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A COMMUNITY APPROACH FOR A SUSTAINABLE GROWTH
OF SCIENCE EDUCATION IN EUROPE

Methodological Guide





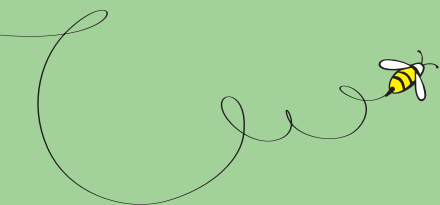
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A COMMUNITY APPROACH FOR A SUSTAINABLE GROWTH
OF SCIENCE EDUCATION IN EUROPE

Methodological Guide

Inquiry-Based Science Education:
Applying it in the Classroom





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The author is grateful to Jean-Pierre Sarmant for his comments and suggestions. His expertise contributed unique and invaluable support for the preparation of this document.



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- Out of the twelve European countries taking part in the Pollen project, some have been experimenting with inquiry-based science education in primary school for several years now, while others have chosen to develop research on the form of education itself. The experience gained on both sides, obstacles encountered and research findings can only be helpful to all of the countries involved in the project.

This document, intended for primary education teachers in all twelve countries, aims to help set up this form of education, clearly defining what inquiry-based science education entails and offering tools derived from those created by certain countries.



Basic principles behind the inquiry-based approach

1. The need to take ownership of the initial question

In order for a child to actually aim to solve a problem, the problem needs to have a meaning for the child, and he or she needs to have taken part, to whatever extent possible, in developing it; in short, the problem needs to become the child's own, so that he or she has the desire to solve it.

Imagine that a teacher wants children to work on hourglasses (observing, understanding, building, etc.) and try to identify the parameters that determine how long the sand will take to fall. Several different options exist:

- A. The teacher shows the students an hourglass and states that the time required for the sand to run out depends on [...] and that the students are going to be able to see this for themselves. This method is akin to the traditional, so-called lecture-type format, in which the teacher is content to pronounce results, and it is worlds away from an inquiry-based approach.
- B. The students observe, draw and describe an hourglass set on the teacher's desk, then the teacher asks them what factors determine how long it takes for the sand to run out. This question is meaningful to most of the students, but not to all of them.



- C. After having observed an hourglass, the teacher asks the students how to increase or decrease the time required for the sand to run out. Here, the child starts to come up with questions as he or she looks for a way to make something happen.
- D. The teacher sets 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 hourglass they have in front of them. Considering the distinctive features of the hourglasses set before them, one will continue to have sand running, while the others will have stopped. The children will take notice of this and instinctively wonder what makes that hourglass run longer. This is one way (though not the only one) to have children take ownership of a problem.

2. The need for individual experimentation

Experimentation here does not mean complicated experiments involving sophisticated and costly equipment. The reader will see that the experiments listed are in fact very simple and require nothing more than ordinary, inexpensive equipment. The sample activities listed on the Pollen site are a good example of what can be done by children.

Children have very good recollection of the experiments they conduct themselves. In addition, very early on, they have ideas about a number of phenomena. Most often, it is not enough to tell them that a given experiment will yield a given outcome (without doing the experiment or just showing it to them), or to tell them that what they think is full of mistakes. They need to reach this realisation themselves, hence the need to let them test the experiments they have come up with themselves (provided that this can be done in a classroom setting) and let them substantiate their methods amongst themselves. Here are two examples:

- A. In the hourglass example, the children might consider the amount of sand, the width of the glass, the size of the sand particles, the size of the hourglass, the presence of certain colour additives, etc. There is nothing quite like leaving the children to carry out the experiments themselves so that they realise they can achieve useable results only if they adjust one parameter at a time (keeping the others constant) and that, taking that into consideration, the size of the hourglass does not play an important part.
- B. The following example is derived from work carried out in Bergerac (Dordogne, France). During the academic year 1998-1999, two teachers (A and B) worked with their CE2 classes (eight-year-olds) on "melting point and solidification" and, specifically, on the temperature at which melting occurs in ice. The two teachers, who had taken part in the same training course on the topic, conducted their classes differently. Two years later, the students were asked the following question: "What is the minimum temperature required for ice to melt?" Here are the results:

Answers	School A	School B
3°C or more	83%	36%
Between -1°C and 2°C	13%	63%
Other	4%	1%

- c. Comparing the above answers with the experiment notebooks, it becomes apparent that most of the students in Class B reported the result they found two years earlier when they conducted their own experiments, hence the spread between $1/3$ and $2/3$, which did not occur with the Class A students.

Actually, Class B's teacher had the students work in groups, each group trying to measure at different moments the temperature of the ice. In addition, those students were given the opportunity to repeat the experiment after checking their initial results, while Class A's teacher performed the experiment only one time, on a table, with students coming up one after another to write down the temperature. This outcome illustrates the extent to which the knowledge students gain on their own, by carrying out experiments themselves, is important and remains engraved in their memory.

3. You can see only what you strive to see

In other words, in order to "see" something, you need to know what you are trying to look at. Many studies have shown this very effectively. We will list four examples:

- The first involves a future primary school teacher who, in her last year of training, was asked to write a paper on the education-related topic of her choice. She chose the subject "observation", recalling her own experience as a student. During a school field trip, she had been instructed to find fossils. She came back empty-handed because she did not know what she was supposed to look for, having no idea what a fossil might be.
- The second involves a teacher¹ who wanted to show the children that a candle placed under a bowl would burn longer if the bowl was larger. The teacher took three bowls of different sizes and explained to the children how to put them over the candles at the same time. Everything went well. Yet, when the teacher asked them what difference they had noticed between the bowls, he was disappointed to hear them say: "None. They were all the same. All of the candles went out". Clearly, not a single child had noticed what the teacher had hoped they would see. The students would have reacted differently had they first noted that the candle went out, then observed the three bowls, each over a candle, and been instructed to note whether the three candles went out at the same time.
- The third is not really specific to primary school children. Many adults have seen and marvelled at rainbows. If you ask them what order the colours are in, only a very small percentage will tell you that the colours are inverted. It is not enough to look; you also have to know what you are trying to see.



¹ HARLEN W., JOS ELSTGEEST, SHEILA JELLY, Primary Science: Taking the Plunge – Vol 2. Heinemann eds, UK., 2001, 160pp ou W. Harlen, 2004. *Enseigner les sciences : comment faire ?* - Collection La main à la pâte, Le Pommier Eds, 220 pp.

- The fourth has to do with the history of science, which abounds in similar examples. For instance, the notes left by Ampère and Arago² state that current flowed through their measuring device (measuring electrical intensity, an instrument now known as the amperometer) when they put a coil carrying electrical current next to another coil, not connected to a generator. They did not “see” the currents, as they were transitory (meaning they disappeared when the coil was no longer being moved) and the phenomenon they were trying to show, or so they thought, was supposed to occur as a permanent current. They let Faraday, nearly ten years later, enjoy the glory of discovering the phenomenon of *electromagnetic induction*.



4. A great deal of information can be found in documentation, but it can be found even more easily by those who know what they are looking for

To illustrate this point, let us look at what happened in one classroom: On that day, the subject was bones. During the previous session, the teacher had handed each student a sheet of A4 paper with the outline of a human body, and each student had to draw the bones as he or she *imagined* them. During the session, the students were divided into groups of four. A sheet of paper (A3, with the outline of a body) was given to each group so that the group could draw, in a certain colour (red, for instance) the bones that all of the group’s members agreed existed, and in another colour (blue, for instance), those on which disagreement remained.

Once this was done, each drawing was posted on the board and the teacher displayed a new body outline (A0). The entire class began talking and drawing, in red, the bones on which everyone agreed. The areas of disagreement gave rise to specific questions: are teeth bones? How many bones are there in the spinal cord? (this question arose because some children thought that the spinal cord was made up of a single bone, but others pointed out that, if that were the case, it would be impossible to bend over to pick up a pencil on the ground). Once this entire process was completed, specific questions emerged and the children went to find answers in their books, knowing full well what they were after.

5. Learning is not only acting on and with objects, it is also talking with other children and writing both for oneself and for others

There is little use in dwelling on this final point as we will have an opportunity to come back to it. Suffice it to say here that learning something by heart is not enough to solve problems and, in many cases, it is by trying to convey one’s viewpoint that one finds answers to one’s questions. Who has not come up against a problem and, in trying to explain it to a third party, found part of the solution?

² ANDRÉ-MARIE AMPÈRE (1775–1836) French physician, chemist, biologist and mathematician. Having observed the so-called Oersted Experiment in 1820, in which the needle of a compass is swayed in a different direction when a current runs through an electrical wire sitting near it, he designed the theory of *magnetic fields* in a few days: a circuit through which a current runs will affect a compass in the same way a magnet will, and thereby create a magnetic field. The unit of measurement for electrical current now uses his name.

FRANÇOIS ARAGO (1786–1853), French physician and astronomer. He made major contributions to developing optics and electromagnetism.

2

Unity and variety in the inquiry-based approach

- **Unity**³: one essential feature of this type of education is not to instruct only the results of science, but allow children to build up the knowledge desired by helping them express their ideas, expose their reasoning, test their hypotheses and strive to be exacting. This type of approach is built around the questions that students may raise about the real world. It causes them to gain knowledge and know-how, as a result of inquiry carried out by the students themselves, under their teacher's guidance.
- **Variety in method**: the inquiry performed by the students can be based on a range of methods, possibly during the same session, such as: direct experimentation, item production (building an object or model, looking for a technical solution), direct or instrument-assisted observation (not a computer), document-based research, investigation, production of a radio programme or short film and a tour. The students do not only observe: they can identify, classify, question, make projections and explain the reasons for their choices, perform simulations, experiment where appropriate, and record their observations for later summary.

It goes without saying that the above means for broaching the subject are complementary and are to be combined as appropriate to the topic of study. However, wherever possible, direct action and experimentation on the students' part are to be favoured.



³ *Enseigner les sciences à l'école*, 2002. Ministère de l'Éducation - Académie des sciences, CNDP- Paris, Collection Ecole, 79 pp.



Inquiry:

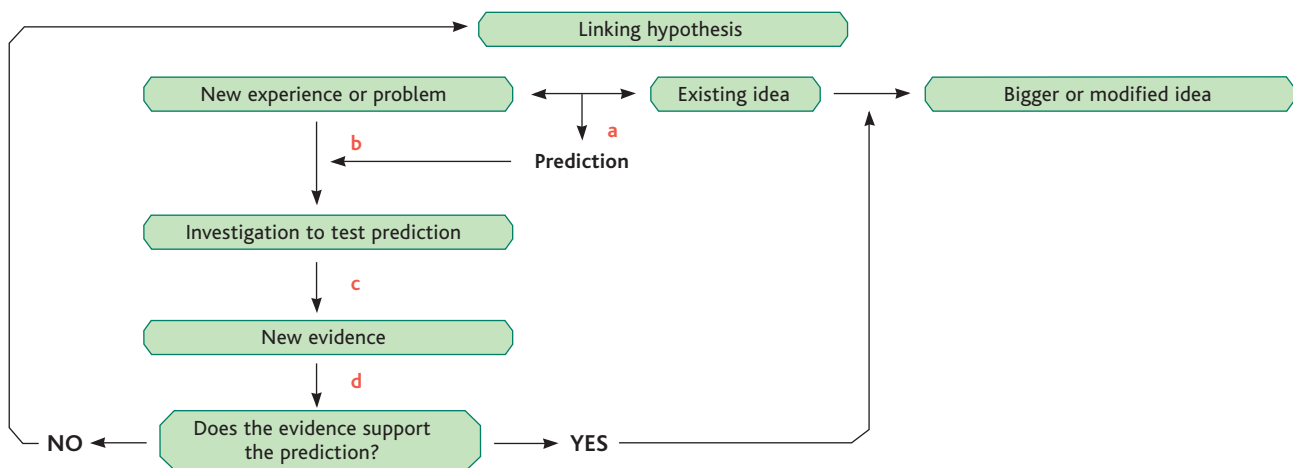
An iterative process

The step-by-step approach

It is important to ensure that the students *understand what is being learned*, and keep from a superficial learning process in which motivation is based on the satisfaction of being rewarded or not, rather than having the satisfaction of having learned and understood something and, thereby, having gained knowledge.

The approach as a whole can be summarised in the following excerpt⁴, which sets out a framework. However, it is important to note that the framework is not a user's manual that needs to be followed step-by-step, but rather a guide designed to help the teacher better position what he or she is doing.

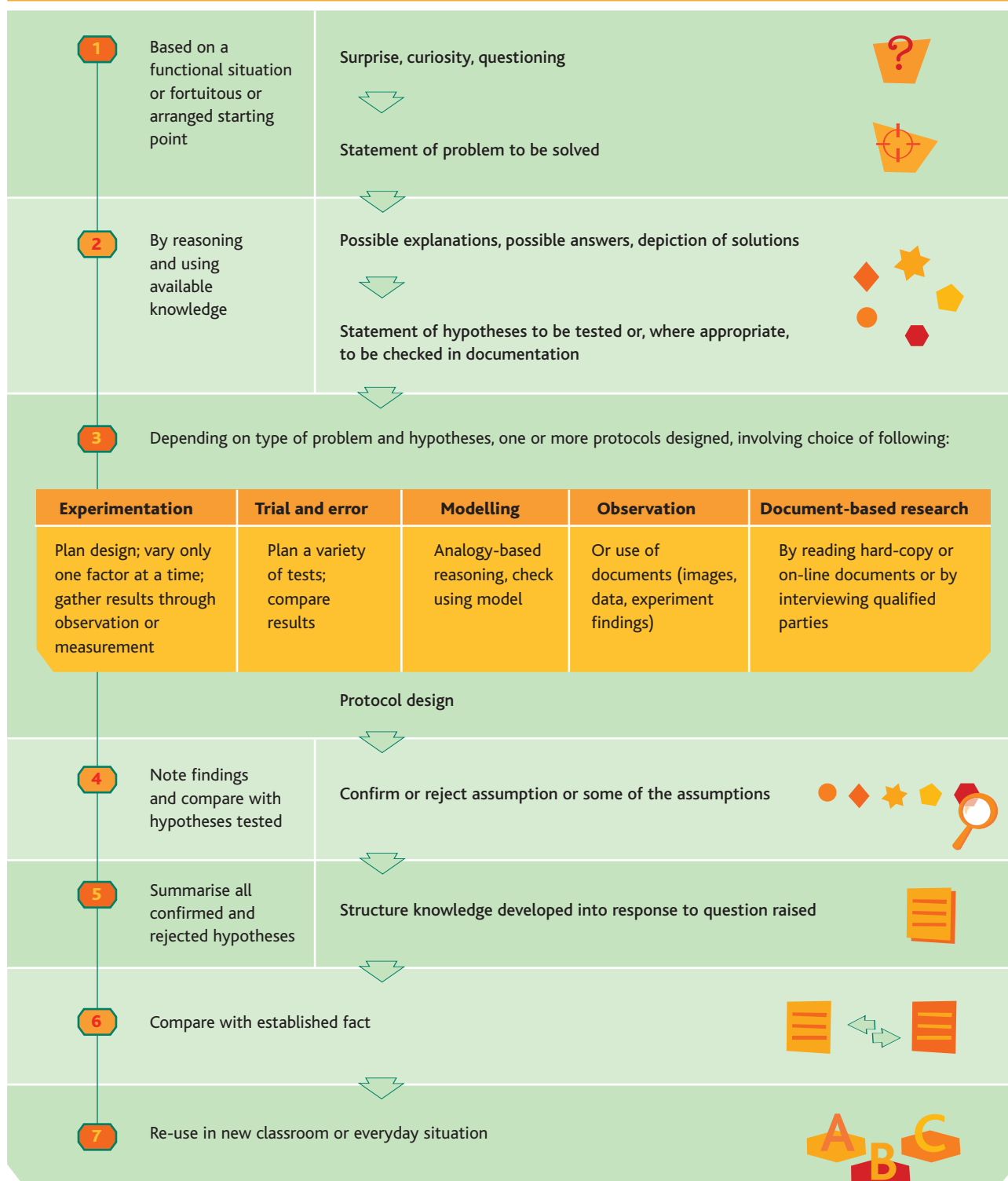
It goes without saying that, depending on the subjects dealt with, and the constraints of the experiments planned (for example, any germination will require time), the teacher will end up at some point along this line. Likewise, one extremely important factor is not listed on this chart, meaning the option of repeatedly coming back to Phase 2 after achieving results in Phase 4, in other words, re-questioning the hypotheses and moving on to a new experiment. As a result, patterns can be repeated, as shown in the flowchart below⁵.



⁴ This framework is based on the one set out by FRANÇOISE DROUARD. Document available online at http://ienpassy.edres74.net/article.php3?id_article=31.

⁵ W. HARLEN: *The interdependence of process and content in learning science*. In Conference - IAP Workshop on the Evaluation of inquiry-based Science Education programmes (Stockholm, September 21-23, 2005).

A REASONED INQUIRY-BASED APPROACH IN SCIENCE EDUCATION





Concrete implementation of an inquiry-based approach

There now exists a large number of documents, either on paper or on websites, suggesting activities to be carried out with students in the classroom (for instance, on the Pollen web site, www.pollen-europa.net, Learning Units section). On each topic, relatively long modules are suggested, encompassing several classroom sessions (10 to 15) and combining to form an instructional and scientific sequence, rather than putting independent sessions side-by-side. A single theme (or subject) is elaborated upon for several weeks, to avoid spreading efforts too thin, barely broaching subjects and discarding them quickly. The idea is to give children enough time to step into the research situation and build up their own knowledge. Two examples of how learning builds up through a module are provided in Annex 1.

Moreover, an activity is also designed as a follow-up or prelude to another one, if only for the child's viewpoint. The sequence in concepts is of importance, as it allows the children to gradually and progressively approach the various aspects of a single theme and, in so doing, grasp the key notions in a more in-depth manner.

Lastly, students' activity and initiative are vital, and when they are divided into groups of three or four, if the subject matter allows, they are motivated to organise themselves, assign responsibilities and communicate with one another, and thus become increasingly independent. When those groups are reunited in the full-class format, each



group is able to report on what it did and achieved, and this also provides a good opportunity to learn to listen to others, realise that there can be several different ways to approach the same problem, etc.

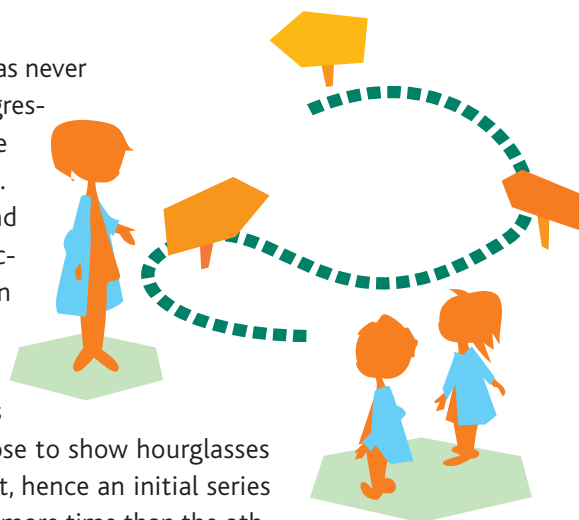
The inquiry-based approach involves a number of key points:

A. How to choose the starting situation

The first step shall be to choose an area of study that falls within the students' cultural environment (germination, shadows, levers, food, electrical circuits, etc.), curricula and general objectives suited to children of the age group under consideration. Once the focus area has been selected, it is important to define the series of concepts that the students are to gain. After this is accomplished, it is time to begin – but how? Which starting point should be used? The situation needs to encourage the students to raise questions and culminate in a statement of the problem to be solved, with the problem possibly requiring time before it is actually solved. It is important to manage to state the problem, as science is built on problems to be solved, and not just observation alone.

● Concretely speaking

When a teacher has never taught science or when he or she has never taught it in this manner, it is not always easy to design a progressive sequence and find starting situations all along the sequence so that the students are moved to question and take action. That is why it can be helpful to look at sample activities⁶ and try them out in order to become familiar with the method recommended. Later on, the teacher can design his or her own starting situations.



Let us return to the hourglass example: initially, the students were asked to watch an hourglass. However, the teacher chose to show hourglasses with very different time requirements for the sand to run out, hence an initial series of questions: Why is it that one of the hourglasses needs much more time than the others? What are the factors determining how much time is needed for the sand to run out? This situation, chosen by the teacher, helped the students take ownership of the problem, by raising the questions the teacher wished to cover.

In some cases, the study can also begin with a question (How is the melting temperature of ice measured? How is saltwater made? How can saltwater be cleaned? etc.). Insofar as all starting situations are intended to lead to the emergence of a problem and spark action, the wording of the initial question is important. For example, if a teacher wants the children to design a Chinese shadow puppet show, he or she can either ask the children to design it (possibly making it necessary for the teacher to provide the material and suitable paper), or ask them, "How might we go about this?"

⁶ See Pollen website (www.pollen-europa.net), "Learning Units" section.



B. What questions should be asked of the children and how to ask them

This is an essential aspect. There are many questions that simply cannot facilitate activities and the reasoning process, which W. Harlen⁷ calls sterile questions, as opposed to meaningful questions, which, in contrast, lead to intellectual or manual activity in the children – to an inquiry. Sterile questions often call for verbal responses (What is this called? What is a battery? Why does the current move from the positive pole to the negative pole? etc.). This does not mean that the teacher should never ask such questions, but they are not the kind of question that make it possible to implement an inquiry-based approach that the child can carry out on his or her own.

So-called meaningful (or “productive”) questions are those that suggest a problem to the children and spark action and reasoning. Such questions can emerge at the start of the session, but not only then, as the aim is to help the children act and reason throughout the session.

It is possible to raise questions such as: “What differences and similarities do you see between these objects (or situations)?”, “Is it more or less compared to the other experiment?”, “Can you find the way to...?”, “In your opinion, what would happen if...?”. (The “In our opinion” is very important here as it does not inhibit the student, who does not feel required to give the “right answer”, which he or she does not necessarily know), “How could we go about...”, “How can you explain...?”, “How can we be sure...?”⁸ or, if the subject is suited to quantitative questions, “How many... ? What is the temperature?”

As Sheila Jelly states in W. Harlen’s work, “The key to expressing specific questions in special situations is none other than practice”. To this effect, she advises a number of paths: examining the questions suggested in children’s science books, asking whether they are empty or meaningful; looking to determine what scientific experiment is encouraged; or using free time to practice looking for meaningful questions.

C. Taking into account students’ questions and ideas

Whatever their culture and age, students generally have many ideas about the phenomena they encounter in their personal experience, regardless of the work they may have done in school. It is important to be familiar with those ideas, referred to as students’ “preconceptions” or “initial conceptions”, as this helps the teacher, first of all, become familiar with the students’ reasoning, then ask certain questions to guide classroom activities and, ultimately, check that they have effectively understood the concepts introduced. By taking the students’ ideas seriously and taking into account their questions, the teacher ensures that the students have the opportunity to see that there exist ideas other than their own, and that the said ideas can be rooted in facts that they had not considered.

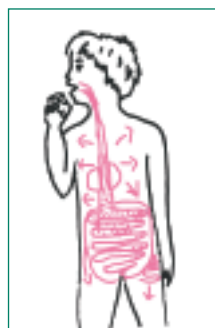
⁷ See reference in Note 1.

⁸ For example, “How do we know where the wind comes from ?”, title of one of the sequences described in *Teaching sciences at primary school* on the Pollen website – Learning Units section. The titles of the sequences in the work are all examples of so-called meaningful or productive questions.

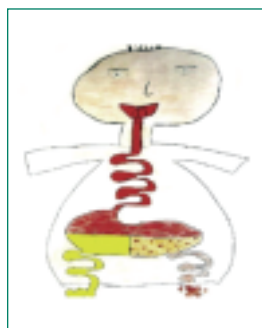
Let us take an example in the field of optics⁹: Many children see the eye as a receptor, rather than an active medium and, in order to see an object, they think that they need something to move from the eye to the object. They, like our ancestors, have a lot of trouble accepting that, in order to see an object, light (which is invisible) must move from the object and enter the eye. The children base their reasoning on the fact that, when light is shone directly in the eye, it is blinding. It takes some time until they can distinguish between looking (to see an object, one obviously needs to look at it) and the light from the object that enters the eye.

Likewise, in electricity, a number of children can be seen to believe that putting a light bulb on a battery pole is enough to light it up. There is nothing quite like letting them experience the phenomena on their own, so that they see the lamp will not shine. Later, many of them think that electricity comes out of the poles, to enter the circuit (some specify that, when the two come together, this is what makes the light shine). It is important to ensure that the children can clearly state that viewpoint and ask them to later explain why, when there are three light bulbs in a row, all three shine.

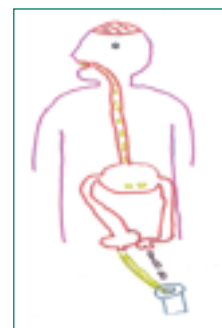
Lastly, when the children are asked what becomes of the food¹⁰ that we eat, it is common knowledge that many think there are two pipes, one for liquid and the other for solids. This idea is strengthened by the fact that there are two exits, the anus and another one for urine.



Nanjing (China)



Paris (France)



Sao Carlos (Brazil)

For this reason, it is important to ensure that the children can express their ideas and, subsequently, encourage them to think, by raising a number of questions, such as: "What happens when you eat minestrone? Has something ever 'gone down the wrong way'?, and what does this mean to you?", etc.



⁹ L. VIENNOT, 2001 "Reasoning in physics, the part of common sense". Kluwer Academic Publisher, 248 pp. (translated from the French).

¹⁰ See Pollen website (www.pollen-europa.net) "Learning Units" section and GIORDAN A., DE VECCHI G., 2002. *L'enseignement scientifique. Comment faire pour que ça marche ?* Delagrave – collection Pédagogie et formation, 271pp.

Quite often (but not always) such ideas are in contradiction with the scientific explanations of the phenomena being studied. It is important to allow a new and more coherent explication to emerge, through a process that will be all the more enthusiastically embarked upon as the students realise that their ideas are inaccurate, incomplete or in contradiction with those of others, by helping students express their ideas and encouraging them to express them orally or in writing; taking those ideas into account, without judging them; not discarding them from the outset, even if they are considered "incorrect" by the teacher; taking them all into consideration, without making value judgements. Then, the inquiry process begins, during which most of the ideas will be able to change.

D. Holding group discussion

The students need time to think on their own and exchange ideas amongst themselves (and not necessarily through the teacher). The teacher needs to take the students' ideas seriously and then, taking their questions into account, he or she can hold a group discussion to give the students an opportunity to realise that ideas other than their own exist and that those ideas can be rooted in facts that they had not considered (spinal cord bone example, mentioned above). In certain cases, they can test them through experimentation. Such debate can come into play at different points in the session:

- At the beginning, when the students sort through their questions to reach one or more productive questions,
- When the students form hypotheses and suggest experimental protocols,
- When the experiments have been completed by all involved and the time comes to set out valid conclusions, based on the results achieved, or
- When they compare and contrast them with scientific knowledge (the last point will be dealt with in g and h).

Reaching more productive questions

Holding such discussion is not always easy as children can put forward strange suggestions. For example, when children are asked to find a way to recover the sugar that has dissolved in water, a child might suggest "To recover the sugar that has dissolved in water, all you have to do is say Abracadabra". One way to make things work is by writing down all of the questions, suggestions, proposals and hypotheses on the board, leaving none out. Depending on the question being considered, the suggestions can be individual or developed as a group (for instance, developing an experimental protocol). It is by taking into consideration each proposal and working on it (in any case, all those that can be) that knowledge is built up.



Throughout this stage, it is vital that the teacher refrain from providing the right answers. Likewise, he or she needs to keep from calling an answer wrong or right too quickly, or settling a disagreement between two students. He or she needs to take the onlooker's attitude: "let's see", "we are going to try...", so as to enable true discussion.

Let us go back to the dissolved sugar. It is important to take seriously the idea of letting the child experiment and note the outcome; afterwards, what the child (and the other children) will observe is that the suggested idea does not match up with the question initially raised.

Whenever possible, it is important to help the children realise that some questions (or answers) can either not be tested, lead to dead ends, or yield nothing at all. It is also during these group discussion periods that the children may raise difficult questions that the teacher cannot answer. The appropriate response would be to say, "I don't know, but we are going to try to find out together". While some questions can be investigated, others can not. In this case, the answer will have to be found in the available documentation or from a scientist (via a network of scientific consultants from the website or a scientific guide, for instance, at the Pollen website (www.pollen-europa.net, "hotline" section)).



(Note: We can not guarantee to answer all questions. Even scientists do not always know. That is why science is exciting).

E. Designing experimental protocols

The next section describes how the students can be assisted in designing an experimentation process, in line with the equipment existing in the school, in order to later have the opportunity to interpret the results. Each student needs to know exactly what is being sought (the question raised) and reflect upon the problem.

One of the first problems lies in the equipment available to the students. Several options exist: either the teacher gives each group of students the material required for the experiment(s) suggested, or the material is put on a table and the students work together to reflect on the protocol and material necessary to perform the protocol. At this point, yet more options exist, depending on the subject chosen and the students' age: either each student thinks individually about what he or she wants to do and goes about achieving it, or there is group work during which the students have to design a protocol that will be suggested to the entire class and discussed jointly.

● Taking into account the results achieved to reach valid conclusions

After each student (group) has performed the planned experiment and noted the results achieved, all of the findings can be pooled for review: Are there doubts as to the findings achieved? Do certain experiments need to be repeated? Which hypotheses were confirmed, and which were not? Is there a need to come up with addi-

tional hypotheses and experiments and, if so, which? This can be the point at which the process is repeated from the beginning, as described above.

The effectiveness of the discussions depends not only on the students' skill at expressing themselves orally, but also their ability to listen to one another. In certain classes, discussion may always go through the teacher, while other students can debate by themselves. The time required to learn these skills is well worth it, remaining patient and determined throughout the process. Thanks to this process, the science class members develop into effective citizens of the future.

F. Class organisation

Before even embarking on the process, it is essential to ensure that the classroom is arranged in such a way that the students and teacher are physically comfortable. Some schools may have a science room (with enough tables so that the children and teacher can experiment as planned). Where this is not the case, there should be no qualms about moving the classroom tables and chairs around, so that teamwork is possible and so that the children have easy access to the equipment.

● The equipment

In primary school, the equipment used is generally not sophisticated, ranging from plastic bottles to rubber bags, plastic and paper bags, plants, seeds, soil, cardboard, rubber, string, scissors, paper clips, recipients of various sizes, fruits, vegetables, a variety of liquids, etc. In short, everyday equipment that is common and inexpensive, except possibly batteries, light bulbs, thermometers, compasses, a scale, and a binocular magnifying glass. It should be noted that it is not always possible to experiment with the actual objects. This is often the case with astronomy, but also when the course focuses on living organisms. In this case, the teacher may opt for either modelling (for example, a physical model, or replica, of the Earth and the Sun, to understand how the length of each day varies over the year, or a model of arm muscles, to understand that the arm can be raised and lowered, etc.), or documentation (see bone example above).

PRACTICAL POINT

The equipment may be available in the school, or it might be borrowed from resource centres or scientists, or the teacher can try to gather the equipment required by possibly calling upon the students and parents (often a very effective option).

Group work

It is important that all students are able to take part in this experimental work. The times during which the students work in groups can be especially enriching if the students are encouraged to discuss, compare their viewpoints and try to agree on a common conclusion. Each group can have a speaker (appointed by the students in the group or the teacher) who tells the entire class the conclusion, and how it is substantiated.



PRACTICAL POINT

Divide the children into groups of at least 3 or 4. The number of groups should not exceed eight. Beyond that number, it is difficult for the teacher to manage all the groups alone and it is unlikely that every member of the group will be fully involved. Within each group, assign each student a role. Each role can be assigned by the teacher or, if the class allows, by the group itself. It is important, however, that the roles be held alternately within the same group. This is to enable each student to realise what each role entails and to limit the dominant personality effect or possible sexist attitudes, for example, with all speaking roles assigned to boys or liquid-mixing roles assigned to a girl.

A teacher trying to put a class to work in groups for the first time can encounter serious difficulties at the start: non-productive groups, very noisy classroom environment, commotion, arguments, etc. It is a learning process in and of itself, for the student and for the teacher. To minimise such problems, it is advisable that the teacher assign the roles him or herself, initially, and give clear instructions as to what the children are to produce (a text, a protocol, a poster, an experience, a presentation, etc.), plan a very detailed timeframe for each stage and, whatever happens, determine a signal when the classroom becomes too noisy (turning off and on the light or clapping or ringing a bell or asking the children to lay their heads on the table and close their eyes, etc.). Initially, it is advised that groups be small and work divided up into small units, with the teacher determining their timetable. Later, once the children have learned to work this way, they can organise themselves and the teacher is much less frequently required to step in.

G. Guiding the students as they design protocols, identify suitable variables and become aware of the need to control variables

Often, the aim will be to determine on what factors a certain phenomenon depends and test the factors, one after another. In order for the experiment findings to be interpretable, certain requirements need to be met, namely varying only one factor at a time (keeping all others constant): in other words, carrying out a controlled experiment.

For example, if the aim is to learn what determines how long it takes for the sand to run out in an hourglass, specifically whether or not it depends on the size of the hole, it is vital to make the children realise that they need only change the factor they are testing i.e. the size of the hole (they can compare two devices with different hole sizes). The amount of sand is the same, the size of the bottles is the same, the size of the sand particles is the same, etc. This requirement should not be impressed upon them automatically; on the contrary, the children can be left free to vary several parameters at the same time in order to realise, on their own, that their results are not useable or comparable.

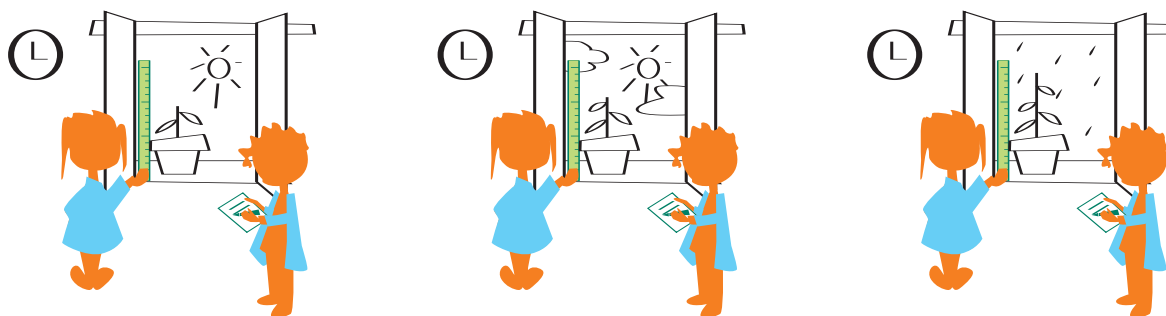
As it happens, the need to vary only one factor at a time (with the others remaining constant) does not always seem obvious to adults. For instance, a number of teachers participating in a training course were asked to put together an experiment to show that fertiliser spread over soil can end up in the water table. To do this, they

planned to take two plastic bottles with holes punched in the bottom, put the same amount of soil in both, then put water in one and water plus fertiliser in the other, then, in a saucer, recover the liquid that came out of the bottle after having passed through the soil. That liquid was to then be evaporated in order to see whether one of the saucers contained solid residues that would indicate the presence of fertiliser. In fact, while some teachers said they wanted to vary only one factor at a time, they poured not only water and fertiliser in the bottles, but also food colouring. Given the freedom to perform the experiment on their own, the teachers quickly saw that they could not learn anything from it, as they had varied two different factors at the same time (fertiliser and food colouring)!

The teacher therefore needs not only to be aware of the issue, but also extremely watchful in class. In another example, a class is experimenting with evaporation. The aim was to show how an open or closed container might affect the process. The teacher asked the students to draw experiment flowcharts. Naturally, the students suggested comparing the liquid level in the containers, either with or without tops. Unfortunately, many students suggested that the comparison be made with containers with very little free surface area, hence part of the class embarked on experiments that could not yield very helpful results.

First of all, it is important that the children realise that varying everything at the same time does not help reach conclusions. For instance, if the children perform experiments that vary several factors at the same time, they can achieve very different results depending on the group. The teacher, when pooling the results, helps the children grasp this issue, by asking the right questions. Next, it is important that they be given the tools needed to establish appropriate protocols. Here, there are several options: teaching the children to draw charts showing the values of the various factors, noting that they will be identical from one line to the next except for the one to be tested, or put labels on a small index card¹¹ indicating:

1. the question on which the experiment focuses;
2. the list of items that can vary;
3. the name of the variable that is to be varied;
4. the list of variables that is not to vary.



¹¹ W. HARLEN, 2004. *Enseigner les sciences : comment faire ?* - Collection La main à la pâte, Le Pommier Eds, 220 pp.



H. Taking each student's results into account, connecting them back to the initial hypotheses and summarising the information

Following each study or experiment, it is important to review what has been achieved and tie this back in with the hypotheses and initial assumptions. From this point, group discussion can begin, coordinated by the teacher, who ensures that everyone has an opportunity to be heard and that every viewpoint is respected. The experimental findings and rationale are what will distinguish between possible divergences, not the number of proponents for a given opinion, or the "leaders'" beliefs.

In order to ensure that the experiment findings are reliable, it is important that the teacher makes sure that each experiment is carried out several times, either by the same group or by two different groups. This helps to ensure that no mistakes have been made, hence more dependable results and, incidentally, confirmation of the right to make a mistake! In some cases, it may be necessary to repeat an experiment.

During the previous stages, the child builds up knowledge, which, if the teacher does not go any further, can be patchy, fragile or even fleeting. A review and summary of the experiment findings or document research will make it possible for the children to structure what they have found out so they are more likely to build up knowledge that is more reliable and meaningful. Once again, the summary process is meaningful to the child when he or she has experienced all of the preceding stages. The synthesis cannot, however, lead in any certain manner to unchallengeable knowledge, unless, under the teacher's guidance, the class compares its findings with what is known as "established fact", meaning that found in books.

I. Comparing and contrasting with "established fact"

The compare and contrast stage is essential, as shown in the real-life example below:

A class experimented on the theme of "mixing solids and liquids" (dissolving). At the end of the session, several groups handed in papers concluding that "water and salt do not mix". The teacher did not react to what he considered were the "children's findings" and planned a different type of activity for the next session.

What happened? To save time, the teacher had given directions as to the amount of solid to use, but not the liquid. The groups that used a small amount of water naturally observed that, even after shaking it, some salt remained at the bottom of the recipient. The limitation of their conclusion is in *general* nature. It would have been helpful if the teacher had suggested that they investigate what happened if the amount of liquid was increased. This would have led to "correct" conclusions, meaning those in line with *established fact*, (in this case, the amount of solid that can be made into a solution cannot exceed a certain value – around 360 grams of ordinary salt per litre of water, at ordinary temperatures). It is important that teachers check the background of topics in available literature.

The recommended approach for teachers is similar to that of a researcher, yet also remains different. The children should "discover" nature's phenomena and properties and experiment and compare their conclusions amongst themselves, like scientific community researchers might do. However, unlike researchers, those children do not have to discover phenomena and laws that are yet unknown to the scientific community, as everything a child learns in school is well-known fact to that community.



Leaving a record



The expression “record” encompasses several different types of documents: texts, drawings, flowcharts, graphs, charts, posters, etc.

The students can be invited, individually or in groups, to produce written documents (texts, drawings, flowcharts, graphs) that are accepted as such and used in class as one of many learning aids. In many schools, each student has an experiment notebook, which includes three types of distinctly different written media: individual writing, intermediate writing and class writing, with the first two open and minimally organised, at least at the beginning. Gradually, with the teacher’s help, but also through self-criticism, the student organises his or her notes, improves spelling and comes to write more effectively.



- A. Individual writing.** Depending on the students’ age, this individual section includes drawings (mainly for 5-6 year olds who do not yet know how to read or write), flowcharts, various texts, an experimental protocol, the required material, a hypothesis and whatever the student thinks he or she will see or do, a report on the completed experiment and the results.

The aim of such written accounts is to help the student not only remember, but also structure, his or her thinking. In many cases, it is in writing that we have an opportunity to think and, as one teacher said, “When the students did not write at length, they had failed to give the experiment enough thought and the ensuing discussion to confirm hypotheses in verbal group exchange was unsubstantial without the prior writing phase”. This shows how very important it is for each child to use that stage without being afraid of being judged by the teacher (spelling mistakes, misinterpretation, incomplete or over-embellished drawings, faulty conclusions, etc.) and understand that the writing is a stepping stone for science activity. This is why we suggest not judging the individual written statements at this stage, and even refraining from correcting them. There is one requirement, however: the child needs to have the opportunity to read back over what he or she wrote.



PRACTICAL POINT

Set aside times (not too long) during which the students can write in their notebooks. This can involve asking them to draw an experimental design, predict outcomes, substantiating them as well (for example, predict whether a given object will sink or float and attempt to say why and come up with an experiment protocol, etc.).

- B. Intermediate group writing.** These are usually (not always) statements produced as a group and, very often, they are intended to convey to others what the group thinks and/or has done. Accordingly, such statements are more elaborate in form than the individual ones, insofar as the other students in the class have to be able to read and understand them. They come in a variety of formats: posters, group reports, etc., and should normally not contain any spelling mistakes, though they may contain incomplete drawings, misinterpretations or faulty conclusions.



PRACTICAL POINT

Every time the students work in a group, they shall be asked to produce a specific written record: poster, experiment protocol, technical object, etc.

- C. Class or group writing.** These are records developed jointly as a class, with the teacher's assistance, to help the pupils to organise their thoughts and to use science language and ideas correctly. Such writing is considered "knowledge" (it can be put on a par with the summary that might be dictated by the teacher but which, here, can be drawn up by the class and the teacher). Expectations as to proper spelling and syntax are very high here.

All of the above forms of writing help the child realise the progress he or she has made, remember what has been accomplished and note the development of this thought process throughout the year, or sometimes over a period of several years. Moreover, as the teacher reads the individual and intermediate written statements, he or she can track the development specific to the student and group and learn their preconceptions, trials and errors and progress. Often, reading the notebook shows the teacher that a specific concept, which he or she thought was well integrated by the entire class, was understood in an entirely different manner. Consequently, he or she is able to arrange and adjust the content of the classroom sessions, rather than waiting until test time, which may be several weeks later. However, it is important to be careful not to totally change a science class into a reading and writing course, but rather to ensure that the science activities simply give the student an additional opportunity to practice writing, speaking and building their language skills.



PRACTICAL POINT

Children can not only draw what they observe, such as flowers, animals, the sun, the teacher, etc., they can also attempt to use their drawings to explain their ideas. For example, if young children are working on shadows, they could be explicitly asked to show what it takes to make shadows in their picture.

Likewise, later on, when they work on electricity, in the beginning, they might draw a battery, or a light bulb with wires that come out any old place on the light bulb. By asking them to draw the set-ups that work (making the light bulb shine) and those that do not (the light bulb does not shine), they themselves will realise the importance of the bulb's fuse and tip.

There are many ways of guiding or structuring the children's writing, such as the ones shown below. A practical tip to present the different types of writing may consist in using different coloured paper or ink.

Some teachers also use a different picture code according to the children's age, as shown in the following illustration, which helps structure the notebook, both the individual component and the group component.

MÉLANGES DE LIQUIDES – LIQUID MIXTURES

	Que va-t-il se passer si on met dans un verre d'eau et du sirop ? What happens if water and syrup are put in one glass?
	Ce que je pense ? What do I think?
	Ce que je fais ? What am I doing?
	Ce que j'observe ? What do I observe?

				
"Nous se savons pas" "We don't know"	"Nous ne sommes pas d'accord" "We don't agree"	"Nous sommes d'accord" "We agree"	"Nous nous interrogeons" "We are wondering"	"Nous pensons que" "We think"

NOTE: Examples from the Montmorency School (above) and from Evelyne Villard, Mâcon (below).

Other teachers post a more comprehensive document in the classroom, to which the teacher and students constantly refer as in the following example:

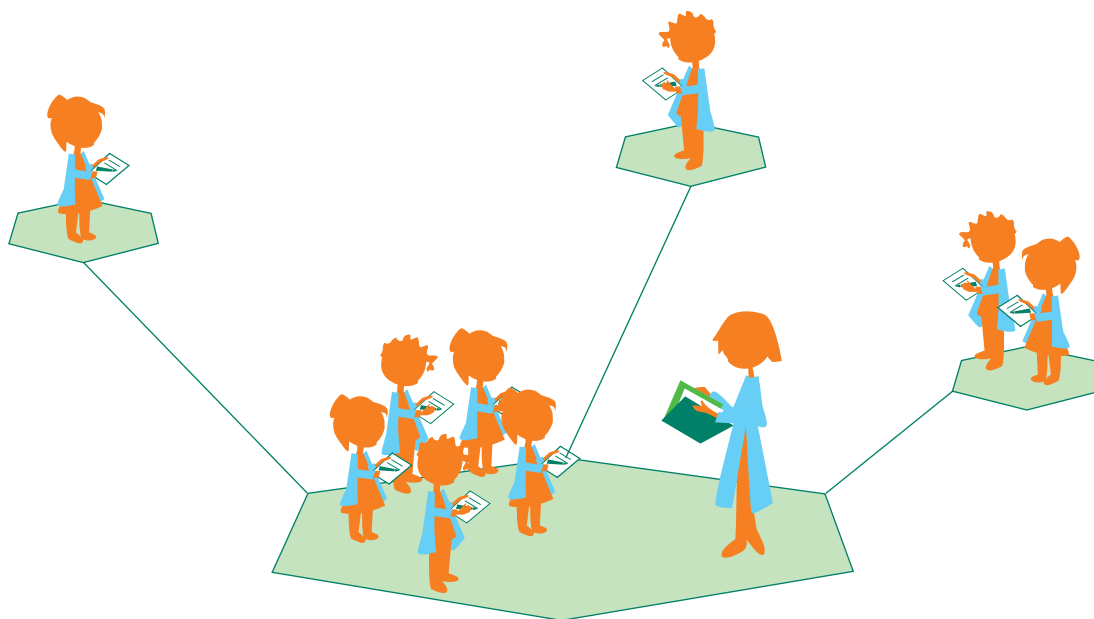
THE EXPERIMENTAL APPROACH TO SCIENCE	
What we remember	
Experiment	
What we think	
What we are looking for	
What I see	
Conclusion	
What I am looking for	
What I am doing	
What we suggest	
What we observe	
Hypothesis	
What I suggest	
What I measure	
Experiment results	
What I can say	
What I remember	
What we are doing What we are measuring	
Problem	
What we can say	
What I plan to do	
What I want to check	

NOTE: This example has been taken from the presentation page of the experiment book of School of Sciences, Bergerac, France.

Connection between individual, intermediate and class writing

Two examples are used to illustrate this:

- A teacher asked his students to take the temperature of an ice cube over a period of time and individually record the related figures. The teacher saw that the results were presented somewhat haphazardly. He combined a few presentations on the same sheet of paper and asked the students to work in small groups to look at the presentations and identify what was missing, what needed to be highlighted and how to highlight it. By combining the results, it became possible to jointly present the results (as a chart), so that the presentation could later be easily used by any student in the class. The process takes time, but there is real learning, as the students showed in their notebooks, where all of the measurement findings were displayed appropriately.
- Likewise, older students (9-10 years old) can be asked to write an individual statement on the experiment, without any further instructions from the teacher. The result can vary significantly: some reports will be three lines long, while others are drawings with very little writing. There, too, the teacher can choose a few different statements and ask groups of students to work on one of them, identifying what is missing, what should be highlighted, etc. Once the results are pooled, the class can work together to state what a report should include. There, too, while it can be deemed that the process is too lengthy, the end result is sizeable!



Now, examples of individual and collective writings:

Below is an extract from Sidonie's experiment notebook. Sidonie is a pupil at Bergerac School who, like the other pupils, observed hourglasses and wrote down what she noticed and the questions she asked herself. Afterwards, the children pooled their observations and thoughts (collective writing).

INDIVIDUAL WRITING



Hourglasses

Observe and compare and then note your ideas
(what I notice – what I think).

1. Grains of sand can be several sizes.
2. There are hourglasses that are longer than others.
3. Different colours can change the speed at which the sand falls.

The hourglasses don't always have the same amount of sand.

Sand falling

Sand falling less quickly

5. Sand that falls from slowest to quickest:



COLLECTIVE WRITING



Hourglasses

After using we observe the differences.

Problem: How to explain that hourglasses last a longer or shorter time?

Class hypothesis

This might depend on:

1. The quantity of sand.
2. The width of the cylinder neck.
3. The thickness of the grains of sand.
4. The size of the hourglass.
5. The presence of certain colouring.
6. The volume of the powder.

To check, we are going to do some experiments.
We need to make some hourglasses.

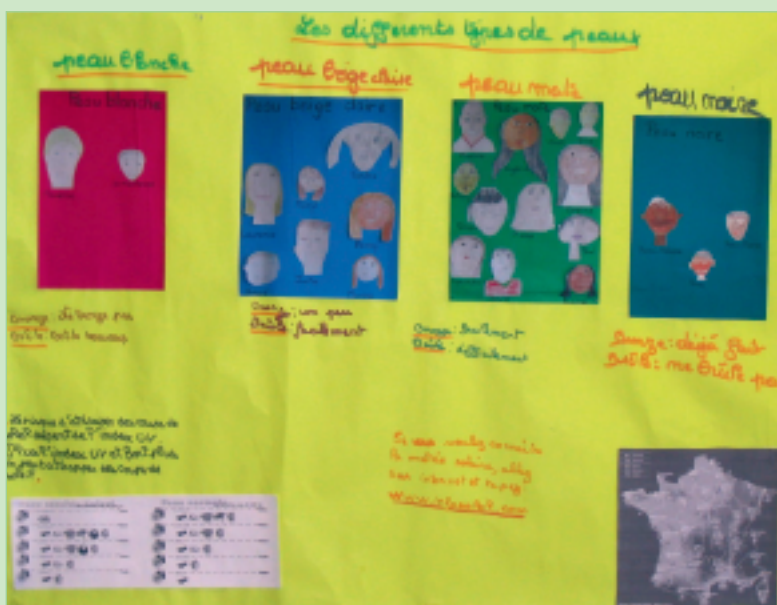
INTERMEDIATE WRITING



Skin type classification,
features given by the children.

Emmanuelle Wilgenbus's classroom
9 years-old pupils
Ecole A. Pajean, France

COLLECTIVE WRITING



Skin type descriptions;
collective writing produced
by the classroom.

Emmanuelle Wilgenbus's classroom
9 years-old pupils
Ecole A. Pajean, France

6



Assessment

Where there is teaching, there should be assessment. We will not discuss “graded” assessment here, meaning testing that gives rise to grades and rankings. We will refer only to “formative” assessment, meaning that which helps children learn and is not a test. The teacher should notice how the children make their observations, express their predictions, explanations and experimental protocol, in order to gather information about the extent to which a given concept has been grasped by the student, some of their skills, etc. From that viewpoint, the experiment notebook can turn out to be a very valuable tool. However, assessment can take place at any time, and need not involve the notebook. Let us look at the electricity example again.

For instance, the children can:

- Be provided with a sheet summarising the various ways in which a battery and light bulb can be put together and asked which work and which do not. The question can be considered an assessment. If, after having answered, the children are given a chance to test the set-ups suggested, they will be able to identify their successes and failures and appraise what they have learned.
- Alternatively, they can be left in groups to design simple electrical set-ups, with the task of drawing all of the results, including those that do not work. Later, the other groups can be asked to check if they are correct by making the drawn set-ups, thus giving the children the opportunity to clearly show what they have grasped and what is not yet very clear.

This kind of assessment turns out to be very effective when used by the teacher to improve his or her teaching, to give the student feedback that is not judgemental, to allow the children to perform self-assessment and to involve them in the decision-making process with regard to how to proceed from that point, etc.



FAQ

Some questions frequently asked by teachers¹².

1. What is the best way to start a new subject?

It is very often said that the child's interest needs to be central to any inquiry-based activity. This does not mean that the child's areas of interests necessarily have to be the starting point. Likewise, in an arrangement where only one child is responsible for the subject, there is no guaranteeing that the entire class will be mobilised regarding the subject. A subject can be broached in a relatively artificial manner, provided that questions arouse the student's enthusiasm.

2. Should misspelling be tolerated in the experiment notebooks?

Whenever students are left to produce written accounts on their own, mistakes have to be expected, especially in spelling and grammar. They are natural and reflect the fact that children cannot do what they have not yet learned... If the teacher makes corrections, it is unlikely that this will lead to progress in the student. It is far preferable that the student him or herself be asked to make the corrections. However, in that case, the risk is that the science sessions become spelling classes and that the students become weary (or inhibited). For these reasons, a certain degree of tolerance appears necessary. However, going too far in that direction could distort the children's view, making them believe that they need only pay attention to their spelling in their reading and writing courses. This would deprive them of an additional opportunity to pay attention to the spelling rules they are supposed to know, recognise and obey. In order to ensure that spelling is gradually understood by the end of primary school, constant attention needs to be paid to it, including during science activities.

The teacher's skill consists of making reasonable demands on his or her students:

- High enough to not tolerate writing that fails to take into account any of what the student is learning or has learned in the field of language, the aim being to develop language "reflexes" and writer behaviours.
- But also to strike the right balance so that certain students do not turn away from their desire to write which, often, can be seen in science activities.

(Note: it is advisable to inform the parents of the "rules of the game" used for the experiment notebook, so that they do not interpret the existence of errors as an excessively laid-back attitude, or even incompetence on the part of the teacher.

¹² Questions and answers extracted from « Guide des formations adaptées à la mise en œuvre des programmes rénovés de l'enseignement des sciences et de la technologie à l'école primaire ». French Ministry of Education, and http://gdes74.edres74.ac-grenoble.fr/rubrique.php3?id_rubrique=30, document available online..

3. How can I go about building upon previously gained knowledge when the students come from different classes?

One option lies in part in the tools set up to ensure that there is continuity between the classes, and even between schools. The experiment notebook that the student keeps throughout his or her schooling is one such tool.

The teacher's log, the sequences and work plans also help ensure continuity and keep teachers informed as to what has already been done.

Lastly, during the progression itself, there are often opportunities to raise many series of questions or raise questions about a single theme, thus making it possible for children from different backgrounds to work on a single topic.

4. How can I go about eliminating faulty rationales without excluding their originators?

This question raises the issue of how an idea and the person who expresses it are often mixed up. Part of the spirit of scientific activity is distinguishing between content (a hypothesis, for instance) and the content producer (the person who comes up with the hypothesis). It can be said that showing the scientific spirit is recognising trial and error as an almost fundamental right and a result of an always-substantiated thought process, even if it turns out to be inaccurate or incomplete. It is thus up to the teacher to not always take into account all of the faulty assumptions, but also to refrain from rejecting them all. Some will help the course of study move forward. In addition, the relationships seen in the classroom between all of the individuals present should make it possible to embrace all proposals and deal with them in a way that is non-judgmental towards people, yet still questions the knowledge involved. It is essential for the teacher to be seen as professional at this time.

5. What should I do if the students do not ask any questions?

The questioning can come from the teacher but, in that case, it needs to be open enough not to inhibit the students and complex enough so that they do not immediately find the answer (*see above*).

6. What should I do when one student immediately provides the answer to the entire class (for example, during a discussion)?

Take it as a hypothesis, just like any other. The fact that one student states the answer precludes neither debate nor experimentation. Remain neutral and unflappable.

7. Asking the students for their hypotheses is an interesting idea. But then isn't there a risk of ending up with a large number of different hypotheses? Should they all be tested? Is this even possible?

It is important to bring out all of the hypotheses, but it is rarely desirable that they all be checked. The hypotheses need to be discussed. As you sort through and deal with them, each step needs to be explained to the students: some hypotheses cannot be checked, while others can be temporarily discarded through reasoning.

Some hypotheses can be set aside temporarily while others are tested. Sometimes, experimentation makes it unnecessary to go back to a hypothesis that has been momentarily set aside.

8. How can I better manage the noise, over-excitement and disturbance often caused by an experimental activity?

- Learning to behave properly is a process that is not specific to science. Regular practice is required. The teacher needs to have set behavioural objectives and, thus, aim for sequential progress in his or her students.
- However, the objectives need to be suited to the students' initial behaviour and age. For that reason, he or she needs to choose the experimental activity in accordance with class behaviour.
- Ensure a proper set-up, and provide enough equipment and time. The experimental stage needs to be short in the beginning (it is important to be able to stop, even if some groups have not finished).
- Constantly go back over the classroom rules. Show that you are present, walk around. Do not give up.
- Your students need to be able to experiment. This is an important part of developing thought.

9. The children do not know how to work in groups. Doesn't this make it very hard to do science?

- Start with paired work to develop cooperative skills.
- Group work needs to be considered a full-fledged learning process.
- To ensure this is the case, have no qualms about moving the tables around so that the students and teacher are comfortably settled in. Give each group member a role (president, secretary, equipment manager, etc.).
- Have no reservations about continuing, even if the initial sessions are not perfect: this is the price to pay for learning.
- Set out a number of rules that need to be abided by, such as:
 - The roles
 - A specific schedule
 - Instructions: what the children must do and produce
 - A signal in case the noise level escalates too far
 - Vary the demands you place on the groups (produce a text, plan, poster, report, hypothesis, carry out document-based research, answer a possibility)



Annexes

Annex 1

Sample module sequence: electrical circuits (From age 8)

Step 1: how to light up a light bulb with a 4.5 V flat lantern battery (model 3R12) but no wires.
(initial approach to concept of closed circuit, emphasising the importance of connections).



4.5 V flat lantern battery (model 3R12), available in some countries.

Step 2: how to light up a light bulb with a flat battery and wires.
(initial approach to concept of closed circuit, emphasising the importance of connections).

Step 3: how to light up a light bulb with a round battery and learning what is in a light bulb.
(third approach to closed circuit: continuous chain of conductors arranged in loop).

Step 4: how to light up and turn off a light bulb without touching the wires. Switches – function and design
(as soon as a circuit is opened, the light bulb stops burning. Consolidating the concept of closed circuit).

Step 5: how to light up and turn off a light bulb without touching the wires. Switches – function and design
(as soon as a circuit is opened, the light bulb stops burning. Consolidating the concept of closed circuit).

- providing different batteries and light bulbs, some working and others out of order, identifying those that work and those that do not or looking at a series circuit involving several light bulbs and seeing what happens when one of the light bulbs is disconnected.

Step 6: how to determine whether electricity is actually short circuiting.
(concept of conductors and insulators, and applying it to security problems).

Step 7 (optional): how to ensure that, when one light bulb is removed from a circuit, the others do not go out.
(concept of parallel and series circuits).

Step 8: various applications

- making a clown whose red nose lights up when his arms are touched (consolidating the concept of closed circuit);
- designing a question and answer game (consolidating the concepts of closed and open circuits);
- lighting up a dollhouse;
- having each group of children design hidden electrical circuits and asking the other children to identify the "hidden" circuit.

Annex 2

Another possible sequence, within the “What happens to the food we eat” module (8-11 years of age)

Step 1: eat (an apple or some bread, for instance).

Observe and describe what happens and what you feel when you chew.

(initial approach to the concept of digestion).

Step 2: drink (water, for instance).

Draw the pathway that food follows inside the body, as you imagine it.

(initial approach to the concept of flow).

Step 2b (optional): dissect an animal (a rabbit or a chicken, for example).

Draw the pathway that food follows inside the body, as you imagine it.

(initial approach to the concept of flow).

Step 3 (optional): watch a movie showing the pathway food follows in the digestive tube.

(consolidating the concept of flow).

Step 4 (optional): produce a model based on the side-view of a head, with moving cardboard components and paper fasteners that make it possible to model swallowing.

(consolidating the concept of flow).

Step 5: produce a model with ping-pong balls and nylon stockings to explain how food can move from the mouth to the intestines.

(consolidating the concept of flow).

Step 6: compare the mass of outgoing waste with the mass of incoming food, if possible from livestock, and make hypotheses to explain the differences observed.

(initial approach to the concept of intestinal absorption).

Step 7: model the passage of food through the intestinal wall into the blood, using a nylon stocking and a mixture of foods (for example, an apple cut up in different sizes suspended in water and a tank to recover what comes out at the end).

(consolidating the concept of intestinal absorption).

Conclusion

1. **Digestion:** meaning the transformation of food into very small pieces.
2. **Intestinal flow:** meaning the movement of food as it is transformed from the mouth to the anus.
3. **Intestinal absorption:** meaning the passage of food into the blood once it is small enough, through the intestinal walls – the larger pieces that remain trapped in the intestine will be eliminated through the faeces.

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