solution was a sequence of numbers which came to be known as the Fibonacci sequence: the number of existing pairs of rabbits at a given month is the sum of the two previous numbers of pairs in the sequence: 1, 1, 2, 3, 5, 8, 13, 21... The Fibonacci number sequence was chosen to represent how mass dissemination of an educational reform could be conceived and planned: a small number of RCs would disseminate inquiry pedagogy and strategies for its implementation to the same number of TC1s and TC2s, and later to twice as many TC3s, thus accomplishing integrative growth similar to that described by the Fibonacci sequence.



A consortium of 25 partners from 21 European countries

The project consortium comprised 25 members from 21 different European countries, with endorsement from universities and major scientific institutions such as science academies (see **Fig. 1**). It included some partners from the previous projects, plus others highly motivated by the need to improve science education in their country or region.

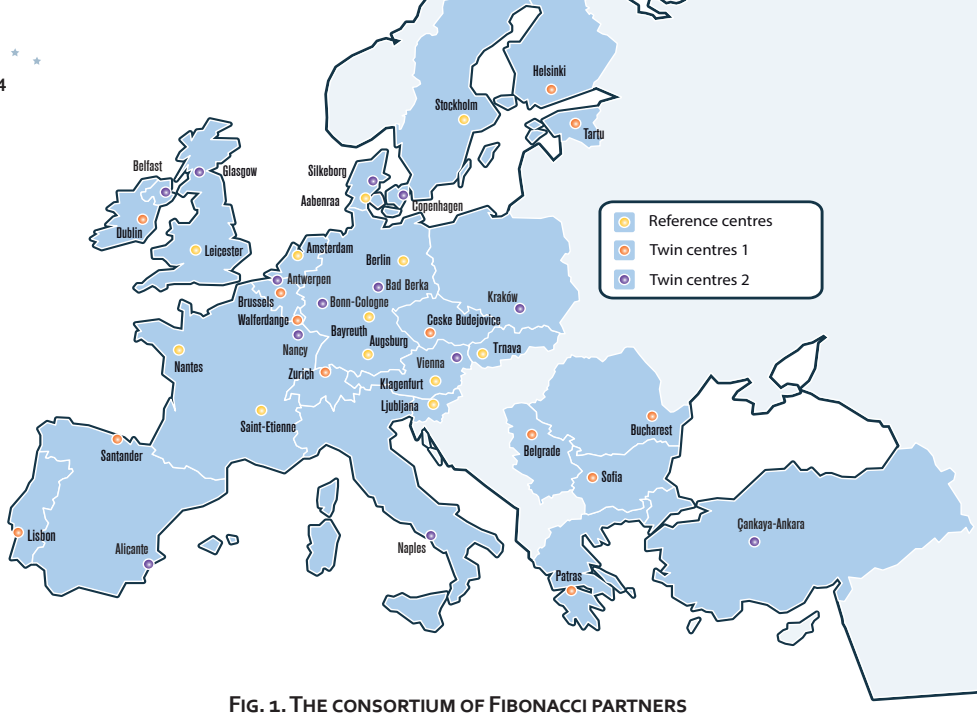


Fig. 1. The consortium of Fibonacci partners and their geographical location.

	City	Country	Coordinating Institution	Level of expertise
	AABENRAA	Denmark	Professionshojskolen Syd University College / University College South Denmark	RC
	ALICANTE	Spain	Universidad de Alicante / University of Alicante	TC2
	AMSTERDAM	Netherlands	Hogeschool van Amsterdam	RC
	ANTWERPEN	Belgium	Dienst Katholiek Onderwijs	TC1
	AUGSBURG	Germany	Universitaet Augsburg / University of Augsburg	RC
	BAD BERKA	Germany	Thüringer Institut für Lehrerfortbildung, Lehrplanentwicklung und Medien / Thuringian Institute for teacher training, curriculum development and media	TC2
	BAYREUTH	Germany	Universitaet Bayreuth - Mathematisches Institut - Lehrstuhl für Mathematik und ihre Didaktik / University of Bayreuth	RC
	BELFAST	UK/Northern Ireland	Queens University Belfast	TC2

	BELGRADE	Serbia	Institut Za Nuklearne Nauke Vinca / Vinca Institute for Nuclear Sciences	TC1
	BERLIN	Germany	Freie Universitaet Berlin / Free University of Berlin	RC
	BONN / COLOGNE	Germany	Industrie- und HandelsKammer Bonn/ Rhein-Sieg und zu Köln / Cologne and Bonn Chambers of Commerce and Industry	TC2
	BRUSSELS	Belgium	Université Libre de Bruxelles / Free University of Brussels	TC1
	BUCHAREST	Romania	Institutul National de Fizica Laserilor, Plasmei si Radiatiei – INLFPR / National Institute for Lasers, Plasma and Radiation	TC1
	ÇANKAYA-ANKARA	Turkey	Türkiye Bilimler Akademisi (TÜBA) / Turkish Academy of sciences - TUBA	TC2
	CESKE BUDEJOVICE	Czech Republic	University of South Bohemia	TC1
	COPEN-HAGEN	Denmark	Aarhus Universitet - Center for Scienceuddannelse / Aarhus University - Centre for Science Education	TC2
	DUBLIN	Ireland	St Patrick's College	TC1
	GLASGOW	UK/Scotland	University of Glasgow	TC2
	HELSINKI	Finland	Helsingin Yliopisto / University of Helsinki	TC1
	KLAGENFURT	Austria	Universitaet Klagenfurt / University of Klagenfurt	RC
	KRAKOW	Poland	Uniwersytet Jagielloński Instytut Fizyki / Jagiellonian University Institute of Physics	TC2
	LEICESTER	UK/England	University of Leicester	RC
	LISBON	Portugal	Ciencia Viva - Agencia Nacional Para A Cultura Cientifica E Technologica / Ciencia Viva - National Agency for Scientific and Technological Culture	TC1
	LJUBLJANA	Slovenia	Univerza V Ljubljani / University of Ljubljana	RC
	NANCY	France	PRES de l'Université de Lorraine / PRES of the University of Lorraine	TC2
	NANTES	France	Ecole Nationale Supérieure des Techniques Industrielles et des Mines de Nantes / Nantes Graduate School of Engineering	RC
	NAPLES	Italy	Associazione Nazionale Degli Insegnanti Di Scienze Naturali (A.N.I.S.N) / National Association of Natural Sciences Teachers	TC2

	PATRAS	Greece	Πανεπιστήμιο Πατρών / University of Patras	TC1
	SAINT-ÉTIENNE	France	ARMINES / Ecole Nationale Supérieure des Mines de Saint-Etienne / ARMINES/St Étienne Graduate School of Engineering	RC
	SANTANDER	Spain	University of Cantabria	TC2
	SILKEBORG	Denmark	VIA University College	TC2
	SOFIA	Bulgaria	Институт по математика и информатика - Българска академия на науките IMIBAS - Institute of mathematics and informatics - Bulgarian Academy of sciences	TC1
	STOCKHOLM	Sweden	Kungliga Vetenskapsakademien / Royal Swedish Academy of Sciences	RC
	TARTU	Estonia	Tartu Ulikool / University of Tartu	TC1
	TRNAVA	Slovakia	Trnavska Univerzita v Trnave / University of Trnava	RC
	VIENNA	Austria	Pädagogische Hochschule Wien	TC2
	WALFER-DANGE	Luxemburg	Université du Luxembourg / University of Luxemburg	TC1
	ZURICH	Switzerland	Universitaet Zuerich - Institut für Erziehungswissenschaft / University of Zurich - Institute of education	TC1

A scientific committee of acknowledged experts in science and mathematics education was set up to supervise the partners' work and provide them with the necessary scientific background on inquiry pedagogy in science and mathematics. An external evaluator, Educonsult, was appointed to work closely with the partners to provide them with formative feedback throughout the implementation of the project and evaluate its impact on the different stakeholders.

The European coordination of the project was taken on by *La main à la pâte* in France (under the supervision of the Académie des sciences) and scientific coordination was to be shared with the University of Bayreuth.

Three 'Basic Pillars' to guide partners' work

Three 'Basic Pillars' guided the actions of partners throughout the lifespan of the project. Their formulation reflected the aim of providing a common framework for education in mathematics and natural science, at the primary and middle school level at least.

Pillar 1: Inquiry-based science and mathematics education for scientific literacy

Inquiry pedagogy goes beyond learning concepts to engage students in identifying relevant evidence and reflecting on its interpretations. By learning

through inquiry, students are expected to develop concepts that enable them to understand the scientific aspects of the world around them through their own thinking, using critical and logical reasoning about evidence that they have gathered. Teachers lead students to develop the skills necessary for inquiry and for understanding science concepts through their own activity and reasoning.

To guide the partners' work, nine 'Basic Patterns' were formulated as touchstones for achieving a change in teaching and learning through inquiry. These patterns were analogous to the successful concept developed within the German SINUS-Transfer programme, and were of similar inspiration to the principles developed by *La main à la pâte* in France, which had framed the Pollen project:

1. Developing a problem-based culture
2. Working in a scientific manner
3. Learning from mistakes
4. Securing basic knowledge
5. Promoting cumulative learning
6. Experiencing subject boundaries and interdisciplinary approaches
7. Promoting the participation of girls and boys
8. Promoting student cooperation
9. Promoting autonomous learning.

Teachers were to be considered as experts in teaching, capable and responsible for further developing and improving their own classroom practice. These 'Basic Patterns' were expected to help them frame their work and share their thoughts and ideas with their colleagues.

Pillar 2: Building on local initiatives for innovation and sustainability

Local and regional initiatives were to be at the core of the projected reform of science and mathematics education in Europe. Indeed, on the basis of the experience acquired with the Pollen Project, the potential for innovation within local initiatives as opposed to delocalised initiatives was known to be strong. Reasons included reduced scale, greater concentration of actors, and better integration into local policies. Local initiatives were also known to enable the use of resources from different actors inside and outside the different formal education systems, progressively involving the whole local community in a joint effort. Finally, working on a small scale would allow schemes and tools to be tested before replicating them on a larger scale.

Pillar 3: Twinning for dissemination of inquiry pedagogy

Dissemination within the project was to be neither top-down nor bottom-up, but rather a transfer of semi-formalised practices and experiences that had

reached a satisfactory level of recognition, expertise and sustainability on a local scale. Successful strategies inspired by RCs would be replicated in TCs. In order to achieve this, each RC would be twinned with two TCs. Concretely, twinning activities would involve visits of members of the TCs to the RC in the field, on-site and distance tutoring from experienced members of the RC to support the TCs' emerging initiatives, and exchanges of good practices among the centres through joint projects and resource sharing. Twinning activities would focus both on implementation strategies and on pedagogical content.

A budget of €4.78 million

€67m is expected to have been invested by the European Union in disseminating inquiry-based education approaches between 2010 and 2016.[9] Of this total, the Fibonacci project was assigned €4.78m. **TABLE 1** shows the approximate breakdown of this budget. It should be noted that the impulse given by the Fibonacci project in the many participating countries led to a significant number of additional local contributions: organisation of seminars, production of resources, etc. These contributions are difficult to quantify, as a quantitative record was not requested, but in quality they demonstrated, in almost every country, the sense of urgency in seeking changes for science education and bringing resources to bear to amplify the EU effort.

TABLE 1: THE PROJECT'S BUDGET (IN EUROS)

Overall coordination	339 900,00
Scientific coordination & committee	117 300,00
External evaluation	93 600,00
Communication	143 740,00
Dissemination (conferences and seminars)	316 000,00
Topics (companion resources and training sessions)	303 500,00
Reference Centres and Twin Centres 2	2 115 374,00
Twin Centres 1	1 077 103,00
Indirect costs	278 080,00
Total	4 784 597,00

9 Dillon, J. (2012). 'Panacea or passing fad – how good is IBSE?'. *Roots,* Vol. 9 (2), pp. 5-8.

2 The Fibonacci adventure

1. Conceptualising inquiry in science and mathematics education

The 'Rocard Report' was useful in bringing a long-established pedagogical and epistemological approach to natural science and mathematics teaching into the realm of educational politics. But the popularity of inquiry pedagogy, added to this new political reality, exposed it to a variety of interpretations. Project partners were conscious from the start that a *loose definition* of inquiry prevailed in Europe, which meant that the type of teaching practice designated by this term varied from one context to another and that some of the existing approaches to inquiry lacked rigorous conceptualisation. The need for such conceptualisation became still more evident as the implementation of inquiry was spread to the different partner countries. The additional challenge was to propose a research–based conceptualisation of inquiry pedagogy in science and mathematics education respectful of local and/or national specificities.

The universal element to be respected in science and mathematics education, whatever the context, is the nature of science and mathematics as realms of knowledge, built through inquiry. Providing partners with a research-based conceptualisation of inquiry pedagogy in science and mathematics education involved taking into account the similarities and differences between the inquiry process in both disciplines. In order to do this, bridges had to be built between these two distinct, yet interdependent epistemologies.

Conceptualising inquiry in science and mathematics so as to help the various centres implement new approaches to teaching in schools was one of the main tasks of the project's scientific committee. This conceptualisation was provided in the project's *Background Resources for Implementing Inquiry in Science and Mathematics at School* (see **Fig. 6**). The *Background Resources* evolved gradually throughout the three-year life-span of the project from a set of documents originated in the framework of the Pollen and SINUS projects. In the following sections, the main components of the conceptualisation and clarification of inquiry provided by the project's *Background Resources* are set out.

Inquiry: a long-established pedagogical approach

Inquiry is by no means a new concept in education, being based on recognition of the importance of learners having active roles in developing their ideas and understanding. The studies of Piaget,[10] the arguments of Dewey,[11] and the

10 Piaget, J. (1929) *The Child's Conception of the World*. New York: Harcourt Brace.
11 Dewey, J. (1933) *How we think: A restatement of the relation of reflective thinking to the educative process.* Boston, MA: D.C. Heath.

insights of Vygotsky[12] among others in the first half of the 20th century drew attention to the important role in their learning of children's curiosity, imagination and urge to interact and inquire. Inquiry is a term widely used both within education and in daily life. It is sometimes equated with research, investigation, or 'search for truth'.

What characterises inquiry in education is that students take an active part in developing their understanding and learning strategies. They do this by pursuing questions or addressing problems that engage their attention and thinking. They bring their existing experience and ideas to bear in tackling the new challenge and in doing so strengthen and extend their ideas and strategies. Because they conduct investigations or collect data in other ways for themselves, they can use evidence to decide what works and what does not work in helping to make sense of different aspects of the world around them. As well as building understanding, they are developing skills such as critical thinking, communication skills and the ability to learn both independently and collaboratively.

Inquiry-based education is firmly rooted in what we know about learning. Some of the key findings from research in learning are that:

- children are forming ideas about the world around them from birth and will use their own ideas in trying to make sense of new events and phenomena they encounter;
- direct physical action on objects is important for early learning, gradually giving way to reasoning, first about real events and objects and then later about abstractions;
- students learn best through mental and physical activity, when they work things out through their own thinking in interaction with adults or other students, rather than receiving instruction and information to memorise;
- language, particularly discussion and dialogic interaction with others, has an important part in forming students' reasoning and ideas;
- the teacher has a key role in promoting students' active rather than passive learning.

Within education, inquiry can be applied in several subject domains – such as history, geography, the arts, as well as science and mathematics – when questions are raised, evidence is gathered and possible explanations are considered. In each area different kinds of knowledge and understanding emerge. The Fibonacci Project conceptualised inquiry in science education and inquiry in mathematics education in ways which recognised the commonalities of these subject domains whilst respecting the specific epistemological processes involved in each of them.

12 Vygotsky, L.S. (1978). *Mind in Society: the Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Why inquiry?

The Fibonacci Project was designed to spread inquiry-based pedagogy among European schools because of its potential to lead to the understanding, skills and attitudes that enhance the lives of individual learners and help to meet the needs of increasingly technology-based societies.

Learning science and mathematics through inquiry can serve the personal interests of individual learners and benefit society. For learners as individuals it enables them to develop the understanding, powers of reasoning and attitudes that help them to lead physically and emotionally healthy and rewarding lives. Developing understanding about the world around and stimulating and satisfying curiosity also informs their personal choices in life that affect their wellbeing and choice of career. For society there are benefits if individuals and groups make more informed choices in relation to avoiding, for instance, waste of fuel and other resources, pollution and the consequences of poor diet, lack of exercise and misuse of drugs. As well as impact on their own daily lives, these things have wider implications for their and others' future lives through the longer-term effects of human activity on the environment. Relating science and mathematics to familiar situations and objects used daily stimulates interest in studying these subjects but should also be used to develop the realisation of how widespread, locally and globally, are the consequences of their applications. Further, the OECD points out that

> Students cannot learn in school everything they will need to know in adult life. What they must acquire is the prerequisites for successful learning in future life. These prerequisites are of both a cognitive and a motivational nature. Students must become able to organise and regulate their own learning, to learn independently and in groups, and to overcome difficulties in the learning process. This requires them to be aware of their own thinking processes and learning strategies and methods.[13]

Opportunities to develop these outcomes of education are important for all students, not only those who will continue to study science and mathematics and later take up occupations related to STEM (science, technology, engineering and mathematics) subjects. However, the results of effective science and mathematics education may well lead to more students choosing to specialise in science and mathematics and so address the problem identified in the 'Rocard Report' of 'an alarming decline in young people's interest for key science studies and mathematics'.[14]

13 OECD (2000). *Measuring Student Knowledge and Skills: A new Framework for Assessment*. Paris: OECD, p. 90.

14 Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H. and Hemmo, V. (2007). *Science Education Now: A renewed Pedagogy for the Future of Europe*. Brussels, Directorate General for Research, Science, Economy and Society, p. 5.

An inquiry-based pedagogy, well implemented, offers to provide the understanding and skills that are clearly required for life in a society increasingly dependent on applications of science and mathematics. To justify this claim we need to consider what is involved in inquiry-based learning and teaching in science and mathematics.

The inquiry process in natural science and mathematics

Both mathematical and scientific inquiry start with a question or problem; some connection is made with questions or problems of a similar kind which have been previously encountered and solved. In both, solutions may be sought through observation, exploration, and through actual or virtual experiments. Also in common is the use of known strategies and techniques for accessing, analysing, interpreting and using evidence, which are applied and adapted where necessary. Finally, both in mathematics and in science, inquiry is a non-linear process, which leads to the progressive development of solutions, key concepts, strategies and techniques.

Despite the similarities with scientific inquiry, there are aspects of mathematical inquiry which are quite distinctly different. These relate in particular to the source of questions or problems, how they are expressed, the nature and function of experimentation and how solutions are validated. Each of these important distinctions is briefly considered in **Box 2**.

Box 2. Differences between the inquiry process in science and in mathematics

Components of the inquiry process…	…in natural science	…in mathematics
The nature of the problem/ question	Problems/questions concern and usually arise from real-life situations.	Problems/questions can arise from a diversity of contexts, both mathematical and non- mathematical.
Modelling	Models are used to simulate events or to describe relationships and offer explanations; they can be conceptual or physical.	Modelling is the process involved in raising questions from real life or from other disciplines, transforming them into questions accessible to a mathematical treatment, treating these questions, and interpreting the answers obtained in the context of the external source in order to examine their validity and usefulness.
Investigating and experimenting	The processes of investigation and experimentation involve observation or manipulation of the real world.	The processes of investigation and experimentation are not limited to observation of or manipulation of the real world.
Validating solutions	Ideas are accepted if predictions based on them are found to be consistent with available evidence.	The validity of mathematical solutions is demonstrated through logical arguments.
The status of truth	Scientific theories and models are those that best fit the facts known at a particular time and properly predict the results of new experiments or observations: they are thus regarded as provisional. In the light of new evidence, what is considered to be true today may need to be modified in order to enclose the new evidence. This does not mean that previous theories and models become entirely false, but rather that the new theory tends more towards truth than the old one because it is better fit to describe precisely the way nature works.	When a mathematical solution to a problem has been proved to be true, there can be no further evidence to invalidate it. Proof liberates the mathematician from the necessity of further tests.

Building understanding through inquiry in science and mathematics education

The similarities and differences between the inquiry process in science and mathematics have important consequences in the way students' understanding is built through inquiry-based education in each of these disciplines.

Learning science through inquiry enables students to build their knowledge of the world around, progressively advance their understanding of key scientific ideas and develop skills of investigation and use of evidence. The process begins in trying to make sense of a phenomenon, or answer a question about why something behaves in a certain way or takes the form it does. Initial exploration reveals features that recall previous ideas leading to possible explanations. Working scientifically, students then proceed to test each possible idea by generating, collecting, analysing and interpreting data to use as evidence, to see how useful it is in providing an explanation of the events or an answer to the question.

From these results a tentative conclusion can be drawn about an initial idea. If it gives a good explanation then the existing idea is not only confirmed, but becomes more powerful –'bigger'– because it then explains a wider range of phenomena. If the evidence does not support the explanation given by the idea, then an alternative idea has to be tried. But knowledge that the initial idea is not the answer is also useful. It is just as important to know what doesn't work as what does work.

It is this process of building understanding by collecting evidence to test possible explanations and the ideas behind them in a scientific manner, that we describe as learning through scientific inquiry. It leads to knowledge about the particular subject being investigated, but more importantly it helps to build understanding of similar events and of the processes involved in scientific activity. For example, investigating whether objects sink or float in water leads to information about these objects, but to be more widely useful this information needs to be linked to other information and organised to form broader principles and concepts. What is important is for students to understand why things do or do not float. However, principles and concepts cannot be directly transmitted to learners, except as meaningless words learned by rote; they must be gradually constructed through the learners' own thinking.

As is the case in natural science, inquiry in mathematics refers to an education which does not present mathematics to students as a ready-built structure for appropriation. Rather it offers them the opportunity to experience, with the teacher's support and under his/her guidance:

- how mathematical knowledge is developed through personal and collective attempts at answering questions emerging in a diversity of fields, from inside or outside the mathematics field itself, and,

- how mathematical concepts and structures can emerge from the organisation of the resulting constructions, and then be exploited to answer 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 mathematical work; modelling and mathematising; exploring and experimenting; conjecturing; testing, explaining, reasoning, arguing and proving; defining and structuring; connecting, representing and communicating. Inquiry-based mathematics education engages students in these forms of activity and fosters the development of associated skills.[15]

Using an inquiry-based approach can enable students to develop their mathematical understanding and result in their mathematical knowledge becoming more robust and functional in diverse contexts beyond those of the usual school tasks. Well implemented, it can 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 can 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.

Consequences for classroom practice

It is important to note that the ideas that emerge from the inquiry process depend on the skills applied to this process being carried out in a scientific way. Students, particularly young children, do not instinctively use these skills rigorously. Unless they do, they may accept ideas that are not consistent with evidence. So if the objective is to advance their understanding it is important to help students develop the skills needed in inquiry. Hence the importance of identifying the skills involved in inquiry and the ways in which teachers can encourage their students to use and develop these skills. This can be expressed in terms of concrete classroom practices involving student actions and teacher-pupil interactions.

The differences in the nature of inquiry in science and mathematics education are reflected in the activities that take place in the classroom. On the one hand, in both science and mathematics, inquiry-based learning engages and develops students' critical thinking, collaborative working, consideration of alternatives and appropriate forms of communication. Students are engaged with a question or a problem, they work collaboratively with each other, they make use of dialogue and discussion, and they consider alternative approaches to

15 See Artigue, M. and Blomhøj, M. (2013). Conceptualising Inquiry-Based Education in Mathematics. *ZDM – The International Journal on Mathematics Education* 45(6). See also Baptist, P. (2011). "Experiencing Mathematics", in P. Baptist, C. Miller, D. Raab (eds.), *Towards New Teaching in Mathematics*, Bayreuth: Bayreuth University.

solving a question or problem. But most importantly, in classroom experiences in both inquiry-based science and mathematics, students are engaged in answering questions or solving problems to which they do not know the solution and to which they wish to find an answer.

On the other hand, there are differences between inquiry-based classroom practices in science and mathematics in the focus of work, how problems or questions are addressed, how solutions are sought, the basis of validation of solutions or answers, and the nature of explanations, as set out in **Box 1**. Although problem-solving in both science and in mathematics includes cyclic processes, there is a significant difference in the role of existing ideas that learners bring to the problem or question. Research in science education shows that when students encounter a new phenomenon or object, they try to make sense of it using ideas formed from earlier experience. This attempt to understanding initiates the inquiry process in which an existing idea is used to make a prediction and tested by seeing if there is evidence to support the prediction or whether it needs to be modified or an alternative tried. Research in mathematics education shows that the inquiry process does not necessarily start from a hypothetical idea about the solution of the problem. Previous experience and knowledge can also suggest a possible strategy, a technique to be used for exploring the problem, familiarising with it, obtaining partial results and producing conjectures. The inquiry process in mathematics is non linear and its characteristics vary greatly depending on the type of questions or problems addressed. This is difficult to encapsulate into a simple general schema, even a cyclic schema as is often proposed in science. However when a solution has been found and validated by a mathematical proof, there is the certainty that no further test or experiment can contradict it. Of course this is only true for the solution of a mathematical problem. When mathematical inquiry starts from a non-mathematical situation and includes a modelling process, the mathematical solution needs still to be interpreted in the original context and its pertinence checked.[16]

What inquiry is not

As explained at the beginning of this chapter, recent developments have exposed inquiry pedagogy to a variety of interpretations which need to be countered. Some interpretations result from over-simplification, others from equating inquiry with existing practices which fall short of matching intentions, and others from misunderstandings of what is involved in the inquiry process in science and mathematics.

The first of these unfortunate interpretations is equating inquiry in science and mathematics with 'hands-on' activities or 'practical work': this is far too limited

16 See Schoenfeld A. (1985). *Mathematical Problem Solving*. New York: Academic Press.

a view. A key characteristic of inquiry is mental activity using evidence and this may be found in a range of ways beyond direct action on objects, and may come from secondary sources, the media and the internet. A related mistaken view is that inquiry means that students have to 'discover' everything for themselves and should not be given information by the teacher or use other sources. This assumes that students come to new experiences with open minds and develop their ideas by inductive reasoning about what they observe and find through their inquiries. As explained in the previous sections, students come to new experiences not with empty minds, but with ideas already formed, from earlier thinking and experiences, which they use to try to understand the new events or phenomenon. If there is no evidence to support their idea then they need access to alternative ideas to try, which may be suggested by other students, the teacher or other sources.

It is also important not to regard inquiry as being only concerned with developing the ability to 'behave as a scientist' and learn about a supposed 'scientific method'. There are two problems here. One concerns the goals of inquiry-based education in science. Placing the emphasis on processes of inquiry has led some to the mistaken view that inquiry is more appropriate in primary school than in secondary education. Whilst it is important for students to know how scientific knowledge is created, their learning must help students at all levels develop ideas that help them to understand the world around, ideas of science, and ideas about science. The other problem is the assumption of a single scientific method. In studying different aspects of the world, such as cosmology or ecology, scientists work in different ways. There is no single formula for defining scientific activity and certainly none that fully includes mathematics and science; thus there is no single approach to inquiry-based education.

Consequences for Fibonacci implementation

The above clarification of the nature of inquiry progressively emerged in the course of the Fibonacci project. Hence, the subtle understanding of inquiry pedagogy it led to was not necessarily perceived in detail by the teachers and trainers across the 60 European centres which successively joined the project and implemented its recommendations. As will be seen later, implementation was also somewhat complicated by other initial and explicit goals of the Fibonacci project. However, the impact of the Fibonacci principles for traditional teaching methods of science and mathematics was strong enough to lead teachers and education authorities to deeply question these traditional and often inefficient methods. Consequently they began to experiment with the new approach and enter into more elaborate analysis of the new proposed principles and practices.

2. Setting up and developing Centres for Science and/or Mathematics Education (CSMEs)

The Fibonacci strategy has been based on successive creations of Centres, each one stimulating and helping teachers locally in an array of schools (either primary, or secondary, or both) to develop new science and/or mathematics education patterns. To properly establish, develop and assess these Centres in the diversity of the 25 countries they belonged to has therefore been a constant task of the project. Within the Centres and all along, teachers have been considered as the main key to change in education. The teaching approaches required to enable students to learn though inquiry, as described in the previous chapter, differ in many respects from conventional transmission teaching approaches. For many teachers it means considerable changes in practices. Bringing about these changes implies preparing teachers to understand and implement new strategies and roles in their classrooms. Inquiry-based education, in particular, requires students to become independent learners. In order for this to happen, teachers must develop new relationships with their students and acquire the confidence to allow students to develop their own ideas.[17]

In deciding how to go about helping teachers implement these changes, the Fibonacci Project built on what is known about change in educational practices. Approaches to changing practice in education can be divided into two main groups: transmission and transformation.[18] Various forms of *transmission* involve the distribution of resources, often in the form of guides with ideas and examples of new content and practices, after these have been developed and published. The idea is that all that teachers are required to do is to follow the guides more or less blindly, since the necessary thinking will have been done for them. This 'top down' approach has, however, fallen out of favour through recognition that the messages received and acted upon in the classroom rarely match the intentions of the producers. We know that mechanistic approaches to implementation that do not recognise the importance of the context when deciding on practice do not work.[19] In *transformational* approaches, rather than assuming that all classrooms are the same – and thus that one solution will fit all – the first assumption is that different learning environments and

17 Harlen, W. and J. Allende, eds. (2009). Report of the Working Group on Teacher Professional Development in Pre-secondary School Inquiry-based Science Education. Santiago, Chile: IAP, The Global Network of Science Academies.

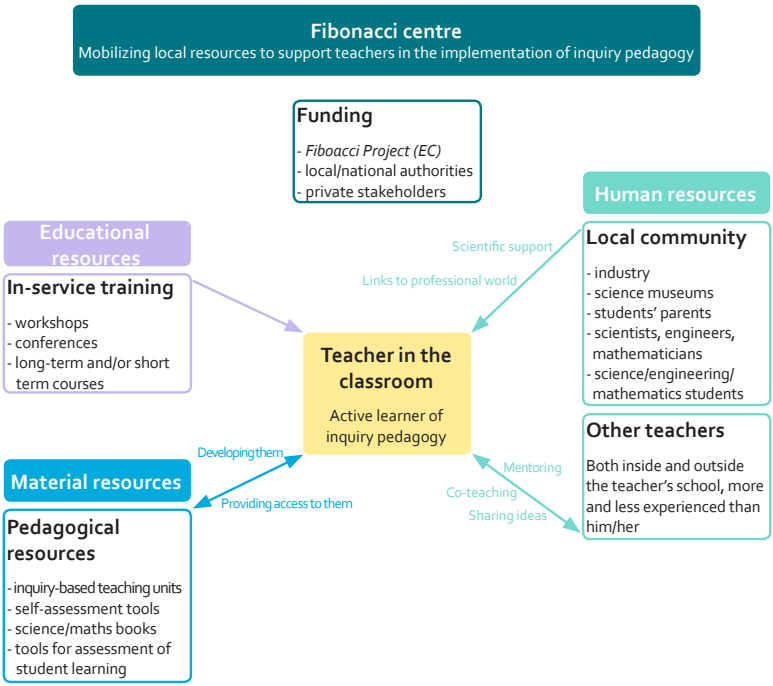
18 Hayward, L. (2010) Moving beyond the classroom, in J. Gardner et al *Developing Teacher Assessment.* Maidenhead, UK: Open University Press.

19 Gardner, J., Harlen, W., Hayward, L., Stobart, G. with Montgomery, M. (2010). Developing Teacher Assessments. McGraw-Hill: OU Press.

cultural backgrounds will require different solutions. The second assumption – also based on strong evidence[20] – is that sustainable development in learning takes place when change is seen as exploring and experimenting, in other words a process of inquiry, by those concerned by the reform.

Fig. 2 shows the main activities of a CSME at a local level. In this chapter we describe the operation of the CSMEs involved in the project. Where relevant, within boxes, we provide examples of implementation collected in the field by Educonsult, the project's external evaluator.

Fig. 2. Activities of a Fibonacci Centre for Science and/or Mathematics Education (CSME)



20 Hayward, L. and Spencer, E. (2010). The Complexities of Change: formative assessment in Scotland. *Curriculum Journal,* 21(2), pp. 161–177.

Teachers as active learners

Change in practice is a matter of learning, and effective learning by teachers has the same qualities as for students. Just as students develop understanding through their own mental and physical activity, so teachers learn best when they take an active part in transforming their practice.

Experience in many areas of change in education, be it in the curriculum, pedagogy, assessment or school organisation and management, is that participation in developing new procedures or materials by those who have to implement them is a most effective way of encouraging commitment to change. When groups of teachers work together with researchers or developers they can be creative and experimental in a safe environment, learn from each other, combine ideas, and achieve ownership of the emerging practices. When opportunities to reflect and develop understanding of principles underlying the changes are added to this, then the experience can be a most effective form of professional learning.

In the Fibonacci Project, teachers were seen as active learners who are capable and responsible for further developing and improving their own teaching. The model of a Fibonacci CSME is based on this main assumption. In addition, at the European level, teachers from CSMEs in different countries also meet and share their practices and discoveries. Good circulation of ideas, resources and experiments is breaking down the isolation in which teachers are too often imprisoned.

Supporting teachers by making the best possible use of local resources

Each Fibonacci centre faced the challenge of providing situations in which teachers could learn collaboratively and work out how to put new ideas into practice and achieve new goals in the particular context of their own classrooms. This implied giving them access to in-service training activities, involving them in the production and/or adaptation of resources and providing good access to these, and creating and promoting teacher networks.

Each teacher support centre involved in the project drew on these different types of activities to build its own teacher support strategy by best utilising its main strengths and the human, material, and financial resources at hand, in order to respond to its teachers' specific needs. **Box 3** provides three examples of teacher support strategies developed by the centres.

Box 3. Examples of local teacher support programmes developed by Fibonacci Centres for Science and/or Mathematics Education (CSMEs)

In **Aabenraa**, the teacher support centre is operated by University College South Denmark, which has an impressive stock of materials for teachers and is connected to a national network of Centres for Educational Resources. In Denmark, inquiry-based instruction is already embedded in the educational system. Thus, the core of Aabenraa's strategy was involving teachers in the adaptation of existing resources from the centres to inquiry-based practice and providing support to individual teachers upon request for teaching specific subjects through inquiry.

In **Nantes**, the teacher support centre is operated by an engineering school (École des Mines de Nantes). Most teachers already have at least some knowledge of inquiry-based practice from their previous training. A strategy based on providing in-class support by engineering students was successfully set up.

Developing and distributing pedagogical resources

Giving teachers easy access to the resources necessary for inquiry-based teaching is fundamental (although not sufficient) for inquiry to happen in the classrooms. Without these resources, setting up an inquiry-based activity may become so burdensome and time consuming for teachers that it leads to discouragement. Teachers need both teaching guides and modules that propose activities especially designed for inquiry-based teaching. **Box 4** provides an overview of the resources produced by Fibonacci teacher support centres, with the cooperation of teachers.

Box 4. Overview of pedagogical resources produced locally with the involvement of teachers

All centres produced resources with and for their teachers in their native languages. Some centres, such as **Naples**, **Klagenfurt**, and **Sofia**, produced a considerable number of publications. Local resources take many different forms: DVDs or films showing how inquiry-based education is applied in concrete classroom situations (**Aabenraa**, **Berlin**, **Ljubljana**, **Saint-Étienne**, **Stockholm**, **Tartu**), pedagogical kits for teachers, descriptions of in-service training activities delivered by a particular centre (**Amsterdam**, **Bucharest**, **Dublin**, **Nantes**, **Trnava**, **Nancy**, **Saint-Étienne**, **Tartu**, **Vienna**), research publications on the impact of inquiry-based teaching on teachers and students (**Augsburg**, **Krakow**, **Leicester**, **Ljubljana**, **Patras**).

Further, each centre developed a website in its own language. In several cases, teachers can upload materials on the website after undergoing a quality check by the centre, making them available to other teachers. In some cases blogs were also created.

Giving teachers easy access to these resources is yet another challenge that requires substantial planning and monitoring. It was not the role of the Fibonacci project itself to produce ready-to-use, universal sets of resources for European schools, since this would have contradicted the bottom-up vision of teachers' active involvement. **Box 5** provides some examples of centres' initiatives for distributing resources at a low cost.

Box 5. Examples of initiatives for giving teachers access to resources

A structured national network of Centres for Educational Resources

The Danish Centres for Educational Resources have been giving teachers access to resources since the 1930s. Their function is to build up a collection of teaching resources intended to be on loan to educational institutions, provide information and offer guidance to teachers regarding the teaching resources in their collection, and support teachers in developing their personal teaching resources. The centres host a complete collection of up-to-date school handbooks and related material covering the educational needs of the schools and institutions they serve. The collection includes a large selection of audio-visual learning materials and multimedia resources. The schools served by the centres have weekly deliveries of materials, which are booked through an online platform or on the phone. The teacher support centre in **Aabenraa** relied on the Centres for Educational Resources present throughout the national territory to disseminate inquiry-based practices in science and mathematics by adapting existing materials to an inquiry-based approach.

Free or low-cost access to resources

Some centres, such as **Paris** , have developed a large collection of inquiry-based science teaching resources which are free of translation fees, provided an agreement of use for non-profit purposes is signed. The teacher support centre in **Belgrade** was started with practically no financial support thanks to the possibility of accessing the French materials for free. Other centres, such as **Bayreuth** , translated a selection of their resources into English and made them available for free download on the Internet.

Creating and promoting teacher learning communities

A qualitative change in teaching practices requires time and depends largely on group effort. A teacher's medium- and long-term willingness and capacity for conscious engagement in transforming their teaching is a key factor to ensure sustainable change.[21] Support, exchange, and co-assessment systems enable teachers to share and compare their practice, thoughts, and individual skills, and thus to consciously engage with others in the transformation of their teaching. And, most importantly, it enables teachers to remain the primary drivers of their own careers. The CSMEs promoted various forms of teacher networking. **Box 6** provides a few examples.

21 Gather Thurler M. and Bronckart, J. (2004). *Transformer l'école.* Brussels: De Boeck.

Box 6. Examples of teacher learning communities created by CSMEs

A teacher networking model

The SINUS project's teacher networking model, under the coordination of **Bayreuth**, inspired the networking model of the Fibonacci Project. The model is based on various forms of close cooperation and networking among teachers at all different levels of the national school system. Cooperation among teachers takes place within the department of a school and also beyond each individual school. Exchanges of ideas and experiences on a state level and supervision and support on an interstate level promote and strengthen cooperation with local implications. In addition, teachers cooperate both in an intra- and inter-disciplinary manner.

Co-teaching

Several forms of co-teaching were set up by the centres, the main objective being always to help teachers gain confidence in teaching inquiry-based science and/or mathematics. In both **Dublin** and **Belfast**, co-teaching was organised between two novice teachers, and in **Tartu** between a novice and an expert teacher. In **Nancy**, students in pre-service teacher education assisted in-service teachers. In **Nantes** and **Saint-Étienne**, students in engineering education assisted in-service teachers. In **Vienna**, students in pre-service teacher education, students in engineering education and in-service teachers set up a triplet of learners.

'Multiplier' teachers

Bayreuth, **Ceske Budejovice**, **Klagenfurt**, **Tartu** and **Trnava** worked with 'multiplier' teachers - expert teachers especially trained to support less experienced teachers in their classrooms. This built powerful learning communities. Learning communities developed within schools at a local or regional level through meetings of all the teachers involved in the project. In **Dublin**, **Augsburg**, and **Belgrade**, teachers who benefited from the CPD provided by the centre acted as multipliers towards some of their colleagues. In **Luxembourg** and in **Zurich**, structured strategies for teachers to share the expertise acquired through their participation in the Fibonacci Project with all the other teachers from their school were developed.

The use of video to reflect on teaching practice

The use of video cameras and of video-based technologies to support collaboration and the exchange of science teaching and learning approaches was instrumental in **Belfast**. Teachers all agreed upon the value of using video, in general, in the classroom for science teaching and learning. It aided both teacher professional development and children's learning. Teachers became more proficient in the use of video cameras with which they claimed they had no prior experience. The use of video also allowed teachers to create new methods of assessment. They could use video clips as records of classroom

practice and could return to the video to re-evaluate or re-address both child learning and their own practice. Teachers specifically identified the video as valuable in allowing them to become reflective practitioners as they could observe their own questioning skills, for example. Teachers could also look back at episodes of child learning and peer interaction and observe events they may have missed during the teaching of the lesson. They could explore more deeply group dynamics as well.

Involving the community

Sustainable change in education takes place when policy makers, researchers and practitioners participate and learn together with integrity, recognising their shared goals of improving learning for all.[22] This implies changing practices at all the different levels of the educational system: classrooms, schools, teacher education institutions, local and national authorities. This is why the centres also worked hard at involving the local community in their activities through the creation of community boards.

Each centre studied its particular context and looked for partners that they could associate with their initiative through local partnerships. Local partners provided many different types of support to the centres, including opening up the schools involved to their environment by linking science and mathematics activities with daily life situations and professional contexts. Local partners were entities of diverse types: academic or municipal authorities, academic or scientific, public or private organisations (universities, museums, research centres or laboratories, enterprises, businesses, industry, associations, cultural centres, etc.), and individuals concerned with science and/or mathematics education.

Each centre developed a community board at a local, regional or sometimes national level, in which all stakeholders were represented, to support and help make the work of the centre sustainable. This allowed resources from inside and outside the local education system to be capitalised on, and tools and strategies developed within the project to be tested at a local level before replicating them on a larger scale. Examples of successful community boards are given in **Box 7**.

22 Hayward, L. and Spencer, E. (2010). The Complexities of Change: formative assessment in Scotland. *Curriculum Journal,* 21(2), pp. 161–177.

Box 7. Examples of community boards supporting the activities of the CSMEs

In **Berlin**, the "TuWaS!" project runs on the basis of an impressive local network involving many different types of partners from the private and public domains who each contributed in a different and creative manner to the success of the Fibonacci Project. Support does not always mean money:

- The co-founder of TuWaS!, the Brandenburg Academy of Science and Humanities, provides knowledge and the support of scientists, as well as a political connection. The academy also hosted two conferences on inquiry-based science education.
- Early on, TuWaS! was supported by the TSB Technologienstiftung Berlin, which funded teaching material for technology topics and provided the salary for the head of the material centre. In addition, it helps to promote TuWaS!.
- The Senate Department of Education, Youth and Science contributes with financial support and knowledge of the school system. They funded the acquisition and adaptation of teaching materials and allow teachers to work part time for TuWaS!, while being paid by the school system.
- TuWaS! Is also supported by companies. For example, GO! EXPRESS & LOGISTICS, which specialises in secure transport of time-critical shipments, delivers and picks up the teaching materials without charge. Companies also helped to buy some of the teaching material.
- The Berlin chapter of the Junior Chamber International provided funds to pay for the professional development of teachers. In addition, young volunteers (*freiwilliges ökologisches Jahr*) work for the project by helping to adapt the material and organise public events.

In **Brussels**, **Dublin**, **Helsinki**, **Leicester**, and **Ljubljana**, the creation of community boards resulted in strong interactive networks of universities, national and local decision-makers (ministries and town councils), academies of science, companies, heads of schools, researchers, teacher educators etc. They all joined together to enhance the quality of teacher support activities and to support their sustainability.

From teacher support to teacher professional development

The Fibonacci project initially proposed to focus its efforts on teacher Continuing Professional Development (CPD). In some of the partner countries, structured CPD programmes were set up and innovative experiences, such as the use of video in CPD, were carried out (see **Box 8**).

Box 8. Examples of structured programmes and innovative experiences in teacher Continuing Professional Development (CPD)

Trnava : a structured, long-term, and credited CPD course

In **Trnava**, the teacher support centre is operated by Trnava University, whose school of education has a long experience in constructivist approaches to science teaching. The educational system is extremely conservative and thus teachers are still trained to implement transmission approaches. To respond to this situation, a long-term, 120-hour, credited CPD course for in-service teachers in inquiry-based science education was designed and successfully implemented.

Dublin : the use of video in teacher CPD

In **Dublin**, members of the Irish Fibonacci professional development team collaborated with the Irish National Teachers Organisation (INTO) (www.into.ie) to develop a national programme for Continuing Professional Development (CPD) on teaching Nature of Science (NoS) in primary schools. As part of this collaboration the INTO co-funded the production of a DVD on teaching NoS through inquiry in primary schools. Two of the Dublin Fibonacci teachers were videoed teaching about different aspects of Nature of Science using innovative inquiry-based approaches. These lessons exemplified some of the innovative methodologies for teaching about NoS in primary classrooms that were developed over the course of the Fibonacci project. It is envisaged that the DVD will be used as a teaching resource for the National CPD programme.

Nevertheless, it soon appeared clear that in most countries, this goal was over-ambitious with respect to the available resources on one hand, and on the other hand, the great diversity of teachers' background, status and working conditions, even in the limited and rather homogeneous fields of science and mathematics. In order to make progress towards a more active pedagogy with this diversity of actors once the main principles – yet to be refined – had been laid down, *teacher support* was the appropriate strategy to follow, and many successful examples of such support were just given above. It would be up to further efforts, either at European or at national scales, to include such a vision of teacher support in a more encompassing strategy of genuinely continuing professional development, supported by explicit detailed quality criteria for improving science and mathematics education. However, the foundations laid down by Fibonacci in its 60 centres, at various depths and strengths of implementation, as well as by other European projects such as S-Team and Primas, will pave the way for this next and much wanted step.

3. Disseminating successful local initiatives among CSMEs

To improve education in general, or more specifically science or mathematics education, the real challenge is to go beyond establishing pilot classes or schools. In pilot studies, carefully chosen and voluntary teachers, coached by researchers or experienced colleagues and fed with quality resources, can easily demonstrate the pertinence of a good pedagogy and achieve outstanding results with their students in the short and longer term. But transferring these good practices and results to other schools, where teacher have limited motivations or rewards, poor support and contacts has proven to be an extremely difficult and slow-moving task. The same is true for the transfer of results or strategies for which research has provided evidence of success. There is an enormous difference between school systems research or industrial organisations where new results or products in the latter can be disseminated very rapidly and efficiently. For the Fibonacci project, then, the feasible goal was to deal with the issue of disseminating successful local initiatives throughout the whole network of partners.

As mentioned in Chapter 1, the Fibonacci CSMEs were of three types. Reference Centres (RCs) were chosen on the basis that they already coordinated a structured and on-going initiative for supporting teachers in taking inquiry-based science and/or mathematics education into the classroom at a local, district, county, or regional level. The RCs' main objective during the three-year life-span of the project was to disseminate their expertise on inquiry pedagogy and on teacher support strategies to two different rings of less experienced centres: 12 Twin Centres 1 (TC1) and 12 Twin Centres 2 (TC2). This dissemination of expertise occurred through a form of close cooperation called 'twinning'. Each RC worked closely with – was 'twinned' with – one TC1 and one TC2 from a different European country.

Clearly, criteria for deciding whether a Centre should be a RC, a TC1 or a TC2 had to be established. The first criterion was 'experience', although this was loosely understood in some cases. But many other parameters were at stake in the choice of a Centre's status, such as: strong willingness on the part of a scientific institution to enter into the project and devote appropriate time and resources; a motivated network of schools; encouragement from education authorities in the country to move ahead. Time was also considered, since in principle, in any Centre, a progression of expertise over time was expected, leading to a capability to coach a TC2, or even a TC3 at the end of the project. This dissemination structure was designed to provide clear and somewhat rigid steps in order to frame the project dissemination strategy and make it easily accessible to its participants. At the same time, it was obviously not possible to establish clear-cut yes/no decisions with sufficiently objective measurement tools.

Just as active learning was a key component of the project's strategy for promoting change in education, both within the classroom and within the local

community, so it was for the dissemination of successful practices. In the following sections we describe how successful local initiatives, such as the ones described in the previous chapter, were disseminated from one centre to the other, consolidating authentic European learning communities.

'Twinning' on the basis of common interests

Partners to be twinned were not chosen randomly. In the first year, RCs organised one-week field visits open to TC1 and TC2. Each TC could visit several RCs. After the initial visits, each TC expressed its twinning preferences. Some twinned mainly on the basis of common linguistic and/or cultural references (e.g. **Saint-Étienne** and **Brussels**); others twinned together mainly because of common research interests (e.g. **Leicester** and **Dublin**); some were motivated by sociological issues (e.g. **Berlin** approached **Çankaya-Ankara** because of the large Turkish population in Berlin). More generally, centres whose priority was maths were twinned together, as were those whose priority was science. Each group of RC-TC1-TC2 can be thought of as a 'cluster'. The configuration of each cluster is provided in **Fig. 3**.

Fig.3. Clusters: partnerships among CSMEs with different levels of expertise.

Reference Centre	Twin Centre 1	Twin Centre 2
Aabenraa	Lisbon	Alicante
Amsterdam	Brussels	Antwerpen
	Bucharest	
Augsburg	Zurich	Kobenhavn
Bayreuth	Sofia	Bad Berka
	Santander	
Berlin	Walferdange-Luxembourg	Köln
		Çankaya-Ankara
Klagenfurt	Helsinki	Glasgow
Leicester	Dublin	Belfast
Ljubljana	Belgrade	Krakow
Nantes	Patras	Nancy
Saint-Étienne	Brussels	Naples
Stockholm	Tartu	Silkeborg
Trnava	Bucharest	Vienna

Learning from each other on the basis of common work plans

Each cluster developed a twinning plan adapted to the local needs and capabilities of each of the centres that composed it and to their common interests. Twinning activities within clusters focused both on the understanding and practice of inquiry pedagogy, and on the strategies to implement it. Learning from peers at all levels of the school system was the key component of twinning. Concretely, this could involve trying out different approaches to teaching and to training teachers, building common teacher networks and learning communities, doing research, developing assessment tools and methods, exchanging ideas on how to introduce inquiry-based approaches in pre-service teacher education, sharing strategies to work collaboratively with other local partners of interest (e.g. scientists, municipalities, science museums, etc.). Field visits where each TC1 and TC2 could visit its respective RC for several days and experience the implementation of inquiry pedagogy at the classroom, school, and local level were organised within each cluster. **Box 9** shows two examples of twinning plans set up within the project which were of great benefit for the three CSMEs involved.

Box 9. Examples of twinning plans: clusters of CSMEs learning from each other

Aabenraa -Lisbon -Alicante : development of a learning unit on sailing ships

At the beginning of the twinning process, this cluster decided to develop and implement learning units in cooperation. Together they searched for common and relevant content that could inspire science and mathematics learning with an inquiry-based approach, and they found that all three countries (Portugal, Spain and Denmark) have long maritime traditions and that the schools in their networks were placed near harbours or coastlines. They therefore decided to develop a unit on sailing ships.

The learning unit was to be used both in in-service courses and by the teachers in their classes. Thus, teachers would face a genuine challenge during the in-service course: inquire into how to design a sailing ship, just as their students would later on. The learning unit was conceived so that teachers could adapt it to their particular classroom context, and also as a reference frame on which teachers could draw in order to develop their own learning units.

The unit on sailing ships was translated into Spanish, Portuguese and Danish and was introduced to teachers in a number of workshops during the four twinning visits. In the three countries, an on-going process to adapt the unit to different age groups, to informal learning environments or for children with special needs was put in place.

The cluster's next aim is to create a community of practice involving teachers from the three countries. A blog was created (http://fibonacci-project-co-operation.blogspot.dk/) so that teachers could share their experience in implementing inquiry-based science and mathematics units in their classes.

Ljubljana -Belgrade -Krakov : didactic material, workshops for in-service teachers, regional networks

As a response to the teachers' requests, cooperation between partners in this cluster was centred mainly around the production of experimental kits and didactic materials and their distribution to teachers. Serbia was particularly active in translating resources for teachers, which benefitted Slovenian teachers as well.

Workshops for in-service teachers and visits to schools and kindergartens involved in the project were organised in all three countries. A workshop on "Fruits and vegetables" was designed by Slovenian teachers, developed further in Poland, and implemented in both countries in a new, richer version.

Cooperation within this cluster exceeded the project's frame: exchanges of young researchers between University of Ljubljana and Jagiellonian University were organised, and a topic group on physics education in South-East Europe was created to raise awareness of the need to implement inquiry in this field. The group's first meeting was held in Ljubljana in September 2012, with attendance of representatives from the three partner countries. This initiative was a continuation of the activities of the Serbian partner, who had already organised five annual South-East European Workshops on Primary Science Education (2005-2010) involving countries in the region that were not involved in the project.

'Tutoring' to support emerging local initiatives

Tutoring was a crucial component of twinning. What was meant by *tutoring* in the Fibonacci project was multifaceted: in a school, a given teacher may receive help from a colleague having more experience on inquiry; a whole school may receive guidance collectively to implement inquiry in all its classes; on a broader scale, a new Centre may be supported by another, more experienced, Centre to begin its first activities or develop them. This last case is the one primarily considered here since it was the one organised in a structured manner by the Fibonacci management.

Tutoring in this sense involved both distance and face-to-face support provided by the experienced partner – the RC – to the less experienced partner – the TC1 or TC2. This form of support began in the second year of the project, once the TCs had already established their own local project. Tutoring activities took several forms: field visits to the RC, adaptation of resources produced by the RC to the context of the TC, organisation of training sessions in the TC with RC trainers, follow-up of the initiatives of the TCs by the RCs.

The Fibonacci project explored many tutoring configurations between CSMEs. There is no question that this process of transfer and adaptation is well received by partners, creates real dissemination of new pedagogical visions and provides a rich and fruitful dialogue across European cultures and pedagogical traditions. On the other hand, the great diversity of tutoring modalities makes it difficult to analyse their individual impact and judge their eventual success.

4. Linking research and practice: transversal topic groups

Scholarly research in science and in mathematics education, carried out in universities and other centres, is remarkably active in a number of countries across Europe. The biennial conferences of the European Science Education Research Association (ESERA) and the European Society for Research in Mathematics Education (ERME) bear witness to the interest in developing a firm evidence base for practice. Several EC projects have focused on supporting this type of research, in the hope it would fuel well-thought changes in schools. On the other side of the Atlantic, the US National Academy of Science as well as the reputed journal *Science* have been constantly advocating the need to foster research and to use evidence proven by research to implement systemic changes in the science education system. Yet, as already mentioned above, the connection between research, no matter how excellent, and actual school practice is usually weak. It was therefore another challenge for the Fibonacci project at least to try to stimulate work on this issue, with the hope it would lead to usable tools at a broad European scale.

Five transversal, or cross-cutting, topics, considered to be critical for a good science and mathematics education, were selected to advance the understanding of inquiry pedagogy and its implementation through collaboration among groups of partners with different levels of expertise in research and development. Each topic group was advised by at least one member of the scientific committee. Topic groups were expected to develop a better understanding of their topic, which involved converging towards common strategies and methodologies. The six topic groups were defined as shown in **Fig. 4.**

Fig. 4. Configuration of the Fibonacci transversal topic groups

Transversal topic	Topic group coordinator	Topic group members
Implementing inquiry in mathematics education	Bayreuth	Augsburg, Sofia, Zurich, Ceske Budejovice
Tools for enhancing inquiry in science education	Paris	Stockholm, Patras, Naples, Saint-Étienne, Trnava
Setting up, developing and expanding a Centre for Science and/or Mathematics Education (CSME)	Berlin	Amsterdam, Bayreuth, Belgrade, Brussels, Glasgow, Klagenfurt, Ljubljana, Nantes, Paris, Trnava,
Integrating science inquiry across the curriculum	Leicester	Amsterdam, Bucharest, Dublin, Nantes, Tartu, Walferdange
Implementing inquiry beyond the school	Helsinki	Berlin, Glasgow, Klagenfurt, Leicester, Lisbon

Each topic group worked towards two objectives: a) to organise a European training session for around 60 participants, aimed at reflecting upon, sharing and disseminating good practices and resources on their particular topic; b) producing a resource on their topic, providing recommendations and good practices based on the three-year experience of implementation. The topic groups were to maintain a constant back-and-forth dialogue between their reflection and classroom work: the topic group's activities were expected to guide the work conducted with the classes in each centre, and the work in the classroom was expected to provide the necessary field work for each topic. Such a working process at European level in education was something of an innovation.

Each topic group worked towards these objectives in a different manner. Three interesting examples of the work developed within the topic groups are presented in this section.

Tools for enhancing inquiry in science education

This topic group was coordinated by **Paris** and brought together partners from **Stockholm**, **Patras**, **Naples**, **Saint-Étienne**, and **Trnava**. Working under the guidance of a member of the project's scientific committee, the group chose the following question: how does scientific inquiry in natural science translate into observable classroom practices? In order to better define the essence of inquiry-based science teaching and learning, the group decided to create a set of indicators which would be descriptive of quality inquiry-based science practice in the classroom.

From these indicators two tools were developed which responded to specific needs identified in the field during the implementation of the project. One was the need to support teachers in the classroom as autonomous learners of inquiry-based science teaching; the other was the need for a reliable tool for diagnosing the specific training needs of each group of teachers, particularly in the least experienced centres.

The *Self-Reflection Tool for Teachers* and the *Diagnostic Tool for CPD Providers* were designed to provide teachers and teacher trainers, respectively, with the means to enhance inquiry in the science classroom through formative assessment of teaching practices. They help teachers and teacher trainers to a better understanding of what is meant by teaching and learning through scientific inquiry, by providing trainers with the means of diagnosing strengths and weaknesses in science teaching practices, and teachers with the means to reflect on their teaching.

In the *Self-Reflection Tool for Teachers*, the indicators are translated into a set of questions that each teacher can ask him/herself about his/her lesson. Explanations and examples taken from real practice are provided for each indicator. In the *Diagnostic Tool for CPD Providers*, the indicators are translated into a set of items of which an external observer can verify the presence or the absence in the classroom. There is a space for collecting qualitative data to support the observations and instructions for using the tools at the different levels of schooling are provided. Specific indicators were developed for use in kindergarten. **Box 10** provides examples of the indicators incorporated in the tools for science and the result of considering the possibility of adapting the tools to inquiry in mathematics.

The process of building these tools involved researchers in science education, science teacher trainers, science teachers, and students from the six Fibonacci CSMEs. The activities leading to development of the tools included a systematic review of bibliography on class observation instruments, regular working meetings of the team members, and three different tests in at least five different classes in each centre involved, at three different stages of development of the tool. During the different rounds of tests, teachers and trainers in each centre would use the tools in the classroom and provide the group with feedback on what needed to be changed to better enhance the comprehension of inquiry pedagogy and its implementation. In parallel, real-life examples of good practice were compiled by the topic group members to illustrate each indicator.

Box 10: Examples of student actions and teacher-student interactions that reflect good implementation of inquiry in the classroom

	Inquiry-based science	Inquiry-based mathematics
Student actions	Students carry out investigations by: • pursuing questions which they have identified as their own, even if introduced by the teacher; • making predictions based on their ideas; • taking part in planning an investigation; • including 'fair testing' in their plan if appropriate; • gathering data using methods and sources appropriate to their inquiry question; • gathering data that enables them to test their predictions;	Students are engaged in problem-solving by: • reformulating problems so that they can be solved with mathematics; • suggesting different ways of solving a problem; • exploring different ways of solving a problem; • using reasoning to decide between ways of solving a problem; • identifying patterns in numbers or the properties of objects;

	• considering their results in relation to the inquiry question; • proposing explanations for their results. Students work with others by: • collaborating when working in groups • engaging in discussions of their investigations and explanations.	• working out for themselves how to solve a problem, not just following an algorithm; • explaining and justifying their solutions using logical argument; • making links between new and previous problems in providing proof for their solution; • using appropriate representations (drawings, numbers or symbols) in working out how to solve a problem. Students work with others by: • collaborating when working in groups; • engaging in discussions of their problems and solutions.
Teacher-student interactions	The teacher builds on students' ideas by: • asking questions requiring students to give their existing ideas; • helping students to formulate their ideas clearly; • providing students with positive feedback on how to review or take their ideas further. The teacher supports students' own investigations by: • encouraging students to ask questions; • helping students to formulate productive (investigable) questions; • encouraging students to make predictions; • involving students in planning investigations; • encouraging students to include fair testing in their planning; • encouraging students to check their results; • encouraging students to keep notes and record results systematically.	The teacher provides opportunities for problem-solving by: • providing problems that can be solved in different ways rather than by using an algorithm; • helping students to reformulate problems so that they can be solved mathematically; • asking questions requiring pupils to think of different ways of solving a problem; • providing feedback that encourages students to try different approaches; • asking students to explain their reasons for choosing the best way of solving a problem. The teacher discusses techniques for solving problems by: • asking students to discuss different ways of solving the problem; • asking students to see if alternative approaches give the same solution; • asking students to think of other problems that can be solved in the same way;

The teacher guides students' analysis and conclusions by:

- asking students to state their conclusions;
- asking students to check that their conclusions fit with their results;
- asking students to compare their conclusions with their predictions;
- asking students to give reasons or explanations for what they found;
- helping students identify possible sources of error;
- helping students identify new or remaining questions;
- encouraging students to reflect on what they have done and found.
- encouraging students to develop strategies or models for solving certain kinds of problems;
- arranging for students to report and discuss their solutions;
- encouraging students to describe the process of arriving at a solution and its proof;
- encouraging students to reflect on what they have done and found.

Interestingly, throughout the different rounds of testing, the tools acquired a life of their own. Although they were initially designed for formative assessment of teaching practices, consecutive trials of the tools in the various countries revealed that they were also useful for other purposes. Local actors in each country used them in different ways according to the specific needs of teachers, teacher trainers, and to the conditions set by their specific educational and political systems. **Box 11** presents a few examples of creative uses of the *Tools for Enhancing Inquiry in Science Education* which emerged from the actors in the field. The examples show that the tools are useful at many levels of the education system (not only inside the classroom) and that they are useful both in the framework of mature and immature educational systems.

In the future, one could think of a further, more systematic dissemination of these tools, or the use of their methodology to build new tools to the benefit of science education in Europe.

Box 11: Creative uses of the Tools for Enhancing Inquiry in Science Education which emerged from their appropriation at a local level

Naples and Patras – Using the tools to trigger the creation of teacher peer learning communities

In the Italian as well as the Greek educational systems, teachers' performance in the classroom is not observed or assessed. Observation or assessment of teachers' performance in class occurs only within the framework of specific training programmes or research projects in didactics. Thus, teachers are rarely familiarised with tools and actions concerning formative assessment of teaching practices.

As a consequence, Italian and Greek classrooms are, in general, closed systems: the presence of a stranger (meaning someone different form the teacher and his or her pupils) in the classroom is rare, particularly in middle school. In **Naples** teachers were, however, willing to use the self-reflection tool and through this became familiar with the indicators and more comfortable with the presence of an observer. One of the most significant consequences of using the *Tools for Enhancing Inquiry* in Italy and in Greece was that closed classrooms became open. The teachers and students no longer perceived the presence of others in the classroom as an unusual event. Teacher trainers and teachers were thus able to observe the usual class interactions that took place in their colleague's classroom, rather than interactions set up by the teacher especially for the occasion of their visit.

The end of isolation among teachers stimulated an atmosphere of reciprocal trust and cooperation. Interactions among teachers from different schools and different grades resulted in collective projects, often using the tools: observing and discussing one another's science lessons, co-teaching, developing and revising teaching and learning resources.

Trnava and Stockholm – Using the tools to support curricular development at a national level

The Slovak National Curriculum team asked the team from the Fibonacci centre in Trnava to cooperate in the process of re-designing the national curriculum for science education in ISCED levels 1 and 2. The *Tools for Enhancing Inquiry in Science Education* provided the basis for discussion with the national curriculum team and thus helped define the main national goals of science education in Slovakia for the preschool, primary, and lower secondary levels.

The Swedish school system has undergone big changes in a short time: a reformed pre-service education for teachers, a new grading system, and a new curriculum of which inquiry-based science education is a central component. The team from the Fibonacci centre in Stockholm demonstrated that the *Tools for Enhancing Inquiry* are aligned and compatible with the new Swedish science curriculum. They thus intend to promote the use of the tools by teachers in the process of implementing the new curriculum. In this manner, the *Diagnostic Tool for CPD Providers* and the *Self-Reflection Tool for Teachers* became, respectively, in the Swedish context, a tool for assessing the implementation of the new science curriculum, and a tool for enhancing the development of the skills needed to teach the new curriculum.

Trnava and Naples – Using the tools to develop and improve pedagogical resources

The Fibonacci team in Trnava engaged in a process of revising the pedagogical resources for their beginner teachers. The frequent use of the *Diagnostic*

Tool for CPD Providers was extremely helpful in this process:

- The tools provided a checklist of the aspects of inquiry that are most important for students of each age group and that needed to be addressed by the pedagogical resources they were reviewing.
- The items describing the teacher's actions helped them to include within the resources indications of suitable actions by teachers to help them guide pupils' work towards authentic inquiry.
- The examples provided by the tool, as well as the class observations made with the tool, allowed the team to develop a large pool of concrete examples from practice that were used for enriching the activities described in the resources.

Italian comprehensive institutes are big educational institutions in which both elementary and middle schools coexist. The comprehensive institutes are particularly interested in what they call 'vertical observation' of classroom practices, meaning observing classes of different grade levels where the same science subject is being taught. Thus, the evolution of the complexity of treatment of the science subject can be discussed and analysed. In the comprehensive institutes where the Tools for Enhancing Inquiry were used, the progressive complexity of treatment of a particular science subject was explored by teachers through observing classes that were working with the same module at different levels of schooling. This experience, added to continuous interaction among teachers of different school levels, triggered also by the use of the tools and by the discussions that followed, allowed teachers to develop an awareness of the specificities of teaching a particular subject in each grade. This awareness led to the development of new pedagogical resources and to the revision of many previously existing ones.

Integrating science inquiry across the curriculum

This topic group was coordinated by **Leicester**, and involved **Amsterdam**, **Bucharest**, **Dublin**, **Nantes**, **Tartu**, and **Walferdange**. It faced the challenge of embedding science investigations with one or more other subjects of the curriculum, such as language acquisition, history, technology, information technologies (ICT), etc.

The group worked on the basis of two principles:

- The priority was to cater for the needs of the teachers and pupils involved in the project; thus, the choice of the subject that would be linked to science depended on the needs of the teachers and pupils in each country. For example, educators in the Netherlands were already developing ICT hardware for improving data logging in science, so they explored ways to use ICT to enhance investigative science.

- Links would be made between different school curriculum areas in order to support learning in each subject; thus, in all of the activities developed, clear learning objectives in each separate subject were set.

Ensuring progression and continuity of skills and knowledge in all subjects is a major challenge. Making good links between science and only one or two subjects initially is important. It takes considerable time for teachers to make effective links between many subjects. One approach is to take one subject as the focus, with other subjects being related to a lesser or greater amount. On the other hand a topic such as 'Water' or 'Environmental issues' can be developed with information from a variety of subjects applied as appropriate. Primary school lessons often more easily allow links to be made than the subject-centred approach in secondary schools.

Research as part of the Pollen Project[23] indicates that there are several stages in moving toward a whole-school cross-curricular approach, which can take several years. Therefore the working group took a developmental approach with the view to enabling teachers to link science with other subjects in a way that teachers are able to plan and assess genuine progressive skills and concept learning in all subjects.

On the basis of this rationale, and of the work done with teachers over the course of the project, the working group developed a progression aimed at full integration of two or more subjects. They built a model to describe and support teachers' progress towards this aim. The majority of activities developed by the group are focused on taking science as the central subject with one or more subjects linked to it in a progressive way. This avoids the risks of a topic approach, where teachers with limited expertise in science only focus on factual elements that they can be sure about or lose sight of the objectives of developing inquiry methods. This is less likely to occur with secondary teachers who have in-depth knowledge in science.

A rich collection of classroom activities was developed and trialled in primary school classrooms. Most of the activities explore links between science and mathematics, but others explore links between science inquiry and technology/engineering, science inquiry and literacy, and science inquiry and history and geography. **Box 12** provides two examples of activities linking maths and science.

23 Jarvis, T. (2009). Promoting creative science cross-curricular work through an in-service programme. *SSR*, March 2009, 90, 332-?-

Box 12. Examples of activities linking maths and science, in primary and secondary schools

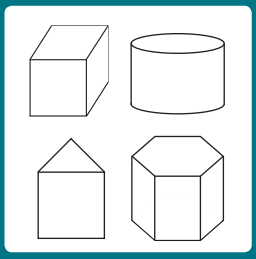
Investigating which shapes make a strong bridge

Finding ways of making a strong bridge using one sheet of A4 paper to span a gap of about 15 cm between two blocks and carry a weight of 100g helped teachers to identify triangles and cylinders for strong shapes.

Following the results of their investigations, the teachers were helped to understand why cylinder shapes were so good. A horizontal card will bend (or compress) easily if its opposite sides are pushed together horizontally. Once the card starts to bend it will buckle upward or downwards. If the card is folded at right angles along its length, it can no longer bend easily. A tube provides more strength than flat paper as it resists bending in any direction. Bundles of tubes are even stronger.

Investigating the shape of pillars for bridges

Classes of 12 year olds investigated the use of different materials and shape for bridge pillars. They tried different shapes and heights. They discussed the properties of the 3D shapes and why they thought some resisted a downward force more than others.



Enclosures for different animals

Secondary mathematics and science teachers planned separate activities for their 12 year old pupils which enabled them to link mathematics and science, despite the fact that they are unable to teach the pupils together. The school timetable requires pupils to study 'area' in mathematics lessons early in the year. In these sessions, pupils will be given different animals to research with regard to their habitat needs. They will then investigate the area of suitable enclosures using a fixed length of fencing. The pupils will make posters of their findings. Half of the posters will be displayed in the mathematics rooms and half in the science rooms.

Later in the term the science curriculum requires pupils to study 'variations in habitat'. The display of posters will be used to recap what has already been done before further studies and investigations are carried out on animal variation. The work will also be recorded in poster form. Again half the posters will be displayed in the mathematics rooms and half in the science laboratories.

The two secondary teachers say that work on the Fibonacci project and this process of shared planning has altered their perceptions and practice. They hope that the posters will influence other staff in their respective departments.

Modelling animal enclosures for a farm

A class of 13 year olds were given information about the area needs of different animals and fixed totals of area and finances available for fencing. They were asked to investigate different ways they could populate the farm with animals.

The work of this topic group showed that there are real gains to be had by overtly linking investigative science with other subjects being taught at school:

- children are taught knowledge and skills in a holistic way in a context that is meaningful to them and more memorable;
- learning is easier because it is less disjointed and more relevant;
- children are enabled to use similar skills in different subjects. This helps them to understand and use these skills;
- children can appreciate the contexts of their learning and so are more able to apply learning to their lives and develop a wider interest in the world;
- language of the context is the same in each subject, making it easier for pupils who speak the home language as their second language to understand skills and concepts being covered;
- mathematics becomes more understandable as it has a real context.

This is particularly important in a society where pupils access so much digital information which is not separated into convenient subjects.

This group's work also showed that mathematics, language and technology are natural partners with science and improve communication of science ideas. They are therefore central to a cross-disciplinary approach. There are also good possibilities for incorporating science investigations with other subjects such as history, geography and sport. The latter demonstrate that science is and has been important in society.

There are real gains to be made in developing pupils' skills, knowledge and cognition in science and related subjects. However there is a risk of links being superficial. It is essential not to lose sight of the aim both to focus on developing inquiry methods and to improve pupils' learning. It is important to have clear learning objectives in each separate subject in activities developed. Consequently teachers need good and sustained in-service training to develop their pedagogical and conceptual skills in all subjects concerned. This takes time and needs the active support of the schools' leaders.

This successful Fibonacci effort for creating relations between subjects across the curriculum is a step in the direction of a much needed interdisciplinarity and knowledge integration in school practice.

Setting up, developing and expanding a CSME

This topic group, coordinated by **Berlin**, involved nine other Fibonacci partners (**Amsterdam**, **Bayreuth**, **Belgrade**, **Brussels**, **Glasgow**, **Klagenfurt**, **Ljubljana**, **Nantes**, and **Trnava**), the Fibonacci European Coordination (**Paris**), the four members of the Fibonacci scientific committee, and the project's external evaluator (Educonsult). This large team collaborated closely in creating a resource to support entities interested in setting up, developing and expanding a CSME. The main strategic areas of activity of a CSME were defined, general and specific objectives were defined for each area, and research-based orientations were given. Finally, successful initiatives from the project partners were analysed and lessons from practice were drawn.

This topic group produced a booklet that provides an organisational framework with strategies, recommendations, and lessons learned through implementation during the three-year life-span of the project in seven strategic areas. It provides a clear reference framework and a set of functional strategies for developing a CSME, leaving a considerable liberty for bottom-up initiatives, capable of responding to specific contextual needs and of making intelligent use of local resources, to see the light.

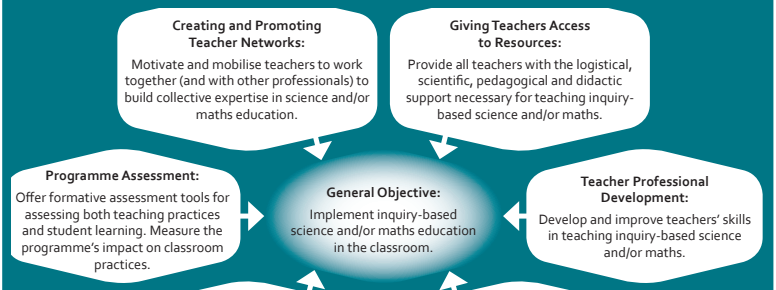
Box 13 describes the strategic work areas developed in the booklet. Each strategic area includes a list of specific objectives which may be more relevant in some contexts than in others: including them or not within the programme is

a decision for each CSME to take according to local needs and to the resources it can mobilise. For each specific objective, some theoretical background is provided. A list of key actions that can be undertaken to reach each objective is provided. Lessons from practice are also provided where relevant, aimed at preventing actors from making the most current beginner mistakes that others have made before them.

In the second part, the booklet provides examples of how these strategies and recommendations were successfully implemented and adapted to specific cultural, political, and educational contexts through nine selected profiles from centres involved in the Fibonacci Project. An overview of the strengths of the other centres that took part in the project is also provided, thus giving the reader the opportunity to identify and contact potential collaborators.

The creation of networked centres, following the strategy outlined in this booklet, is not necessarily the ultimate or only solution to guarantee a proper dissemination of new ideas and best practices and to answer the challenge of large scale changes in science education, as mentioned above. But the Fibonacci experience shows that such centres are clearly part of an efficient set-up towards reaching this long term and complex goal.

Box 13. Strategic work areas of a Centre for Science and/or Mathematics Education.



3 Outcomes of Fibonacci

The Fibonacci network : 62 partners from 33 European countries

By the end of the project in early 2013, the Fibonacci network included 62 CSMEs, 5,908 teachers, and their 306,618 pupils (see **TABLE 2**). This huge network spreads across 33 different European countries. As we will see in the following sections, these actors are motivated to teach and learn science and mathematics through inquiry and constitute a consolidated learning community.

TABLE 2: NUMBER OF CSMES, TEACHERS AND PUPILS INVOLVED IN FIBONACCI AT THE END OF THE PROJECT

	Number of CSMEs	Number of teachers	Number of pupils
REFERENCE CENTRES	12	4,109	270,703
TWIN CENTRES 1	12	1,164	19,681
TWIN CENTRES 2	13	635	16,234
TWIN CENTRES 3	25		
TOTAL	62	5,908	306,318

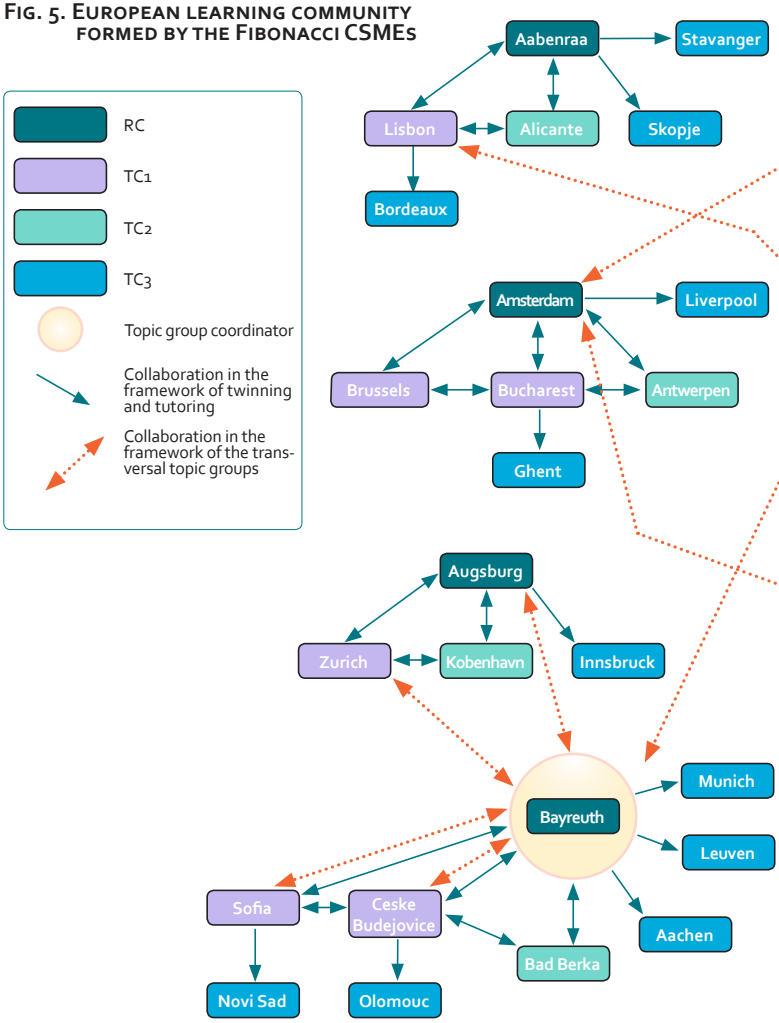
A European learning community

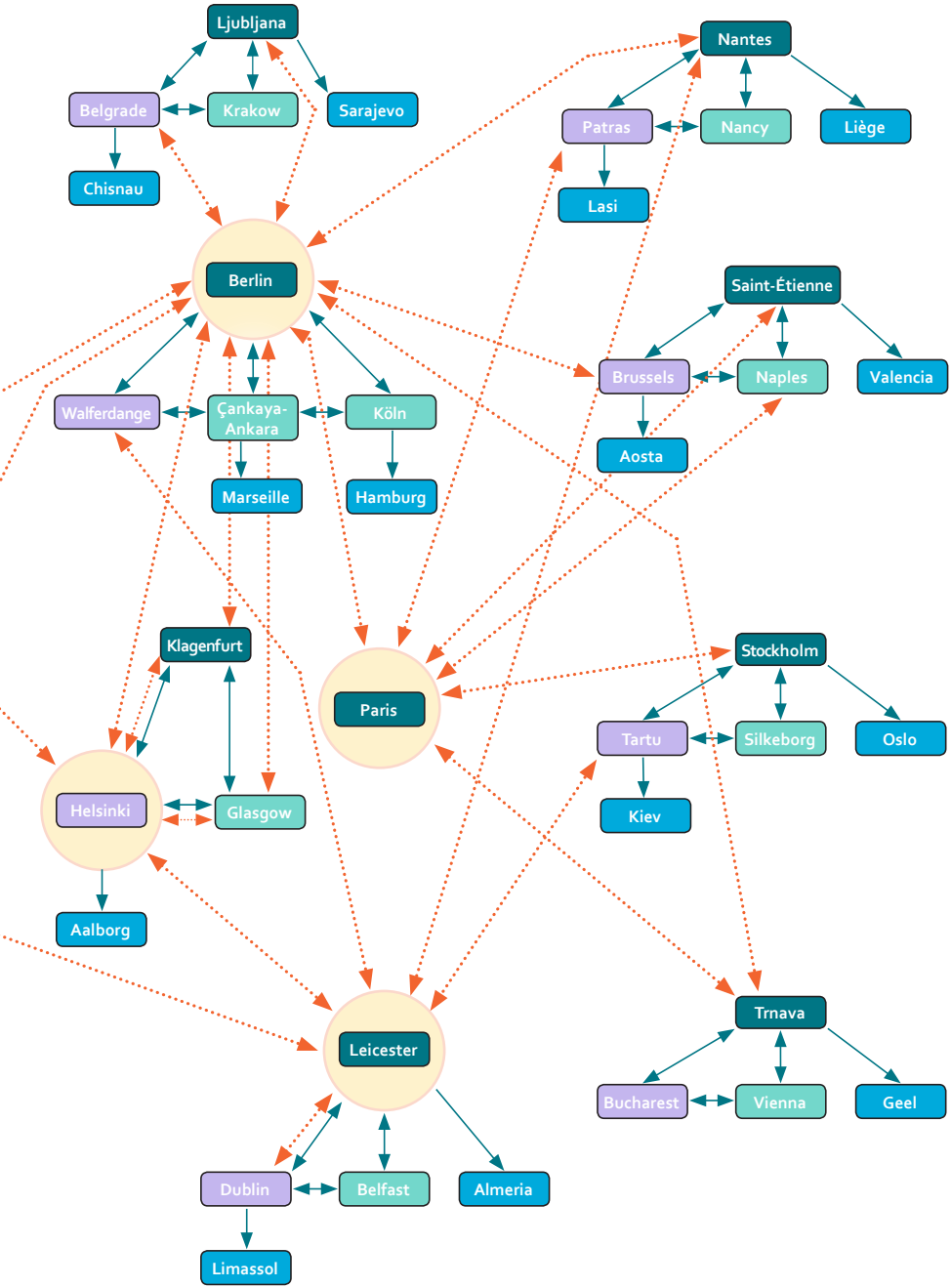
By the end of the project, nearly all TC1s had acquired the necessary expertise and experience to become RCs, which means that a teacher support system capable of insuring dissemination activities towards another centre was up and running.

According to Educonsult, the project's external evaluator, all centres increased their expertise and knowledge in inquiry-based education and enlarged their network or learning community. For most TCs, twinning led to an acceleration of the process of acquiring expertise, as well as gaining access to recent research on inquiry-based teaching and learning. At the same time, most RCs learned how to better promote and implement inquiry-based education and to disseminate the outcomes of what the RC had already accomplished. Twinning was a win-win situation for both partners. Furthermore, most centres integrated inquiry pedagogy into pre-service teacher education by developing either optional or compulsory modules for future teachers, thus ensuring continuity between pre-service and in-service education. This integration enhanced the sustainability of the educational innovation. The level of satisfaction of Fibonacci partners with twinning is such that 80% of the Fibonacci centres have declared their willingness to continue collaborating with their twinned partners beyond the formal end of the project in 2013.

These successes of twinning and tutoring show that, as a result of the Fibonacci Project, a broad European learning community in science education has been built. Of course, given the above mentioned heterogeneity of Centres and without precise measurements of their actual practices, it is not possible to demonstrate quantitatively how engaged, how deep, how broad or how sustainable this community built by Fibonacci is. We nevertheless have converging and strong indications that, for its members, science education will never be what it was before Fibonacci. **Fig. 5** describes this learning community.

Fig. 5. European learning community formed by the Fibonacci CSMEs




Ljubljana
Belgrade
Krakow
Sarajevo
Chisnau
Nantes
Patras
Nancy
Liège
Lasi
Berlin
Saint-Étienne
Brussels
Naples
Valencia
Walferdange
Çankaya-Ankara
Köln
Aosta
Marseille
Hamburg
Klagenfurt
Stockholm
Paris
Tartu
Silkeborg
Oslo
Helsinki
Glasgow
Kiev
Aalborg
Trnava
Leicester
Bucharest
Vienna
Geel
Dublin
Belfast
Almeria
Limassol

A significant rise in teachers' confidence

The key persons for innovations in school are the teachers. Confidence in teaching was taken as an indicator of the impact of the Fibonacci Project. The issue of confidence when teaching science or mathematics with inquiry is critical, but has to be analysed differently for primary and secondary school teachers. For the former, lack of confidence in themselves often inhibits their teaching of science, even when it is prescribed by the curriculum. For the latter, when facing an inquiry lesson, even when they have good training in mathematics or science, lack of confidence in accepting a new teaching approach can frustrate the effort. There is significant research evidence that when teachers do not feel confident in a particular curricular area, they tend to teach as little as possible of that subject, or in a very standard manner, and compensate by teaching more in high confidence areas.[24]

The impact of the Fibonacci Project on teachers was assessed by Educonsult through questionnaires addressed to the teachers involved in the project which were delivered at the beginning and at the end of the project. The questionnaires requested information on the teachers' personal characteristics (gender, age, experience with inquiry pedagogy, level of teaching, type of school) and asked them to assess their confidence in teaching in general and in teaching mathematics, science and technology in particular.

Teachers declared that their involvement in the project has enhanced their professional knowledge and skills on how to teach through inquiry. Eighty percent or more of the teachers indicated that the activities they were involved in during the project stimulated their motivation for teaching and that they increased their knowledge of how to help students work in a scientific manner. Three-quarters of the teachers also indicated that they are now more confident in teaching mathematics or science and their knowledge and skills for implementing inquiry pedagogy have increased.

Box 14 provides quotes from teachers who participated in the project. Looking in greater detail at these teachers' statements, it appears that the strongest conclusions relate to science teaching in primary schools. The secondary school systems and its teachers throughout Europe have more diversity; the target of Fibonacci was less specific there with, for example, more focus on mathematics in high schools and on science in middle and primary schools.

The evaluation carried by Educonsult, within the limited budget allocated, undoubtedly suffers from some weaknesses. More detailed quality criteria are needed to analyse the achievements of Fibonacci using questions consistent with the inquiry-based pedagogy recommended by the project. Enthusiasm

24 Harlen et al., 1995. *Confidence and Understanding in Teaching Science and Technology in Primary Schools. Edinburgh: SCRE.*

and confidence of teachers are necessary ingredients to implement inquiry, and it is good that Fibonacci has reached this goal. Nevertheless, they are not sufficient ingredients, and in the future more precise measurement tools of their practice should be implemented.

Box 14. Statements from teachers who participated in the project

'Overall, I have gained a lot professionally from my involvement in Fibonacci. I am now a more confident and effective science teacher. I found it very interesting interacting with teachers from other schools. I also greatly value the opportunities we were given to travel abroad and experience Fibonacci at work cross-culturally. Having said that, the whole project was much more demanding of my time and energy than I would have expected when I signed up for it. On a further positive note, I feel that my students have really enjoyed their science experience during the past two years. Inquiry has been a very positive force in my teaching and in my pupils' learning.'

'The Fibonacci Project has had a really positive effect on my teaching of science. I am really enthusiastic about teaching science and teach it much more frequently. Honestly, science was one of my least favourite subjects to teach and now it is one of my favourites.'

'For the first time in more than twenty years I felt that my eyes were sparkling again while I was teaching. The course has really given me a boost!'

A collection of resources for understanding inquiry and implementing it in the classroom

The outcome of the work of the scientific committee and of the topic groups is a collection of resources: *Resources for Implementing Inquiry in Science and Mathematics at School*. They support the effective implementation of inquiry pedagogy in science and mathematics throughout Europe. They are all initially written in English, but some of them have been translated into other languages before the end of the project (see **Fig. 6**). The collection includes two groups of resources:

1. The *Background Resources*, developed by the scientific committee, define the general principles of inquiry pedagogy and of its implementation in science and mathematics education. They are addressed to teachers and teacher educators and tackle the pedagogical, didactical, and epistemological implications of such an approach.
2. The *Companion Resources* are based on the collaborative work of the five topic groups of partners. They provide practical information, classroom ideas and activities, and evaluation tools for the effective implementation of inquiry pedagogy in science and mathematics in schools. These booklets have undergone a strict editorial process supervised by the project's scientific committee. There are cross-references among them and to the *Background Resources* where pertinent.

Together, the *Background* and *Companion Resources* convey a clear and shareable definition of inquiry pedagogy and define a common inquiry-based proposal for science and mathematics education, notwithstanding the important epistemological differences between these two disciplines. Protected by a Creative Commons licence, they are available for free download on the Fibonacci website, in the Resources section. They may be reproduced, distributed, and even modified (i.e. translated or complemented), for non-profit purposes, as long as credit is given concerning the original document, and any new document is licensed under the same conditions. Many reprints, translations and adaptations of the resources by individual Fibonacci partners are already (end 2013) under way. Translations and adaptations will be made available on the Fibonacci website.

Fig. 6. The Fibonacci *Resources for Implementing Inquiry in Science and Mathematics at School*

Available for free download at www.fibonacci-project.eu, in the *Resources* section.

Leverage and spin-offs

Initially, the Fibonacci Project was scheduled to involve 2,500 teachers and 45,000 pupils. As mentioned above, by the end of the project 5,908 teachers and 306,618 students had been involved. The impact as to coverage is thus much larger than initially planned. This was possible because several CSMEs managed to secure additional funding from their national, regional or local authorities. For example, the mathematics section of the project, led by **Bayreuth**, triggered extensive interest in Bavaria. In **Trnava** and in **Naples**, the CSMEs had an important national impact (see **Box 15**).

In many of the countries in which centres were created, Fibonacci led to fruitful discussions and exchanges about science education, thus increasing awareness

that inquiry pedagogy should become part of pre-service teacher education. **Amsterdam**, for example, published a report targeting this goal.[25]

Twelve of the Fibonacci partners, from eleven different European countries, decided in 2012 to pursue their cooperation. They proposed to create a Comenius multilateral network, focused on introducing inquiry pedagogy in education for sustainable development. The goal is to jointly develop new tools and provide teacher support in this area, capitalising on the networks and resources already established by Fibonacci. This Comenius project was accepted by the European Commission in July 2013, and is set to begin in January 2014.

25 Van den Berg et al. (2013). *Making IBSE durable through pre-service teacher education*. Knowledge Centre for Teaching and Education, Hogeschool van Amsterdam, Netherlands.

Box 15. Naples and Trnava: examples of CSMEs that gained national impact.

Naples - The birth of SID, an Italian inquiry-based science education programme

Naples joined the Fibonacci Project as a TC2, and it twinned with **Saint-Étienne**. Naples' participation in the project gave birth, in 2011, to a programme called *Scientiam Inquirendo Discere* – SID, whose long-term objective is to disseminate inquiry-based science education practices at a national level throughout Italy, in close collaboration with the French *La main à la pâte* programme (to which Saint-Étienne belongs). Throughout the lifespan of the Fibonacci Project, SID set up five new teacher support centres in Naples, Venice, Pisa, Rome, and Milan, as well as a system of national and international cooperation. The programme is acknowledged by the national ministry of education (MIUR), it benefits from the support of the national academy of natural science (Accademia Nazionale dei Lincei), and the experience in research in didactics of ANISN (National Association of Natural Science Teachers). The programme has influence through a multi-level governance structure including a national consulting and operative body in Rome, set up at the science academy, as well as local centres configured as didactical research centres with a scientific and a didactic coordination, and administered in the schools by teacher trainers belonging to the centre's coordination team. Every centre organises an annual plan of activities which includes training teacher educators, training experimental teachers, interventions in cooperation with scientists, promotion of discussion groups both on didactical and scientific subjects among teachers with different levels of expertise, in-class support and observation of classroom practices.

Trnava – The knock-on effects of Fibonacci on national policies in Slovakia

On the basis of a revised version of the national curriculum for primary science education, publishing houses together with authors of primary science textbooks released textbooks including items of inquiry teaching. Textbooks approved by the Ministry of Education are the main source of teaching content for most primary teachers in Slovakia. This will allow the introduction of inquiry learning into formal science education on a large scale in the country.

Further, representatives of the National Institute of Pedagogy started to become interested in inquiry learning. As a consequence, some members of the local Fibonacci team integrated the national team for the revision and continuous development of the national science curriculum for levels ISCED 0, 1 and 2. This will ensure the sustainable application of inquiry into formal science education in Slovakia not only now, but also in the future.

Finally, during the Fibonacci project, Trnava successfully asked the Ministry of Education for accreditation of two in-service inquiry-based science education courses (one for 25 credits lasting 110 hours and another for 8 credits, lasting 25 hours). Both of them will be open for new teachers every year to support sustainable development of the ideas introduced by the Fibonacci project.

4 Towards Europe 2020

The success of the Fibonacci Project, despite the methodological precautions mentioned above, calls for a EU extension of the effort in science education which, in the future, ought to be more systemic and less of a pilot programme. Better strategic partnerships for science and mathematics education, including industry, must be created. For the period 2014-2020, a new six-year planning period opens for the European Union, the Commission and the Parliament, with the aim of *building a smart, sustainable and inclusive Europe*. This strategy, focused on a better economy in which science and scientific education clearly have a major role to play in fostering innovation in European societies, is designated *Europe 2020*.

It is important not to raise unrealistic expectations that changing pedagogy from transmission to inquiry-based will alone improve students' interest in and attitudes towards science and mathematics. There are many factors both within and outside school that impact students' interests and dispositions. But the approach to teaching and learning that they experience is certainly one of them, and since is it one that we can change with actions focused on schools and teachers, it is well worth the effort, particularly as it has other benefits deriving from students' understanding of science and mathematics.

The implementation of the Fibonacci Project has revealed that a number of challenges still lie ahead for inquiry-based science and mathematics education in Europe.

Challenges for inquiry pedagogy in science and mathematics

- There is more to be found out about effective approaches in inquiry pedagogy at different stages of science education, from pre-school to middle and high school where there are substantial changes of subject content, maturity of students, boys and girls behaviors, teachers' profile, assessment methods, not to mention national practices and educational traditions.
- In the case of mathematics education, although problem-based learning is a long-standing pedagogical tradition, inquiry is a very recent term in the field. The introduction of this term and the dialogue it implies with science education is a new issue, filled with unexplored challenges.
- The Fibonacci Project was one of the first large-scale European projects to have explored the bridges between inquiry in science and inquiry in mathematics by taking into account the nature of each of these disciplines. Whether or not this exploration has interesting perspectives in practice can only be determined through implementation and further research.

- It is urgent to develop tools for the assessment of student learning in inquiry pedagogy, both in science and mathematics.[26]

Challenges for large-scale dissemination throughout Europe

- There is a need to develop means of ensuring that the findings, however modest, of projects such as Fibonacci are effectively used to inform practice in schools across the European Union. Further, the support needed to maintain partnerships between education systems and universities in different European countries after and outside projects such as this has to be considered.
- Fibonacci has made a contribution to effective methods of spreading new pedagogy, but further research on scaling-up changes in education in Europe is badly needed.
- Providing organised teacher support, as implemented in Fibonacci, has clearly been effective in giving teachers confidence, stimulating exchanges among them, and offering resources for an inquiry pedagogy with the ultimate aim of improving students' learning of science and mathematics. It remains nevertheless far from a structured continuing professional development for teachers (CPD). A strategic plan for CPD in mathematics and science should be created with opportunities adapted to the various situations of primary, middle or high school, specialised or unspecialised teachers. Future CPD programmes should provide for a non-university form of accreditation as a means of rewarding those teachers who want to pursue accreditation without having to leave the classroom. These programmes will necessarily have to fit with national requirements, but the universality of science, as well as the universality of the learning process one observes among youngsters, suggests, in line with Fibonacci experience, that strategies and exchanges across Europe could be extremely fruitful.
- According to the analysis of the project's external evaluators, creating a European network of Reference Centres would be helpful to fully exploit what has been achieved through the Fibonacci project, to maintain and further develop the quality of the work of the centres, to support the sustainability of their activities and to enhance networking between them.

26 The EU has begun to respond to this need by funding two FP7 assessment projects – SAILS (Strategies for Assessment of Inquiry Learning in Science) and ASSIST–ME (Assess Inquiry in Science, Technology and Mathematics Education). In addition, the Science Education Programme of the Global Network of Science Academies (IAP) published in 2013 a guide on the same subject titled "Assessment & Inquiry-Based Science Education: Issues in Policy and Practice" (free download at http://www.interacademies.net/File.aspx?id=21245), recognised worldwide as of capital importance for the development of inquiry-based science education

A final message

It is fortunate that the financial recommendations of the 'Rocard Report' were followed by the Commission, and the impulse it gave to initiatives such as the Fibonacci Project was critical. Yet, there is another important recommendation of the Report which has not yet been implemented in 2013 : the establishment of a high level Advisory Committee which, in parallel with the European Research Council which deals with research, would stimulate a strategy in science and mathematics education from primary school upward and contribute to a long term European vision, to be submitted to the Council of Ministers of Education[27]. The quality of mathematics and science education in primary and secondary schools is so rooted in the bright scientific history of Europe and so critical for its future that every effort should be made to remedy a far from optimal situation, such as that which we observe at the beginning of this 21st century. The European Union has all the necessary talents and tools to rebuild a strong educational system in science, able to communicate to every young person a taste for science, an understanding of its place in culture, and a vision of professional careers.

27 The installation, early 2013, of a new «Advisory Council for Science and Technology» attached to the Commission President Manuel Barroso and chaired by his Scientific Adviser Anne Glover, may be an important step in that direction.

Consortium members