The Fibonacci Project

DISSEMINATING INQUIRY-BASED SCIENCE AND MATHEMATICS EDUCATION IN EUROPE

BACKGROUND RESOURCES FOR IMPLEMENTING INQUIRY IN SCIENCE AND MATHEMATICS AT SCHOOL

Inquiry in Science Education

WITH THE SUPPORT OF

EUROPEAN COMMISSION

SEVENTH FRAMEWORK PROGRAMME

Resources for Implementing Inquiry in Science and Mathematics at School

The Fibonacci Project (2010-2013) aimed at a large dissemination of inquiry-based science education and inquiry-based mathematics education throughout the European Union. The project partners created and trialled a common approach to inquiry-based teaching and learning in science and mathematics and a dissemination process involving 12 Reference Centres and 24 Twin Centres throughout Europe which took account of local contexts.

This booklet is part of the *Resources for Implementing Inquiry in Science and in Mathematics at School*. These Resources include two sets of complementary booklets developed during the Fibonacci Project:

1) Background Resources

The *Background Resources* were written by the members of the Fibonacci Scientific Committee. They define the general principles of inquiry-based science education and inquiry-based mathematics education and of their implementation. They include the following booklets:

- 1.1 Learning through Inquiry
- 1.2 Inquiry in Science Education
- 1.3 Inquiry in Mathematics Education

2) Companion Resources

The *Companion Resources* provide practical information, instructional ideas and activities, and assessment tools for the effective implementation of an inquiry-based approach in science and mathematics at school. They are based on the three-year experiences of five groups of Fibonacci partners who focused on different aspects of implementation. The *Companion Resources* summarise the lessons learned in the process and, where relevant, provide a number of recommendations for the different actors concerned with science and mathematics education (teachers, teacher educators, school directives, deciders, policy makers...). They include the following booklets:

- 2.1 Tools for Enhancing Inquiry in Science Education
- 2.2 Implementing Inquiry in Mathematics Education
- 2.3 Setting up, Developing and Expanding a Centre for Science and/or Mathematics Education
- 2.4 Integrating Science Inquiry across the Curriculum
- 2.5 Implementing Inquiry beyond the School

Reference may be made within this booklet to the other *Resource* booklets. All the booklets are available, free of charge, on the Fibonacci website, within the *Resources* section.

Editorial coordinator : Susana Borda Carulla

Fibonacci Scientific Committee : Michèle Artigue, Peter Baptist, Justin Dillon, David Jasmin, Wynne Harlen, Pierre Léna

WWW.FIBONACCI-PROJECT.EU

Fibonacci Project, December 2012

This project has received funding from the European Union's Seventh Framework Programme

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Inquiry in Science Education

Wynne HARLEN

Member of the Fibonacci Scientific Committee

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1. Introduction

A key aim of science education is students' *understanding*, not merely being able to repeat facts and memorised knowledge. Inquiry has an important role in developing understanding since it involves learners making sense through their own action, thinking and reasoning of different aspects of the world around. Inquiry-based science education promotes both conceptual understanding and the development of capabilities widely recognised as needed by everyone in the twenty-first century – such as critical thinking, collaborative working, consideration of alternatives, effective communication. Rather than a superficial learning process in which motivation is based on the satisfaction of being rewarded, motivation when learning through inquiry comes from the satisfaction of having made sense of something that was not previously understood.

Justification for these claims becomes clear as we consider in Sections 2 and 3 of this booklet the nature of scientific inquiry as practised by scientists and by students, and how learning takes place through inquiry. In Section 4 we discuss in more detail what students gain from inquiry and why it is such an important way of learning. The focus shifts to teaching through inquiry in Section 5, where we discuss eight key aspects of inquiry-based pedagogy, offering some practical suggestions for each one. Section 6 very briefly points out the support that is available for teachers as they implement scientific inquiry. We end with a conclusion which lists the directions of change in pedagogy which may be needed for implementation of inquiry-based teaching and learning.

We should be clear at the start that inquiry is only one of a range of ways of learning and teaching involved in science education. But it is a particularly important one, being based on research and modern views of how students learn and the importance of progressively developing understanding of phenomena in the world around as experience increases.

2. The nature of scientific inquiry

Inquiry is a term used both within education and in daily life to refer to seeking knowledge or information by asking questions. It is sometimes equated with research, investigation, or 'search for truth'. Within education, inquiry can take place in several subject domains, such as history, geography, the arts, as well as science, mathematics and technology, when questions are raised, evidence is gathered and possible explanations are considered. In each area different kinds of knowledge and understanding emerge. What distinguishes *scientific inquiry* is that it leads to knowledge and understanding of the natural and made world around through methods which depend on the collection and use of evidence[1].

Scientific inquiry starts from the exploration of an object, event or phenomenon that raises questions, leading to speculation about what might explain it, informed by what is already known about it. The speculations (hypotheses) lead to predictions and investigations, which may or may not involve experimentation, to test them. By 'testing' we mean comparing what is predicted by some theory or model with what has been found or observed. This often involves experimenting, but may also involve collecting data by observation, such as in the case of the relative movement of Moon and planets. What will always be involved, though, is the collection of data and analysis and interpretation of the data to provide evidence in relation to the questions raised and hypotheses being tested. After testing various predictions and checking and repeating data collection where possible, conclusions may be drawn which add to understanding of the event or object under study. Throughout this process scientists will be keeping careful records, consulting others' work and presenting and discussing their ideas and procedures with others –at conferences and through journals– and sharing their findings. The work of Darwin illustrates aspects of this process. By studying the detail of particular organisms, he developed possible explanations for the differences he found, then he tested these hypotheses by further observations

1 The discussion of the nature of science is elaborated in the Fibonacci Background Booklet *Learning through Inquiry*, available at www.fibonacci-project.eu, within the *Resources* section.

and experiments. Darwin was driven by curiosity and the desire to answer questions, just as were the science educators in Box 1.

It is worth pointing out some key characteristics of scientific inquiry as it is done by scientists, to bear in mind when considering whether inquiry carried out by students is truly scientific inquiry[2].

Scientists conducting inquiry:

- do not know the answer to the question or problem being studied;
- consider the inquiry to be important and engaging and are excited about trying to find an answer;
- know enough about the topic of the inquiry to have some ideas about what might be the explanation or answer;
- know how to conduct an inquiry scientifically;
- use data as the basis for evidence but do not necessarily collect new data.

A similar discussion of the nature of inquiry in mathematics can be found in the companion Guideline *Inquiry-Based Mathematics Education*.

Box 1

In a lecture entitled ‘Wait, wait! Don’t tell me!’, Marc St. John[3] spoke about the excitement of finding an answer to questions for oneself. He recounts how he and another eminent science educator, Hubert Dyasi, came to wonder whether, if you shine a light on a candle flame, the flame will make a shadow. They held different ideas about this, both based on experience of related phenomena. With the candle in front of them, one said “That flame is nothing but light, and I am sure that light passes right through light. Therefore the flashlight should shine right through the flame and not make a shadow”. The other said, “No, I can’t see through the flame. The flame must be blocking light on the other side. There must be a shadow”.

Without spoiling the story by telling what happened when, of course, they shone the flashlight onto the flame, the point to note here is that *they did not know the answer*. The author concludes: “inquiry requires that you know that you don’t know something that you feel you should know. And, in that process, you get this engagement, this excitement, and energy, just as we did here”.

2 A similar discussion of the nature of inquiry in mathematics can be found in the Fibonacci Background Booklet *Inquiry in Mathematics Education*, available at www.fibonacci-project.eu, within the *Resources* section.

3 St. John, M. (1998). “Wait, wait! Don’t tell me!” The Anatomy and Politics of Inquiry. The 1988 Catherine Molony Memorial Lecture. City College Workshop Centre, New York.

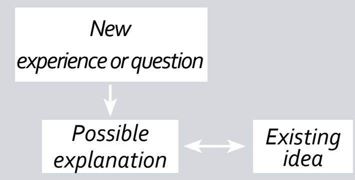
3. Learning science through inquiry

In the process just described, scientists are learning, adding to their own and others’ knowledge about the world around. Students learning through inquiry are also adding to their knowledge and understanding of science and in science and at the same time they are learning to inquire: learning how to learn.

3.1 A model of learning science through inquiry

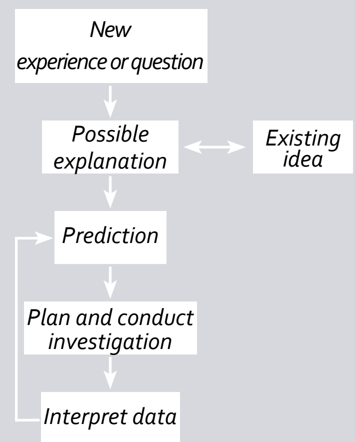
The process begins by trying to make sense of a phenomenon, or answer a question, about why something behaves in a certain way or takes the form it does. Initial exploration reveals features that recall previous ideas leading to possible explanations (“I think it might be...” “I’ve seen something like this when...” “It’s a bit like...”). There might be several ideas from previous experience that could be relevant and through discussion one of these is chosen as giving the possible explanation or hypothesis to be tried (Figure 1)

Figure 1



Working scientifically, students then proceed to see how useful the chosen existing idea is by making a prediction based on the hypothesis, because only if ideas have predictive power are they valid. To test the prediction new data about the phenomenon or problem are gathered, then analysed and the outcome used as evidence to compare with the predicted result. This is the ‘prediction > plan and conduct investigation > interpret data’ sequence in Figure 2. More than one prediction and test is desirable and so this sequence may be repeated several times.

Figure 2

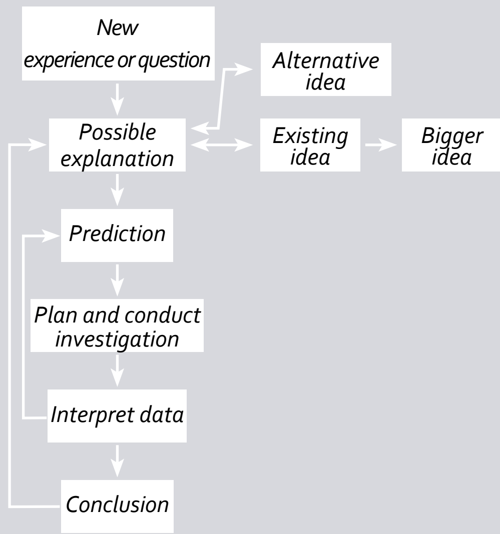


From these results a tentative conclusion can be drawn about the initial idea. If it gives a good explanation then the existing idea is not only confirmed, but becomes more powerful –‘bigger’– because it then explains a wider range of phenomena. Even if it doesn’t ‘work’ and an alternative idea has to be tried (one of the alternative ideas in Figure 3), the experience has helped to refine the idea, so knowing that the existing idea does not fit is also useful.

This is the process of building understanding through collecting evidence to test possible explanations and the ideas behind them in a scientific manner, which we describe as learning through scientific inquiry.

Modelling the building of understanding in this way offers a view of how smaller ideas (ones which apply to particular observations or experiences) are progressively developed into big ideas (ones that apply to a range of related objects or phenomena). In doing so, it is important to acknowledge, and to start from, the ideas the students already have, for if these are just put aside the students will still hold onto them because these are the ones that they worked out for themselves and make sense to them. They must be given opportunities to see for themselves which ideas are more consistent with evidence. Also, since ability to question, describe, propose, communicate and conclude through language are involved in this process, it follows that inquiry is closely tied to the development and use of appropriate language.

Figure 3



3.2 The role of inquiry skills

However, the development of understanding in this way depends on the processes involved in making predictions and gathering evidence to test them being carried out in a scientific way. Students, particularly young children, do not instinctively use these processes rigorously. They may not test their initial ideas and when they do they may not do it scientifically. Their existing ideas may influence what is 'observed' through focusing on certain observations that confirm their ideas, leaving out of account those that might challenge them. Students sometimes make 'predictions' that they already know to be true and so are not a test of an idea. In setting up a test they may not control variables that should be kept constant. When these things happen, the ideas that emerge are not consistent with evidence: hence the importance of helping students to develop the skills needed in scientific investigation.

Even when children are capable of using these processes in some circumstances, they do not necessarily do so in others. Indeed, there is plenty of evidence that knowledge of the subject matter under study has a strong influence on how these processes are carried out. To some extent this is obvious, since it might be expected that familiarity influences recognition of what variables are likely to be relevant in an investigation. So even a young child might be able to plan a 'fair test' of how well balls bounce on different surfaces but not be able to plan a fair test of something much less familiar to them, such as how the concentration of a liquid affects its osmotic pressure. In other words, the way in which the processes are carried out crucially influences the ideas that emerge. But at the same time the content can influence the use of process. This complex interaction of process and content means that conceptual understanding and skills of investigation and reasoning need to be developed together.

4. Why learning science through inquiry is important

There are several reasons why learning through scientific inquiry should be part of the experience of all students. It will not be the only form of pedagogy that they encounter in their science education, for there are some things to be learned such as skills of using equipment, names, conventions and symbols which are best taught directly. Also, in the secondary school, students need to be introduced to complex and abstract ideas that are not accessible to them through inquiry. However, the experience of developing understanding through their own thinking and reasoning has many benefits for students which are not obtained in other ways. These include:

- enjoyment and satisfaction in finding out for themselves something that they want to know;
- seeing for themselves what works rather than just being told;
- satisfying and at the same time stimulating curiosity about the world around them;
- developing progressively more powerful ideas about the world around;
- developing the skills needed in scientific inquiry through participation in it;
- realising that learning science involves discussion and working with and learning from others, directly or through written source;
- understanding science as the result of human endeavour.

If these benefits are to be realised in practice there are implications for the experiences that they need and thus for teachers. We consider these in general here and then in more detail in the following section.

Enjoyment and satisfaction in finding out for themselves something that they want to know

Enjoyment is a strong motivation for doing anything including learning science. If there is to be genuine engagement, then students must see the question or problem as a real one, to which they do not know the answer and want to find it out. Practical work in school laboratories or classrooms often concerns questions that are given by the teachers and are not interesting to students. This is sometimes because the answer seems obvious (they probably know that the car starting higher up the slope will go further than the one starting lower) and sometimes because it hasn't been set in a context which allows the students to make the questions their own (why should they be concerned about what affects the swing of a pendulum?). Box 2 illustrates how different approaches influence the extent to which students take ownership of the question.

Box 2

Imagine that a teacher is leading a unit on measurement of time. One of the time keeping tools the students are investigating is the hourglass. The students are challenged to think about how hourglasses are made and what factors (variables) are important in controlling the time it takes for the sand to fall through. A second important outcome is that the students realise they can only achieve useable results if they adjust one factor or variable at a time (keeping the others constant). How the teacher sets the stage for the investigation can influence the sense of ownership and the understanding of the students.

a) One teacher might show the students an hourglass, state the factors that the time required for the sand to run out depends on, tell the students that they are going to be able to see this for themselves, and then give them directions for carrying out the experiments. This method is akin to the traditional, lecture-type teaching, in which the teacher gives the results. This is very different from inquiry-based teaching.

b) Another teacher might have the students observe, draw and describe an hourglass set on the desk, ask them what factors determine how long it takes for the sand to run out, and then proceed to discuss the investigation they will do. This question may be meaningful to some of the students, but probably not for those with little experience of hourglasses.

c) Yet another teacher might set out at least three hourglasses, one of which takes much more time than the others to run out of sand. The students, divided into groups, observe, draw and describe the hourglasses they have in front of them, noticing the distinctive features of each and that the sand does not finish falling at the same time in the different hourglasses. Many are likely to wonder why. This is one example of setting the stage for an investigation in which students are likely to take more ownership of the problem[4].

Seeing for themselves what works rather than just being told

Direct experience is necessary so that students see for themselves whether the ideas and explanations that they bring to a new phenomenon 'work'. We know from masses of research[5] that students come to school with ideas, theories, and explanations of how the world works. These ideas may be scientifically correct or not, but they work for the student. Words alone have little power to change these ideas. It is not enough to tell them or to show them that the results of an experiment prove that their idea can't be true.

4 From Saltiel, E. (2006). Methodological Guide. Inquiry-Based Science Education: Applying it in the Classroom. Pollen Project. Available at http://www.pollen-europa.net/?page=%2Bag%2BXQhDnho%3D&action=uNvczPt%2FKio%3D&lg=lyjj7CJGIPU%3D.

5 For example, see http://www.nuffieldfoundation.org/primary-science-and-space.

Students need to come to this realisation themselves just as they have done outside of school. They need to raise questions, test their ideas about what might be the answer, and draw new conclusions, as exemplified in Box 3.

Box 3

In one classroom described in an article by Konicek and Watson[6], two students were talking about heat and temperature and insisted that their 'warm' sweaters and jackets created the heat that made them warm. They carried out a number of experiments with different materials and thermometers wrapped up inside them, but kept insisting that cold must be getting inside and thus the thermometers were not showing any rise in temperature. It was only after a number of experiments and discussions that most students were willing to let go of their original idea.

Such experience may lead, in the long term, to an understanding of the difference between temperature and heat, two abstractions which often are not distinguished in common usage.

Developing progressively more powerful ideas about the world around

One of the overall goals of science education is to enable students to understand some fundamental or 'big' ideas *of* science – and *about* science – that enable them to lead physically and emotionally healthy and rewarding lives and to make informed decisions as responsible future citizens. These big ideas are highly abstract, independent of context, and not the ideas that students can develop through their own inquiries, which are just the starting points towards these goals. Progress from small to bigger ideas depends on the expansion of experience, development of powers of reasoning, and access to different ways of explaining phenomena and relationships. For instance, moving from an idea of why a particular object floats in water, to the big idea of floating that applies to all objects and all fluids, is a large step, which involves seeing patterns in what happens in very different situations.

The path of progress will therefore vary from student to student according to their opportunities both in and out of school. A precise description of progress, applying to all students, is thus unrealistic. But there are common trends that enable a broad description of what might be expected at various points as students move from pre-school through primary and secondary education. These trends include:

- increasing ability to consider that properties may be explained by features that are not directly observable;
- greater recognition that several factors need to be understood if phenomena are to be explained;
- greater quantification of observations, using mathematics to refine relationships and deepen understanding;
- more effective use of physical, mental, and mathematical models[7].

At all stages students' ideas have to be taken as the starting point for progress; there is no one path of progress for all students and all ideas. The ways of addressing students' own ideas and moving from smaller to bigger

6 Kopnicek, R. and Watson, B. (1990). Teaching for Conceptual Change : Confronting Children's Experience. Phi Delta Kappan, 71, 680-685.

7 From Harlen, W. (2010). *Principles and Big Ideas of Science Education*. Hatfield, Herts: Association for Science Education. Available from www.ase.org.uk in English, from www.fondation-lamap.org in French, and from www.innovec.org.mx in Spanish.

ones vary according to the nature of the idea and the experiences which lead to it. For instance, in some cases students have different ideas about the same phenomenon encountered in different contexts and need some help in linking them and seeing that the more scientific idea applies to both (Box 4). Often their ideas are based on limited experience, and their experience has to be extended in order to lead to a more widely applicable idea. Again, students' reasoning is likely to be limited: either they take notice only of evidence confirming their idea, or they retain an idea, despite contrary evidence, for lack of an alternative that makes sense, and which needs to be introduced.

Box 4

A small aquarium tank half full of water was left uncovered to explore some six-year-old children's ideas about evaporation. Among the children's suggestions for why the water level went down was that mice were drinking from their tank at night. Asked how they would test this, the children suggested leaving some cheese beside the tank. Evidence of nibbling of the cheese, they said, would be a test of their idea about the participation of the mice. The teacher helped them to carry out this test. Untouched cheese but continued loss of water forced them to consider an alternative explanation. The teacher helped them to do so by turning the children's thinking to water disappearing from clothes put out to dry on a washing line, asking the children to think about the similarities between the two events. Since they acknowledged that the water from the clothes went into the air, she helped them link this to the loss of water from the about tank and consider whether the same thing could be happening. Further experimenting with dishes of water, covered and uncovered, provided evidence for the children to see that this was a possible explanation – although only after the demise of the hypothesis about mice, since this, too, would have explained the difference!

As a result of testing the idea drawn from other experience, the children developed a notion of how water can be taken into the air that was just a little broader than their initial one. The development of the bigger idea of water changing state into vapour would require further experience of the different forms of matter[8].

Developing the skills needed in scientific inquiry through participation in it

There are many important science inquiry skills such as asking questions, making predictions, designing investigations, analysing data, and supporting claims with evidence. Of these many skills, one of the most important is observing closely and determining what it is important to observe. Students observe and react to many things and they ignore many things, just as adults do. When trying to understand something, it is important that they look closely at specific characteristics of a phenomenon. Otherwise their observations –the data they collect– may be irrelevant to the question or problem raised. In other words, in order to "see" something, you need to know what you are trying to see and what you are looking for (see Box 5).

Often, students are simply told to observe something closely. But what does that mean? What are they looking for? Many will need guidance. For example, being asked to 'observe two flowers' is very different from being asked to 'look at these flowers and note the similarities and differences'. For students to learn to use the skills of science inquiry, they need guidance such as this and often need to be taught the skills directly.

8 From Harlen, W. (2006). *Teaching, Learning and Assessing Science 5-12* (4th edition). London: Sage.

Box 5

In a class studying air, the teacher was hoping to show a group of students that a candle under a jar would burn for longer the larger the jar. He had three jars of different size and explained to the students how to put them over three burning candles all at the same time. It worked well. So when the teacher asked the students what differences they saw between the jars he was disappointed in their reply. "*Nothing. It was same for all of them. All the candles went out*." None of the students had observed what the teacher hoped they would notice – the difference in time of burning in each jar, a difference quite large enough to be noticed by someone looking for it. The teacher might easily have assumed that because the difference was observable it therefore had been observed. Perhaps some discussion of what might influence the time for the candles to go out would have focused their observation on the differences that were there to be observed.[9]

Realising that learning science involves discussion and working with and from others, directly or through written sources

In order for direct experience to lead to understanding, students need to think about their hands-on work, discuss it thoughtfully with others, and write about it. Students' ideas and theories, predictions, ideas for designing an investigation, conclusions, all need to be made explicit, and shared and debated orally and in writing. In many cases, it is by trying to convey one's viewpoint to others that one finds answers to one's questions. Who has not come up against a problem and, in trying to write it or explain it to someone else, found part of the solution? The reverse is true as well. It is often in trying to explain something that one's lack of understanding becomes clear. For many students (and adults as well) talking comes first. Once something has been said, it can be written.

Scientific inquiry includes the use of data from secondary sources such as books, experts, and the Internet. As noted earlier, students cannot find all that they need to know through direct action (see Box 6). However, in inquiry the ways in which secondary sources are used is different from more traditional uses. They are used in the service of students' explorations, not a substitute for them. Direct investigation often leads to questions that cannot be answered directly or conclusions that are only tentative. That is the moment to turn to other sources. Not only do students find in this way the information they want, but they learn how and where to look and the need to consider secondary sources with a critical eye.

Box 6

In one classroom students were working on a unit about the human body. On that day, the subject was bones. During the previous session, each student drew the bones, as they imagined them, on a body outline. In this session the students were divided into groups of four and drew on a new body outline the bones that all of the group's members agreed existed, and in another colour those on which disagreement remained. During the ensuing class discussion, the areas of disagreement remaining were identified. One question concerned how many bones there are in the spine, one or many? Other questions arose as well and the students went to find answers in their books, knowing full well what they were looking for[10].

Understanding science as the result of human endeavour

Science investigation is rarely an individual activity: it is a collaborative one. True, there are examples of individual study, such as the naturalists, who spend time alone studying the behaviour of a certain species, as did Darwin, but they too must submit their work to a larger audience for discussion and debate. When students work together in small groups or teams, they are working as many scientists do: sharing ideas, debating, and thinking about what they need to do and how to do it. Because they are working as a team, they need to work together to get organised, assign responsibilities, and communicate effectively with one another. They also need to prepare to share their ideas when the whole class gets together. This is an important opportunity to learn to present and defend ideas; listen to, question and debate the ideas of others; and realise that there can be different ways to approach the same problem.

Finding things out for themselves is a means to understanding how scientific ideas are created and initiates appreciation of the nature of scientific activity, of the power and the limitations of science. This is important because students need to know, not just the scientific ideas that help us to explain the world around, but also how these ideas are derived. Without knowing how ideas were developed, learning science would require blind acceptance of many ideas about the natural world that run counter to common sense.

Learning about the people and history of science supports appreciation of science as an important human endeavour in which reliable knowledge is built up through the systematic collection of data and use of evidence. Students can learn, for instance, the story of how Pasteur used his knowledge of microbes in studying the perseveration of wine[11], or in a different cultural background, the story of understanding light propagation by Al Haitham[12].

5. Key aspects of teaching science through inquiry

All teaching in science will involve teachers in a range of pedagogical decisions. These include: decisions about classroom organisation; encouraging collaborative work; the kinds of questions to ask; using students' prior experiences; developing students' knowledge, understanding and skills; organising different kinds of discussions; how students will record and report their work; what kind of feedback to give to students on their work; and using assessment to help learning. Enabling students to learn through inquiry may require a shift in how these aspects of teaching are carried out. In this section we consider what is required in relation to these aspects of teaching and make some practical suggestions about how to implement them in practice.

5.1 Organizing the classroom

If students are to engage in hands-on investigations in groups, the rooms where science takes place must be set up to make this possible. Groups need space to work together, access to materials, and places to put work in progress. Some primary and most secondary schools have a science room where all this is possible. Where this is not the case, it may be necessary to move tables and chairs around, and use small boxes or trays for materials and on-going work.

In primary schools, the equipment used for experimentation is generally common and inexpensive, ranging from seeds and soil to string and paper clips. There are some items that are more expensive, such as batteries, measuring instruments, prisms, stop clocks, and a binocular microscope. In some subjects, such as astronomy or earth science, experimentation with actual objects isn't possible and there may be a need for models, charts, or other media. Regardless of the nature of the materials, it is important that they are accessible to students as they need them and that they take some of the responsibility for their care.

9 From Harlen, W. (ed.) (2001). *Primary Science: Taking the Plunge* (2nd Edition). Portsmouth NH: Heinemann. This example is also quoted in the video document for teacher training published by La main à la pâte (French, English, Spanish): *Learning Science and Technology in School* (2010), available at http://dvdsciences.fondation-lamap.org/#.

10 From Saltiel, E. (2006). *Methodological Guide. Inquiry-Based Science Education: Applying it in the Classroom*. Pollen Project. Available at http://www.pollen-europa.net/?page=%2Bag%2BXQhDnho%3D&action=uNvczPt%2FKio%3D&lg=lyjj7CJGIPU%3D

11 See Jasmin, D. (2004). *L'Europe des découvertes*. Paris: Le Pommier. Available in English as *European Discoveries*, at http://www.fondation-lamap.org/en/page/9620/european-discoveries-teachers-section.

12 See Djebbar, A., De Hosson, C. & Jasmin, D. (2009). *Les découvertes en pays d'Islam*. Paris : Le Pommier. Available in English as *Discoveries in the Islamic World*, at http://www.fondation-lamap.org/page/9534/laction-internationale-ressources.

Practical suggestions

- Space for materials, work in progress, and displays can be an issue in many classrooms. There are no easy solutions, but in some places teachers can work together to find common areas for storing materials and displaying students' work.
- It is not always easy to find the equipment and materials needed if they do not exist in the school, but there are other sources to try. In some settings items can be borrowed from resource centres or scientists. In others the teacher can try to gather some of the equipment and materials by calling upon the students and parents. In still other situations, local organizations and businesses may be able to help.

5.2 Encouraging collaborative work

Inquiry in learning science means students working together, trying things out, coming up with and sharing new and tentative ideas, and learning from what doesn't work. This is unlikely to happen in an environment where students worry about having the correct answer. Nor can it happen where the interaction among students is not respectful: certain students always take the lead, or boys rather than girls are considered the hands-on students. There needs to be a classroom culture in which all students feel comfortable and all have the opportunity to participate in all aspects of the science work – the hands-on, thinking, talking and writing.

Practical suggestions

- Establishing collaborative groups is not easy. It is a learning process in itself for the student and for the teacher. It is advisable to teach explicitly some of the behaviours needed such as how to disagree respectfully, listen to one another, share materials, and give everyone time to speak. There are a number of specific approaches to cooperative learning that may be useful to consider here including assigning roles (e.g. recorder, coordinator, materials manager, speaker) that change frequently[13].
- If students are reluctant to share ideas unless they are sure they are right, it can help to talk explicitly with them about the importance of everyone's ideas and the value of discussing something from many points of view.
- Groups work best if they are small (four is ideal) and clear about their goals. With some materials, when students are learning to work together, or with younger students, the group of four may actually work as two pairs for the hands-on part.

5.3 Asking productive questions

The questions that teachers ask –whether of the full group, small group or individual– play a very important role in teaching through inquiry. Good questions move the work forward; less good questions are unlikely to do so. As Jos Elstgeest put it: "*A good question is a stimulating question, which is an invitation to a closer look, a new experiment or a fresh exercise... I would like to call such questions 'productive' questions because they stimulate 'productive activity*'."[14] Productive questions encourage students to start thinking about their own questions and how to find answers. They may move a group of students to a deeper level of work and reasoning. Unproductive questions often call for a short verbal response and nothing more. ("*What is this called?*" "*What is a battery?*" "*Did the current move from the positive pole to the negative pole*?"). This does not mean that the teacher should never ask such questions, but they are not the same as the carefully crafted questions that lead students into inquiry.

13 See Kagan S. (1993). *Cooperative Learning*. San Juan Capistrano, CA: Kagan Cooperative Learning.

14 Elstgeest, J. (2001). The right question at the right time. In W. Harlen, *Primary Science : Taking the Plunge* (2nd edition). Portsmouth NH : Heinmann.

Practical suggestions

- When beginning an inquiry or starting a new investigation, the leading question is very important. It must be specific enough to set students off in the desired direction, but it must be open enough that they are challenged by it. For example: "*What do you think is important to know in order to light a bulb with a battery and a bulb?*" is different from "*What makes a bulb light?*", and "*What parts does a plant develop as it grows?*" is less productive than "*How do you think we might describe the life cycle of a plant?*"
- Questions asked while students are working can also be more or less productive. Questions such as the following encourage new work and thought: "*What differences and similarities do you see between these objects (or situations)?*", "*Why do you think these results are different from the other experiment?*", "*In your opinion, what would happen if... ?*", "*How do you think you could go about...*", "*How might you explain?*", "*How can we be sure?*", "*How many... ?*", "*What is the temperature?*". The "*in your opinion*" and "*do you think*" are very important here as they do not ask the student for the right answer, rather they ask what the student is thinking.
- Giving students a few minutes to think about a question or letting them talk with a partner can also encourage students who are reluctant to speak.

5.4 Using students' prior experiences and ideas

Students generally have many ideas about the phenomena they encounter in their day-to-day lives. Quite often such ideas are incomplete or contradict the scientific explanations of the phenomena being studied, as noted earlier in Section 3.1 and illustrated in Box 3. It is important to keep in mind that some of these ideas may be quite reasonable but are constructed on limited experience and knowledge. It is important to give students an opportunity to share their ideas and how they know what they know. Doing so helps them to become clear about what their conceptions are at the moment and on what they are based. At the same time, hearing the ideas of others, whether they are accurate or not, may open up new ways of thinking.

Communicating and discussing their ideas is just one way of helping students to more scientific explanations. Teachers who are familiar with the research on some of the more common naïve conceptions, who listen to students and take their ideas seriously, will recognise what experience is needed to enable students to consider different ideas. It may be that their idea is based on limited experience, in which case extending the range of experience is the appropriate action. Or it may be that linking to an idea used in explaining a related phenomenon (as in Box 4) will help.

Teachers are often unclear about how, when or whether to introduce the scientific view of things. It is right to be cautious since there is a risk that students will not understand an explanation and will be left with the impression that science is too difficult for them. However, there are times when introducing the scientific idea is just what is needed to advance the students' ideas. When doing so it is important for the teacher to provide some scaffolding, that is, some support while students try using the new idea to see if it provides a satisfactory explanation. For example, students who interpret the apparent movement of the Sun round the Earth may be introduced to an alternative way of explaining this using a model. The teacher's role is to offer the alternative idea in a way that allows the students to try it out to see it if makes sense to them, not to impose it as the 'right answer'. This can ensure that students have the opportunity to see that other ideas than their own may explain a phenomenon more effectively.

Practical suggestions

- Research has identified some common naïve conceptions students of different ages hold. Knowing about these is helpful in allowing some anticipation of what might emerge and to have some activities available to broaden students' experiences. Examples of research findings can be found on the Internet[15].
- Where possible, a unit or new investigation should begin with a discussion about what students think about the topic in order to give the teacher a first glimpse of their experiences, ideas, and ways of reasoning about a phenomenon. More will be revealed in what the students say and do as they engage in their investigations.
- In order for students to express their initial ideas, they need to feel that it is OK to be wrong and that their ideas will be respected, that it is safe to share their thinking and that they will not be considered foolish for being 'wrong'. Several teaching strategies can be used to encourage this sharing orally and/or in writing. These include: accepting students' ideas without judging them even if they are 'incorrect'; asking students how they know ("*What makes you think that? How did you find that out?*"); and asking for more detail so that they feel that their ideas are valued.
- When students share ideas that are correct, it is important simply to accept these along with all the others. Any sign that these are correct may inhibit other students from continuing to share their ideas.
- It can take time for students to let go of their original ideas that work for them. They have accumulated a lot of experience out of school, which is unlikely to be outweighed by one classroom investigation. They are likely to need a variety of experiences and discussion before they are willing to question and modify their ideas.

5.5 Helping students to develop and use inquiry skills

The importance of developing and using inquiry skills was underlined earlier in Section 3.2. Developing scientific understanding in the way discussed earlier (modelled in Figures 1 -3 on Section 3.1)) depends on observing, predicting, planning, collecting and interpreting data rigorously. Attention to the development of these skills is therefore important if inquiry is to be scientific and to lead to scientific understanding.

For the development of all inquiry skills, the most important factors are that students have the opportunities to use them, and to discuss their use. In many science lessons students do not have the experience of observing closely at first hand, or of deciding how to conduct an investigation, or of gathering data for themselves and using it to answer their questions. This may be because these things are done for them by the teacher or the text book or they are following step-by-step instructions which give them no room for thinking about what they are doing and why.

The skills most often absent from students' experience in text-based science lessons –and indeed in some lessons where there is 'hands-on' but not 'minds-on'– are those concerned with planning and conducting investigations and those concerned with interpreting data and drawing conclusions. These are key skills in scientific inquiry and for this reason deserve a little more consideration.

Planning is a complex skill requiring experience and ability to think through to the possible outcomes of actions. Young children may not be able to do this. Characteristically they think whilst they are doing, but they can be introduced to planning by simply asking "*tell me what you are going to do*". Older primary school children can be helped by a series of questions, in the case of an experimental investigation, to decide what factor is to be changed, what will be measured or observed, and what must not be changed for a 'fair' test. If the investigation is observational rather than experimental, students need to discuss what would be important to observe,

15 For example, see http://www.nuffieldfoundation.org/primary-science-and-space.

how they will observe, and how they will collect their data. Secondary school students should, if they have had this experience earlier, be able to plan a controlled experiment without the scaffold of questions. If not, at whatever age, they will need plenty of opportunity to do their own planning, to make mistakes and to learn from them.

Whilst students are carrying out investigations and gathering data they extend their experiences and add to their knowledge. However, without discussion, reflection and review, this knowledge can be patchy, fragile and even fleeting. This essential stage of **interpreting and drawing conclusions** is often neglected, perhaps because time runs out and teachers feel pressure to get on to the next topic. All investigations should begin with a clear idea of the problem or question under investigation; all should end with some statement of how the findings relate to the problem or question. Thus following the collection of data it is important for each working group to develop some tentative conclusions:

- What claims or propositions can they make that are supported by the evidence gathered?
- What tentative explanations might they come to?
- How do these compare with their starting assumptions and predictions?

Groups should then report their answers to these questions in a whole class debate. Where several groups have been working on the same investigation, differences among groups need to be discussed, which may lead to recognising the need to repeat some parts of the investigation. All this takes time but it should be recognised that if this time is not given to completing an investigation, a great deal of the value of the activity is likely to be lost. Fewer activities from which more is learned is preferable to fragmented learning from many.

Practical suggestions

- In planning, provide some structure to help students think through the various steps they should take. In an experimental activity this can be a series of questions about variables to be changed, controlled and measured. In an observational activity, it can be an overview of the situation in which observations will be made.
- Anticipate the equipment that groups may need in their plan, show them what is available and tell them to make their selection from this when they have decided what to do.
- Review the steps of their investigations after completion and consider how, with hindsight, the plan could have been improved, to be kept in mind for future planning.
- In the discussion of conclusions it may be useful to distinguish between claims supported by the evidence the students gathered (e.g. "water evaporates more quickly from the containers with a larger surface area") and explanations which are attempts to explain why or generalise from the specific claims (e.g. "I think this is because the water evaporates from the surface and therefore more can escape at the same time if there is more surface").
- As an alternative to whole class reporting, groups can share their data on a class chart or post their claims and evidence around the room. In this way the discussion can start with the key questions rather than group reports.
- Help students to understand that evidence and scientific reasoning determine the conclusions, not the number of proponents for a given opinion or the arguments of the strongest students.
- A brief written summary of what has been learned (or needs to be re-examined) is often a good way to end the session.

5.6 Holding discussions

Discussion among students takes place throughout the inquiry process in pairs, in small groups and as a whole class. Most students, if they are engaged in interesting small group work, will talk with one another with minimal input from the teacher other than an occasional reminder to stay on track. Effective large group discussions are more difficult and students must learn new skills and habits, as must the teacher. These are not the more traditional discussions where the teacher asks a question, selects a student to respond and, depending on the response, validates it or not before moving on to the next question or student. Instead these discussions are characterised by interaction among students as they add to what someone has said, ask a question, present a different idea, or challenge a peer. The time required to learn the skills required is well spent.

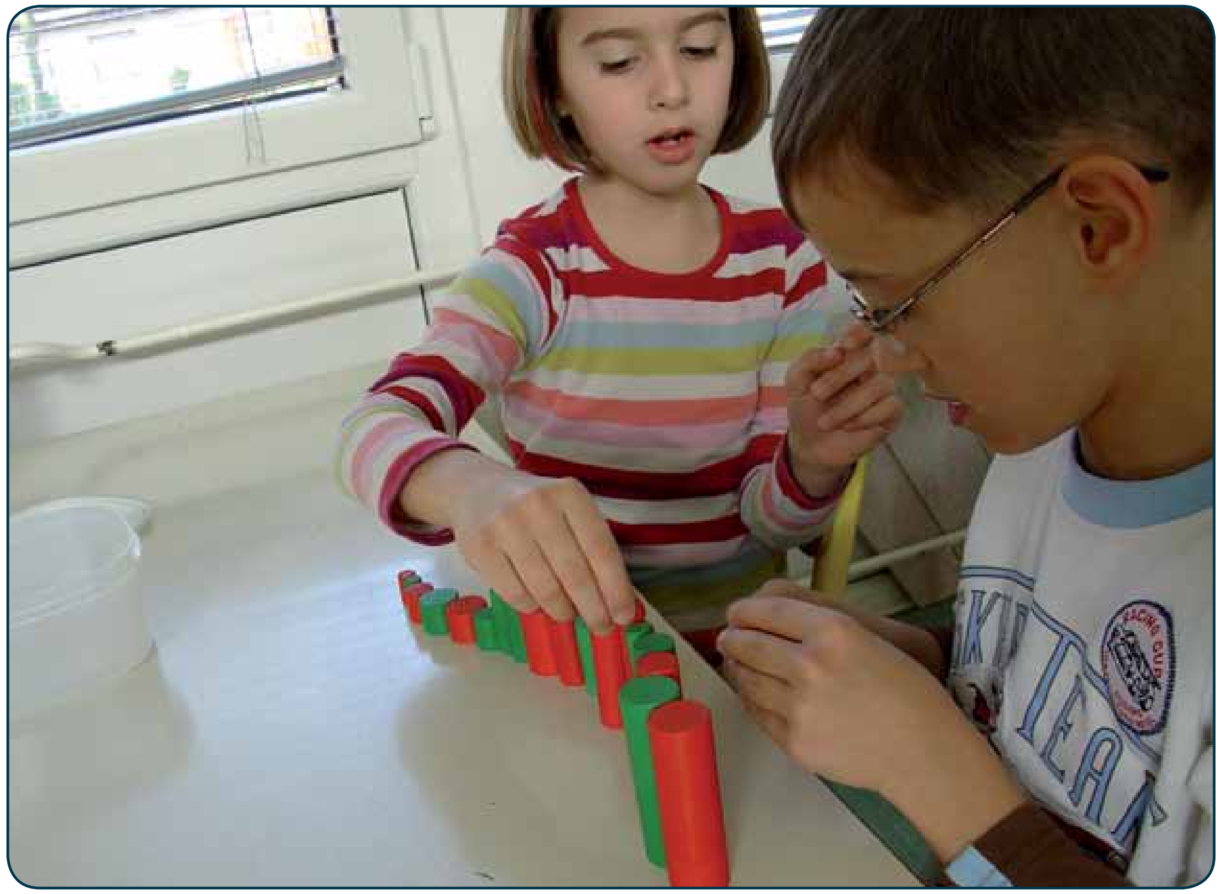
When they take place, these whole group discussions have an important role. They give the students the opportunity to make their own ideas explicit. Students also hear and discuss the ideas of others, realise that the ideas of others may be rooted in facts they had not considered (such as in the example in Box 6) and, in certain cases, decide as a group to review and possibly revise their investigations. Eventually, this is the time and place where conclusions are confirmed and agreed upon.

Practical suggestions

- Seating students so that each student can see every other student –such as arranging seats in a circle– makes discussion easier and can make an enormous difference in the dynamics of a discussion. This can be impossible in some rooms where there is little space or fixed benches, but moving seats and asking students to turn and face each other can be done in most places.
- Slowing down the pace of the discussion helps many students to join in. This can be done by asking students to think for just a few seconds before responding to a question. Waiting 5-10 seconds when there is a silence also can deepen a discussion or release new ideas.
- It can be hard at first to stop students from addressing the teacher and talk with one another instead. Being direct and explicit may help: "Talk back to Louis, not to me", "Amahl had a question for you", "Marie, what did you think about what Sam said?", "Allen, do you have anything to add to what Jeanne said?"
- Opening up discussions to students presents the issue of what to do with naïve conceptions when they are shared. Much depends on when this happens. At the start of the unit or investigation and even as it proceeds, it is usually best to accept a naïve idea while at the same time highlighting results that raise questions about it. At the end of the investigation or series of activities, however, as noted in relation to helping students draw conclusions, it is important to guide the class to a more accurate conception based on evidence and reasoning.
- More open discussions also invite student questions, many of which cannot be answered by investigation and some of which the teacher may not be able to answer. One way to respect all of the students' questions is to write them on the board, leaving none out. These can be sorted into categories such as questions that might be investigated successfully through direct experience, questions that can be adapted for investigation, and those that cannot be answered though investigation. The students may find the answers to some of the latter from the teacher, from a scientist, in books, or on the Internet. Responding to questions by saying "I don't know, but we can find out" models good behaviour.

5.7 Guiding student recording

Making a record of science work, including text, drawings, flowcharts, graphs, charts, posters, etc., is an essential part of working scientifically. It supports students' learning as they try to clarify their thoughts. It helps them realise the progress they have made, remember what has been accomplished, and note the development of their thinking. Teachers, as they read the students' work, can learn about their preconceptions, assess their development, and note the nature of their thinking. By reading the notebooks, teachers may realise that a specific concept they thought was well understood is not really clear or is understood in an entirely different manner.



Student writing in science happens in a variety of ways. Students keep science notebooks; they produce written documents for presentation (texts, drawings, flowcharts, graphs), and they prepare reports. Each requires the use of different types of writing and forms of documentation. Science activities give the students rich and authentic opportunities to practice writing and speaking and to build their language skills. However, it is important to be careful not to change a science class into a reading and writing course. Language is at the service of science here, not the reverse.

Few students spontaneously record what they are doing as they go along. The use of a personal notebook helps them to work scientifically. This notebook may take a variety of forms and include a variety of types of writing and drawings. It includes in some form the question or purpose of the investigation, predictions, ideas, and investigation plans. It is the place for recording the data collected, analysis of the data, emerging ideas and reflections, and intermediate and final conclusions. Such written accounts help students clarify and structure their thinking, return to previous work and ideas, reflect on what they have done, and in many cases change or deepen their understanding. The science notebook is relatively informal, and allows students gradually to develop the skills needed to organise and keep complete records of their work. It can be read, but not 'marked' or corrected by the teacher.

More formal records may be prepared by individuals or groups. The teacher may ask them in advance to prepare a group written record, a poster, a plan or a demonstration to present their ideas and tentative conclusions to the whole class. Group working on a record helps students to synthesise their thinking and decide how best to convey to others what they think and/or have done. Such statements have to be clear and concise presentations for the other students in the class and use appropriate scientific terms and representations. In addition there is a further form of recording which brings together the thinking of the whole class. Developed jointly by the students and the teacher, these class recordings express the final conclusions –the knowledge gained– during the investigations.

Practical suggestions

- Students will not record in the science notebook unless time is set aside during which each of them can write. Short time periods at important stages of the investigation work well, for example, taking a few minutes to write a purpose or question and a prediction before starting an investigation. A short time at the end of a lesson for a quick reflection can also be useful, but when students are asked to stop and reflect on their work and come to a tentative conclusion, more time is needed.
- Even very young students, who do not yet know how to write, can and should record their work through drawings in a science notebook. Older students are likely to need guidance on points of detail and labelling as well as on how and when to use diagrams and other graphics.
- A variety of structured pages may be helpful in supporting students' notebook writing. These may help organise the page, remind students of key elements, provide a structure for recording data (table, graph, etc.). Such pages are best when they guide the recording and do not control the students' thinking.
- Students need to be able to write in their notebooks without being afraid of being judged and corrected by the teacher (spelling mistakes, misinterpretation, incomplete or over-embellished drawings, faulty conclusions, etc.). Rather than correcting individual work it can be helpful to provide students with productive comments. For example: "*How might you organise your data next time so it is easier to read?*", "*I wonder why you predicted that this would happen?*", "*I noticed that you didn't have the amount of liquid you used for…*", "*Try to explain more about this idea*".
- It is important that students use their notebooks in authentic ways such as: going back over what they did; comparing data with a friend; checking their results; and finding evidence to support their claims. If this does not happen, the notebook is less useful and students may feel that the only purpose is to satisfy the teacher's requirements.

5.8 Using assessment to help learning (formative assessment)

Enabling students to develop their understanding through inquiry, recognising that learning takes place inside the students' heads and has to be done by them, implies a pedagogy that includes the formative use of assessment. The aim of using assessment formatively is to enable students to take ownership of their learning – one of the key features leading to genuine understanding. It extends the notion of teachers taking students' ideas into account, applying it not only as a starting point but as an on-going process throughout learning activities.

The formative use of assessment is a continuing cyclic process in which information about pupils' ideas and skills informs teaching and helps learners' active engagement in learning. It involves the collection of evidence about learning as it takes place, the interpretation of that evidence in terms of progress towards the goals of the work, the identification of appropriate next steps and decisions about how to take them. Although very different from testing and other ways of finding what students have achieved, the process is called 'assessment' since it fits the definition of assessment as a process that involves collecting data in a systematic way, interpreting it as evidence of where learning has reached in relation to the goals, and using that information to help further progress. It is described as 'formative' because it helps to 'form' learning, which is why it is also called 'assessment for learning'. This makes a clear distinction from 'summative assessment' or 'assessment of learning', which is assessment for the purpose of summarising learning at certain times in order to report on students' achievement. Although all assessment should help learning in some way, in the case of formative assessment this is through the immediate use of information in making teaching decisions.

Formative assessment helps to ensure that there is progression and regulates the teaching and learning processes to ensure learning with understanding, by providing feedback to both teacher and student. If it is evident that students are experiencing difficulty this feedback helps teachers to decide what, if any, adjustments are needed to the pace of the work or amount of help given to students. The feedback might indicate a misconception held by many that must be addressed. By revealing student thinking, assessment may suggest ways to provide non-judgmental feedback to an individual student.

There are many different places and situations in which the teacher can gather information. The science notebook is one very useful source. So also are observations of students as they work in groups, their presentations, and the questions they ask each other. In the case of primary students it is likely that normal work presents enough opportunities for teachers to gather information to use as formative feedback, although some specific questions might be asked in order to probe on-going understanding. At the secondary level, however, where teachers see many classes for shorter times, ways of gathering such information need to be planned into lessons. These may take the form of challenging activities that make students think, or require particular skills and ideas. As far as the students are concerned these are part of their science work, but for the teacher they probe the students' understanding and reasoning to inform teaching decisions. Formative assessment is useful not only to teachers to guide their instruction but also to students to guide their learning. One of the features of formative assessment is that it involves students in assessing their own achievement and in deciding the steps they need to take to improve it or to move on. Helping students to recognise what are the learning goals of their activities and the quality criteria to be applied enables them to assess where they are in relation to the goals. When students consider their own learning and are involved in the decision-making process regarding how to proceed, they become more and more independent learners.

Practical suggestions

- Lesson plans should include identifying how progress towards understanding and the development of skills will be assessed as students are engaged in learning. This may be by including some challenging activities or probing questions or opportunities to observe or listen to students' talk.
- It can be helpful to identify certain objectives and skills to assess in different sessions. While many others may be visible as well, there is simply too much going on at once to try to capture student behaviours across the board.
- Different students express their understanding in different ways. It should not be assumed that students who have trouble writing or speaking do not understand science. They may have learning needs in communication but not in understanding science. These students should be given opportunity to show the teacher and their peers what they can do, thus encouraging their communication skills and preserving their self-esteem.
- It helps to keep some record of observations made in order to consider what action may be needed or to keep track of students' progress. This is not difficult for data from students' written work, which can be collected, read, and responded to outside of class. For observational data that must be collected on the spot many teachers find it useful to make notes on post-it notes or similar and organise the information later.
- It helps to discuss data from formative assessment with other teachers to build up a repertoire of ways of responding to particular problems in developing students' scientific understanding.

6. Supporting teachers in implementing inquiry-based science education

The implementation of all the key aspects of teaching science through inquiry may seem daunting to many teachers. So it is important to point out that it is not expected to happen all at once and that there are many forms of support that are available to teacher to match particular needs. This short section therefore discusses some of the common obstacles to teaching through inquiry and the support that teachers can find to overcome them.

6.1 Obstacles to inquiry-based teaching[16]

It is commonly found in many countries that primary school teachers encounter many problems teaching science due to their lack of confidence in their grasp of the subject matter. This may not be such an obvious problem for secondary school teachers with qualifications in science, but in reality it does occur when they are required to teach science subjects which they have not studied in depth. For instance those trained in biological science may lack confidence in teaching aspects of physical science. However both primary and secondary teachers, whatever their science background, may be deterred from teaching through inquiry on account of lack of time, an over-crowded curriculum, large classes, and an assessment system that requires only factual knowledge.

The solutions of many of these problems require action relating to curriculum and assessment reform, changes to initial teacher education, resource allocation, and other systemic changes over which teachers have little control. However, there is much that can be done to change pedagogy within the constraints that apply by helping teachers to develop the confidence and understanding required to provide students with opportunities to learn through inquiry. Conversely, even the most favourable circumstances will not lead to students learning through inquiry unless teachers can develop this confidence and understanding.

6.2 Approaches to supporting inquiry-based science teaching

During the past two decades the many inquiry-based projects in countries across the world have devised ways of helping teachers to incorporate inquiry into their science teaching. Indeed, any successful project will provide far more than new guidelines and books for teaching and will develop tailor-made approaches to professional development and on-going support for teachers[17]. As well as formal courses, which may or may not be associated with accumulating credit towards a qualification, there are many other ways of providing professional development. These include: teachers being mentored by a more experienced colleague or adviser; in-school sessions led by a teacher trained in a project-based course; on-line or telephone help-line; visiting scientist or higher education science student. Which one or combination of these is most appropriate in a particular case will depend on the diagnosis of need[18]. There is a good deal of research to show that there are various stages in making changes in pedagogical knowledge and practice and clearly those at the early stage need different help than those more advanced in their development[19].

16 This section draws on Harlen, W. and J. Allende (2009). *Report of the working group on teacher professional development in pre-secondary school inquiry-based science education*. Santiago, Chile: IAP.

17 Several of these approaches have been adopted and refined by the partners in the Fibonacci project and are accessible at www.fibonacci-project.eu, within the *Resources* section.

18 *A Diagnostic Tool for CPD Providers* is available in the Fibonacci Companion Booklet *Tools for Enhancing Inquiry in Science Education*, available at www.fibonacci-project.eu, within the *Resources* section.

19 Joyce, B. & Showers, B. (1980). Improving in-service training : the messages of research. Educational Leadership, 37(5), 379-385.

For most teachers wishing to introduce inquiry into their teaching some first-hand experience of inquiry-based learning is important. It is only through conducting an inquiry that the real meaning of using observation, making predictions, collecting data, interpreting data and coming to conclusions about a question to which they did not know the answer can be reached. At the same time they will develop their understanding of aspects of science and particularly of the nature of scientific activity.

However it is not possible for many concepts to be developed in this way, for inquiry at any level takes time. Teachers unsure of their own grasp of the content will need additional forms of support. In some projects a teachers' guide provides sections giving background science information, but this is insufficient on its own and more interactive support is preferable. This may be provided by access to a more experienced teacher in the same school or a teacher given responsibility for mentoring teachers in several schools. There is also a role for scientists in helping teachers to develop their understanding of science. In France, a partnership between scientists (some being university students) and primary teachers has been in operation for several years[20]. The project ASTEP enables collaboration between teachers and scientists which may take the form of support in the classroom or at a distance through e-mail or in the context of a professional development event. Web-sites are also used in this way. The Latin American website *Indagala* (www.indagala.org), derived from the French *La main à la pâte* web-site, enables Latin American teachers to put questions to science experts and to communicate with other teachers.

Nevertheless, there will always be questions from students that teachers cannot answer – and indeed some that they should not attempt to answer if students can find the answer for themselves. It is crucial that teachers learn how to deal with such situations since anxiety that students may ask difficult questions leads many teachers to organise the students' work so that opportunities for asking questions are minimised. This is to be avoided since questioning has a very important role in students' learning, particularly when they are encouraged to do their own reasoning. So it is important that teachers are prepared with strategies for handling students' questions. 'Handling' is not the same as answering; it means responding according to the kind of question being asked and trying to turn their questions into ones that they can investigate for themselves where possible[21]. Teachers should also realise that not being able to answer a question immediately and having to ask an expert or consult another source is useful learning for students.

The widespread awareness of the importance of teachers' confidence and understanding should ensure that no teachers attempting to implement inquiry-based science education should feel overwhelmed by the task of bridging the gap between what is described in Section 5 and their current practice. It is acknowledged that teachers starting out in active practical learning may need some structured activities to try with their students. This gives them access to one of the most important sources of encouragement – seeing the response of their students. Such encouragement will inevitably lead to the confidence that enables continuing development towards more open-ended inquiries.

20 Hvass M., Jasmin D., Lagües M., Laporte G., Mouahid G., Saltiel E. (2009). *Supporting Teachers Through the Involvement of Scientists in Primary Education*. Paris: Académie des sciences. Available at http://www.fondation-lamap.org/fr/node/9598.

21 See Jelly, S. (2001). Helping Children Raise Questions – and Answering Them. In W. Harlen, *Primary Science: Taking the Plunge* (2nd edition). Portsmouth NH: Heinemann, 36-47.

7. Conclusion

Inquiry-based science education means students progressively developing their knowledge and understanding of the world around through their own mental and physical activity. They learn and use skills similar to those employed by scientists, such as raising questions, collecting data, reasoning, reviewing evidence in the light of what is already known, drawing conclusions, and discussing results. Genuine inquiry means that students work on questions to which they do not know the answer and which they have identified as their own even if introduced by the teacher.

Although learning through inquiry is not the only form that is needed in learning science, it is particularly important because it leads to understanding, not only of fundamental scientific ideas but of how these ideas are developed. It provides enjoyment and satisfaction in finding something out or answering a question, development of skills that will enable continued learning, recognition of the value of discussion, working collaboratively, and learning from others and from secondary sources.

For teachers, implementing inquiry-based science education may mean a change in several aspects of their pedagogy, from the arrangement of the learning space to the questions they ask and the feedback they give to students. Moving from more traditional to inquiry-based teaching is likely to involve a shift in which teachers…[22]

…do more of this	…do less of this
Having students seated so that they can interact with each other in groups.	Having students seated in rows working individually.
Encouraging students to respect each others' views and feelings.	Allowing students to force their own ideas on others, not listening to others.
Asking open questions and ones that invite students to give their ideas.	Asking questions that call for nothing more than a one-word or short, factual response.
Finding out and taking account of students' prior experiences and ideas.	Ignoring students' ideas in favour of ensuring that they have the 'right' answer.
Helping students to develop and use inquiry skills of planning investigations, collecting evidence, analysing and interpreting evidence and reaching valid conclusions.	Giving students step-by-step instructions for any practical activity or reading about investigations that they could do for themselves.
Arranging for group and whole class discussion of ideas and outcomes of investigations.	Allowing students to respond and report individually only to the teacher.
Giving time for reflection and making reports in various ways appropriate to the type of investigation.	Giving students a set format in which to record what they did, found and concluded.
Providing feedback on oral and written reports that enables students to know how to improve their work.	Giving grades or marks and allowing students to judge themselves against each other in terms of marks or scores.
Providing students with a clear picture of the reason for particular tasks so that they can begin to take responsibility for their work.	Presenting activities without a rationale so that students encounter them as a set of unconnected exercises to be completed.
Using assessment formatively as an on-going part of teaching and ensure student progress in developing knowledge, understanding and skills.	Using assessment only to test what has been achieved at various times.

22 A detailed description of what inquiry-based teaching and learning might look like in the classroom, in terms of teacher's and students' actions, is provided by the Fibonacci Companion Booklet *Tools for Enhancing Inquiry in Science Education*, available at www.fibonacci-project.eu, within the *Resources* section.

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Consortium members

Credits

Template design : Brice Goineau

Graphic design : www.lezard-graphique.net

Inquiry-based science education means students progressively developing their knowledge and understanding of the world around through their own mental and physical activity. They learn and use skills similar to those employed by scientists, such as raising questions, collecting data, reasoning, reviewing evidence in the light of what is already known, drawing conclusions, and discussing results. Genuine inquiry means that students work on questions to which they do not know the answer and which they have identified as their own even if introduced by the teacher.

Although learning through inquiry is not the only form that is needed in learning science, it is particularly important because it leads to understanding, not only of fundamental scientific ideas but of how these ideas are developed. It provides enjoyment and satisfaction in finding something out or answering a question, development of skills that will enable continued learning, recognition of the value of discussion, working collaboratively, and learning from others and from secondary sources.

For teachers, implementing inquiry-based science education may mean a change in several aspects of their pedagogy, from the arrangement of the learning space to the questions they ask and the feedback they give to students.

Contact details

Fondation *La main à la pâte*
1 rue Maurice Arnoux
92120 Montrouge - FRANCE
+33 (0) 1 58 07 65 97
Fibonacci@fondation-lamap.org

WWW.FIBONACCI-PROJECT.EU