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Seed Cities for Science

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

Designing and Implementing Inquiry-Based Science Units for Primary Education

Text

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www.pollen-europa.net

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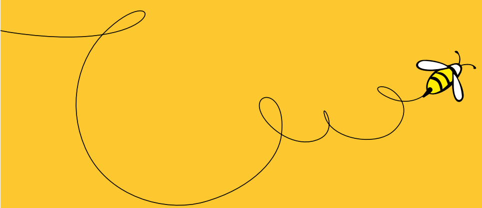

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Preamble

Out of the twelve European countries taking part in the Pollen project, some have been experimenting with the implementation of inquiry-based science education (IBSE) in primary school for several years now, while others have chosen to pursue research studies on the nature of this form of teaching science. The experience gained, obstacles encountered, and research findings are helpful to all of the countries involved in the project. The purpose of this document, intended for primary education teachers in all twelve countries, is to present in Part One some aspects of inquiry-based science, clearly defining what inquiry-based science education entails, and offering some teaching tools drawn from those created by different countries. Part Two provides guidelines for adapting or designing units of study.

PART ONE

Implementing Inquiry-Based Science Education

What is the science inquiry-based approach?

Inquiry-based science education is an approach to teaching and learning science that comes from an understanding of how students learn, the nature of science inquiry, and a focus on basic content to be learned. It also is based on the belief that it is important to ensure that students truly *understand what they are learning*, and not simply learn to repeat content and information. Rather than a superficial learning process in which motivation is based on the satisfaction of being rewarded, IBSE goes deep and motivation comes from the satisfaction of having learned and understood something. IBSE is not about quantities of information memorised in the immediate, rather it is about ideas or concepts leading to understanding that grows deeper and deeper as students get older.

Student learning

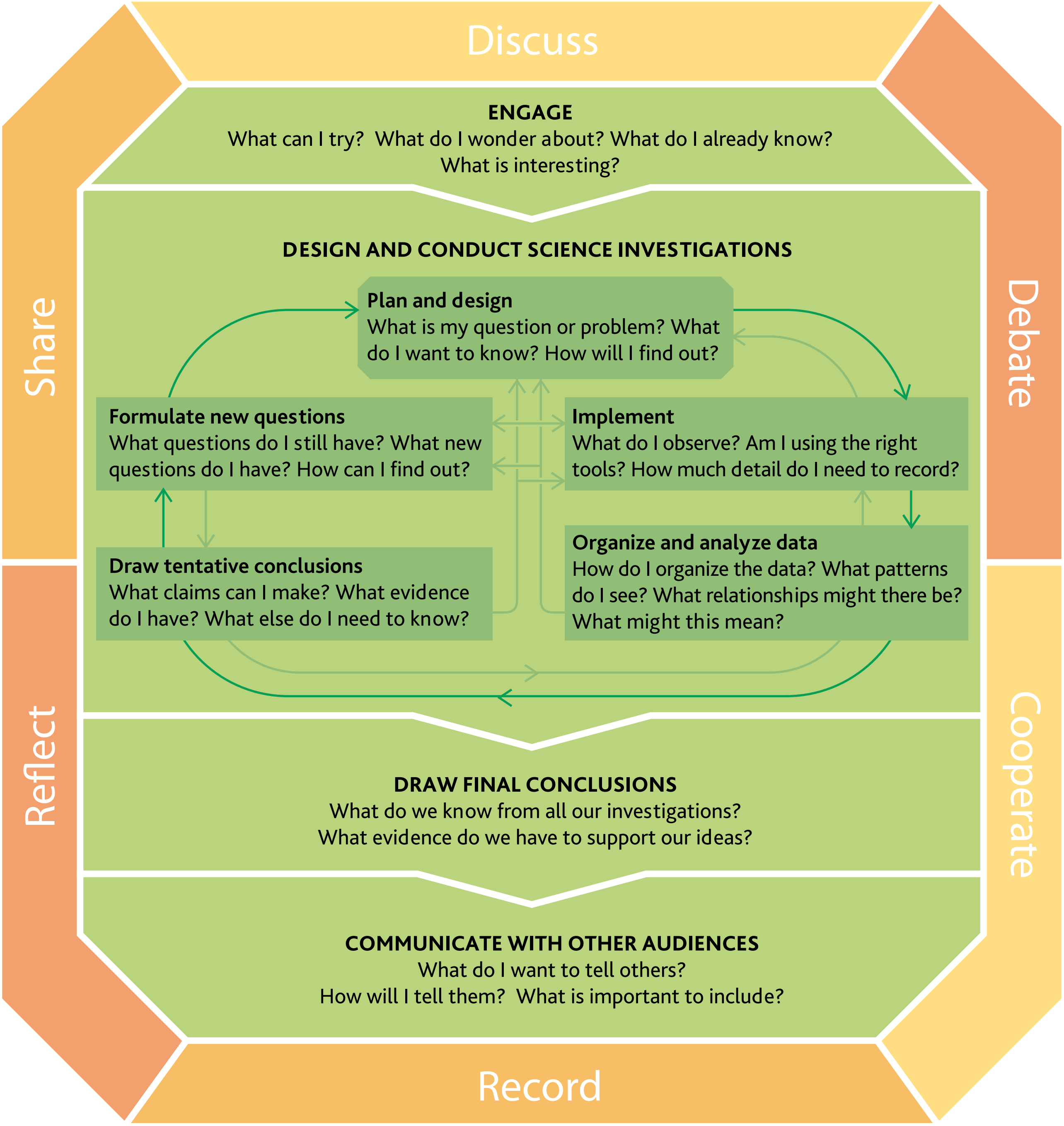
The IBSE draws heavily from experience and research that is providing a clearer and clearer understanding about how students learn science[1]. This research suggests that the natural curiosity of students is, at least in part, an attempt to make sense of the world around them – to make it predictable – by looking for patterns and relationships in their experiences and through interaction with others. Students construct their understanding through reflection on their experiences. It is important to note that this often leads to so-called naïve conceptions that are the result of quite logical thinking but are not scientifically accurate. One example often cited is the belief on the part of many students (and adults too) that the earth's shadow causes the phases of the moon. Given daily experience that indicates that an object casts a shadow when the sun shines on it and that the sun shines on the earth, this idea is not irrational. It simply reflects inadequate background experience and knowledge. Science education involves providing students with additional carefully chosen experiences structured to allow them to continue developing their ideas towards those that are more scientifically accurate.

The nature of science inquiry

Another foundation of IBSE is an understanding of the process of science inquiry. It is represented here as a framework or set of stages that is quite similar to the ways in which scientists go about their work. But there are cautions to observe. **The framework is not a set of steps to be followed**. Rather it is a series of stages that guide the process. For students, it begins with an exploratory stage where they have the opportunity to become familiar with the phenomenon they will study. It then moves to an investigation stage with many parts. The many arrows in the Design and Conduct Science Investigations stage are to suggest that **this is not a linear process**. Science inquiry, whether that of the student or of the scientist, is a complex process and various parts may need to be revisited, dwelt upon, or even skipped at times. For example, if the results of students' investigation do not validate their original prediction, they need to question their assumptions, return to the beginning of their investigation and develop a new experiment. If they design an investigation plan and it doesn't work, they need to redesign. If they come to a tentative conclusion but it differs from that of another team, both teams may need to redo their investigations. A third stage in this framework occurs when students have done a number of investigations and are ready to synthesize what they have learned, often as a whole class and come to some final conclusions. A fourth stage is included here where students communicate their new understanding to a wider audience. There are two final cautions. First, depending on the subjects dealt with, and the nature of the investigation planned, the teacher may emphasize different stages of this framework. Second, a single session almost never includes all of the stages.

1 Duschl, Richard A., Heidi A. Schweingruber, and Andrew W. Shouse, eds. 2007. *Taking Science to School: Learning and Teaching Science in Grades K–8*. Washington, DC: The National Academies Press.

A framework for science inquiry



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

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

Basic science content

A question that is continuously debated is what content students should learn at different levels of their education. When should a specific concept be introduced? What level of understanding should be expected? What information is critical? The general answers to these questions often appear in country or district frameworks and standards. But the specifics depend heavily on the local context and the interests of students and teachers. For example, basic concepts of ecosystems are important for all students to begin to study, but which ecosystem will depend on the context. Do the students live near an ocean? Do they live in a city with a park? Or, when studying electric circuits, students might focus on the use of electricity, on how to wire a dollhouse, or on creating a game using electric circuits.

What are important principles of the inquiry-based approach?

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

Direct experience is at the core of learning science.

Students need to have direct experience with the phenomena they are studying. There are two fundamental reasons for this. The first is that we know from research that direct experience is key to conceptual understanding. The second is that students are continuously building their understanding of the world around them from their experiences. This being true, they come to school each year 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. In most cases, it is not enough to tell them or to show them that a given experiment yields a given outcome and therefore their idea can't be true. Nor is it helpful to tell them that what they think is laden with error. Students need to come to this realisation themselves just as they have done outside of school. They need to raise questions, test them, and draw new conclusions. This does not mean special field trips or complicated experiments involving sophisticated and costly equipment. The experiences can in fact be very simple and require nothing more than going outdoors or ordinary, inexpensive equipment. The sample activities listed on the Pollen site are a good example of what can be done by students. (➔ **www.pollen-europa.net**)

Example

In one classroom described in an article by Konicek and Watson[2] students were talking about heat and temperature and insisted that their "warm" sweaters and jackets created the heat that made them warm. They did 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.

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2 Konicek, Richard and Watson, Bruce. (1990). *Teaching for Conceptual Change: Confronting Children's Experience*. Phi Delta Kappan, May, pp 680-685.

Students must own and understand the question or problem that is the focus of their work.

For students to become engaged and invested in a science investigation and struggle to understand, they must fully understand the question or problem they are working on and it must be meaningful to them. One way this happens is if students have the opportunity to take part in determining the question or problem. But regardless of whether or not this takes place, the students need time to become acquainted with the subject matter; discuss possible questions and problems, think about what will be investigated and how to go about it.

Example

Imagine that a teacher is doing 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 parameters are important in controlling the time it takes for the sand to fall through. A second important outcome is that the students realize they can only achieve useable results if they adjust one parameter 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, so-called lecture-type format, in which the teacher gives the results. This is very different from IBSE

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) And 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.

Doing science inquiry requires that students be taught many skills. One of the most fundamental is focused observation.

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. 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 observe the 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.

Example

In a class studying air, a teacher[3] wanted the students to see 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 students 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 student 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 how quickly the three candles went out.

Learning science is not only acting on and with objects, it is also reasoning, talking with others, and writing both for oneself and for others.

IBSE is sometimes understood to mean only hands on activity. 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 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 a third party, found part of the solution? And, 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.

The use of secondary sources complements direct experience.

IBSE also is sometimes understood to exclude the use of secondary sources such as books, experts, and the Internet. But students will not and cannot rediscover all they need to know through inquiry. The use of secondary sources in IBSE is important but the ways they are used is different from more traditional uses. In IBSE, it is akin to what scientists do and is 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 needed information this way, but they learn how and where to look and the need to consider secondary sources with a critical eye.

Example

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 4 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, there were areas of disagreement and questions. One concerned how many bones there are in the spinal cord, 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.

3 Harlen Wynne, Elstgeest Jos, Jelly Sheila, *Primary Science: Taking the Plunge – 2nd edition*. Heinemann, UK, 2001, 160pp or Harlen Wynne, 2004. *Enseigner les sciences : comment faire ?* - Collection *La main à la pâte*, Le Pommier, 220 pp.

Science is a cooperative 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, 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 there can be different ways to approach the same problem.

Important pedagogical considerations in IBSE

Just as there are important principles to consider when engaging in IBSE, there also are some particular pedagogical strategies that are important to consider.

Organizing the classroom

The physical environment

If students are to engage in hands on investigations in teams, the classroom must be set up to make this possible. Teams need space to work together, access to materials, and places to put work in progress. Some 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 school, 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 a bit more expensive, relatively few, such as batteries, measuring tools, a scale, 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.

Practical suggestions

- Space for materials, works in progress, and displays can be an issue in many classrooms. There are few good solutions, but in some places teachers can work together to find common areas for storing materials and displaying student 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.

The classroom culture

IBSE is about 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 are considered the hands-on students. For IBSE to be effective, 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

- 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.
- Questions that you ask can help as well: *"What **do you think** is happening here?"* may elicit more ideas than simply "*What is happening here?"* Giving students a few minutes to think about a question or having them talk with a partner can also encourage students who are reluctant to speak.
- Establishing well working teams is not easy. It is a learning process in and of 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.[4]
- Teams work best if they are small (4 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.

Crafting and asking questions

The questions teachers ask, whether of the full group, small group or individual, play a very important role in IBSE. Good questions move the work forward; less good questions are unlikely to do so. Jos Elstgeest in *Primary Science: Taking the Plunge*[5] states it this way: *"A good question is the first step toward an answer; it is a problem to which there is a solution. 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'."* 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.

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?"* Or, *"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?"*

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4 Kagan Stephen. 1993. *Cooperative Learning*. Kagan Publishing; Johnson, David & Johnson, Robert. 1999. *Learning Together and Alone*. Edina, MN. Interaction Book Company.

5 Harlen Wynne. 2001.

- There are other questions you might ask students as they are working. These too can 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.
- Sheila Jelly states in W. Harlen's work, that *"the key to expressing specific questions in special situations is none other than practice"*[6]. To this effect, she suggests examining the questions suggested in students' science books, trying to answer the questions, asking whether they are empty or meaningful; looking to determine what scientific experiment is encouraged. Working with other teachers also can be very helpful.

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. It is important to keep in mind that some of these ideas, referred to as students' preconceptions, initial conceptions, misconceptions or naïve conceptions may be quite reasonable but are constructed on limited experience and knowledge. One example is the belief that seeds need light in order to germinate. As plants grow they do, but initial growth can happen without light. 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. Hearing the ideas of others, whether they are accurate or not, may open up new ways of thinking.

Teachers who are familiar with the research on some of the more common naïve conceptions, who listen to students, and take their ideas seriously can adapt and guide classroom activities so they provide students with specific challenges that allow new and more coherent explanations to emerge. This can ensure that students have the opportunity to see that other ideas than their own may explain a phenomenon more effectively. (➔ **See formative assessment section**)

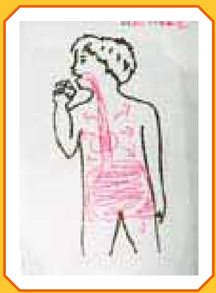
Example

One example comes from electricity. A number of students believe that putting a light bulb on one battery pole is enough to light it up. There is nothing like letting them experience the phenomenon on their own and see that the bulb will not light. Other students think that electricity comes out of the two poles and enters the bulb. Some will specify that the bulb lights when the electricity from the two poles comes together. Although incorrect, both of these explanations show a certain logic. They know the bulb needs "energy" from the battery (many have battery operated toys) and that "energy" has to get to the bulb but they don't know exactly how. Experience lighting a bulb with wires and using more than one bulb in a series can help them to begin to expand their experiences and arrive at a different conclusion.

6 Harlen Wynne. 2001.

Example

Another naïve conception held by quite a few students relates to their body functions. When asked what becomes of the food[7] we eat, 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. In these and other cases, it is important to ensure that the students first express their ideas and, subsequently, are encouraged, through questioning and discussion, to think again. "What happens when you eat minestrone?" "Has something ever gone down the wrong way?" "What does this mean to you?"



Nanjing (China)

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Practical suggestions

- Research has identified some common naïve conceptions students of different ages hold. Knowing about these is helpful in allowing you to be prepared for them to emerge and also to have some activties for your students to broaden their experiences. You can find good resources on the web and in publications on student learning. See Pollen Web site (www.pollen-europa.net) "Learning Units" section and Giordan André, de Vecchi Gérard, 2002. *L'enseignement scientifique. Comment faire pour que ça marche ?* Delagrave – collection Pédagogie et formation, 271pp.
- As often as possible, consider beginning a unit or new investigation with a discussion about what students think about the subject of the unit so you and they can get a first glimpse of their experiences, ideas, and ways of reasoning about a phenomenon. More will be revealed in what they 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. In other words they need to feel that it is safe to share their thinking. 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.
- If there are students who share ideas that are correct, it is important to simply accept these along with all the others. Any sign that these are correct will likely 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 experiences by the time they come to your class. One classroom investigation is unlikely to outweigh that experience. They are likely to need a variety of experiences and discussion before they are willing to question and modify their ideas[7].

7 Konicek Richard and Watson Bruce. 1990.

Holding group discussions

Discussion amongst students is one of the most important aspects of IBSE. It 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 characterized 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 worth it.

When they take place these whole group discussions have an important role to play. They give the students the opportunity to make their own ideas explicit. Students also hear and discuss the ideas of others, realize that the ideas of others may be rooted in facts they had not considered (such as in the spinal cord bone example, mentioned above) and, in certain cases, decide as a group to retest their results and continue 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 makes discussion easier and can make an enormous difference in the dynamics of a discussion. One way to do this is to seat students in a circle that includes the teacher and in which there is no front of the class. This can be impossible in classrooms where there is little space, but by turning chairs, pushing some pieces of furniture aside and having students turn their bodies it can happen in most places.
- Slowing down the discussion helps many students to join the conversation. Asking students to think for just a few seconds before responding to a question allows them more time to organize their thinking before participating. Waiting 5-10 seconds when there is a silence also can deepen a discussion or surface new ideas.
- It can be hard at first to stop students from talking to you and have them 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?"*.
- As your role shifts from questioner and teller to facilitator and guide, it is vital that you talk less and refrain from providing or leading students to the "right answers". Likewise, you will want to consider carefully when it is time to intervene to settle a disagreement between two students. Questions and comments such as *"How could we find out?"*, *"We may need to try…"*, *"Let's look at our data…"*, encourage students to continue the discussion.
- 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 unit, however, guiding the class to a more accurate conception is important.
- More open discussions also invite student questions, many of which cannot be answered by investigation and some of which you may not be able to answer yourself. 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 you, from a scientist, in books, or on the Internet. You will model important behaviour if you simply respond to questions you can't answer by saying *"I don't know, but we are going to try to find out together."*

Guiding student recording

Making a record of science work, including text, drawings, flowcharts, graphs, charts, posters, etc., is an essential part of the IBSE. It supports students learning as they try to clarify their thoughts and put them into words in written form. 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 realize that a specific concept they thought was well understood is not really clear or is understood in an entirely different manner. This allows them to arrange and adjust instruction rather than waiting until test time, which may be several weeks later.

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. Writing gives 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.

The science notebook

The primary context for individual student record keeping is the student's science notebook. Just as scientists do, each student in IBSE keeps a notebook. This notebook may take a variety of forms and include a variety of types of writing. Whatever the structure, the notebook contains the story of the students' inquiry throughout a unit, several units, or even over several years. It may include drawings, flowcharts, as well as text. It includes in some form the question or purpose of the investigation, predictions, ideas, and investigation designs. 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 to gradually develop the skills needed to organize and keep complete records of their work.

Team recording

When students take on a group project, the teacher may ask them in advance to prepare a group written record, a poster, experiment protocol, technical object, etc., to present their ideas and tentative conclusions to the whole class. These conclusions generated by the working group help them to synthesize their thinking and figure out how to convey to others what they think and/or have done. Such statements may be more formal than the records in the notebooks, as they have to be clear and concise presentations for the other students in the class.

Class recording

These are conclusions developed jointly as a class with the teacher's guidance, with the specific goal of expressing the thinking of the whole class while ensuring that the conclusions do not stray from facts established by the scientific community. Some would call such writing a summary and/or the "knowledge" the class has come to. These class recordings are a more formal recording as they 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; describing the protocol to be used; or pausing for a moment during an investigation to quickly record new data. A short time at the end of a lesson for a quick reflection can also be useful. When students are asked to stop and reflect on their work and come to a tentative conclusion, more time is needed.

- There are many recording skills students need to learn and practice if they are to make best use of their science notebooks. These may need to be taught specifically (hopefully during their language instruction time). It is helpful as well if students see models of ways to record and have time to share their work. Even very young students can and should record their work in a science notebook. If they do not yet know how to write, you may ask them to draw. Older students are also likely to need guidance on points of detail and labelling as well as on how to use diagrams and other graphics.
- 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 organize 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 elaborate on 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 your requirements.
- Care should be given to make sure that the writing students do is essential to their science work. Copying from the board, for example might be replaced by a sheet to be inserted in the notebook.
- A variety of structured pages may be helpful in supporting students' notebook writing. These may help organize 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 thinking of the student.

Specific pedagogical strategies

The strategies described above are quite general and apply to the whole module. There are, however, several processes at particular stages of an IBSE module which are difficult for students. Some strategies suggested for guiding students are described below

Guiding students as they design an investigation

Learning to design an investigation is an important part of understanding the nature of science. But it is not easy and students need to learn the skills. This means working closely with them, especially in the beginning. The process often begins with a full class discussion to clarify the question or problem and determine what elements of the phenomenon are important to study. In an experimental investigation, the next step is to discuss how to test the factors, one after another, using the equipment available. Students often have a difficult time realizing that in order to be able to interpret the experiment, only one factor can be varied at a time with all others kept constant: they must learn to do a controlled experiment. This is a skill that develops over time. For very young students identifying one variable is enough. If the investigation is observational rather than experimental, students need to discuss what would be important to observe, how they will observe, and how they will collect their data.

Example

Using the hour glass example again, the students in one class decide to determine whether the time it takes for the sand to run out is determined by the size of the hole. They need to realize eventually that they must set up two hour glasses changing only the size of the hole. (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.). Left on their own, a number of groups vary several parameters at the same time. The ensuing group discussion leads them to realize that their results are not useable or comparable and that they need to redesign their experiment.

Another class is studying the concept of habitat focusing on the land snails they have seen around the class. The students are excited about going outside to look for the snails. The teacher brings them together and prompts them to think more carefully about what they will do asking, “Once you find one, what will you look for?” “What information do you think we need to gather in order to know how the snail meets its needs?” “How will you record what you see?” Teams of students then gather together and each comes up with ideas of what to do. In a class discussion, they agree that each of them will go to a different place to look. A discussion ensues about what to do if some teams find no snails. The teacher carefully guides them to realize that collecting data from places with no snails might be just as important as the data they would collect where they found snails.

Practical suggestions

- When designing an experiment, it is important for students to realise that varying everything at the same time does not help reach conclusions. When pooling the results, it is advisable to help students grasp this issue, by asking questions such as: *“Why do you think these results are so different?”*, *“How did you decide that…”*, *“What suggestions do you have for next steps?”*, *“How might we redo the experiment?”*.
- Students are often reluctant to carry out an experiment several times in order to ensure that no mistakes have been made and the results are dependable. When they are encouraged to do so, they begin to realize that mistakes and differing results are expected and therefore repeating experiments or observations must be built into the plan. They also will realize that if their results are not compatible with the results of another group then it may be necessary to repeat an experiment.
- When students are designing a more observational study, you may want to first take them to the site or show them what they will be observing in class. This will give them a context in which to design their investigation and determine what is important to look for.
- One of the problems when designing investigations lies in the equipment available to the students. Several options exist: either you give each group of students the material required for the suggested investigation(s), or the material can be put on a table and the students can work together to decide how they will do the investigation and what materials they will need.
- Students need to learn how to use various tools to establish “appropriate” designs for their investigations including ways to record data such as charts and graphs, and diagrams. Students may need guidance in making and recording quantitative observations. They are likely to use terms such as bigger/smaller, many/some, faster/slower. They need reminders and sometimes explicit instructions on how to quantify their observations and use appropriate tools.

Helping students analyze their results to reach valid conclusions

During the experimental or investigative part of a study, the students build up experiences and some tentative knowledge. However without rigorous reflection, this knowledge can be patchy, fragile or even fleeting. An analysis of the findings from the investigations, and the drawing of conclusions will make it possible for the students to build knowledge that is more reliable and meaningful. Following each investigation, it is important for each working team 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? This is followed by a full class debate about important questions such as the following: *"What differences are there among the groups? Are there doubts as to the findings?"*, *"Do certain experiments need to be repeated?"*, *"Is more observation necessary?"*, *"Which predictions were confirmed, and which were not?"*, *"Is there a need to come up with additional ideas and experiments and, if so, which ones?"*. This may lead to a return to the beginning of the investigation stage of inquiry.

Example

A class was studying what plants needed to grow and develop. They had predicted that plants would need light and proceeded to plant several beans in two containers, placing one in the light and one in the dark. To their surprise the beans grew in both places and had real leaves. The plants were brought to the whole group discussion at which point they noticed that the plants growing in the dark were tall and skinny and those in the light bushier: "healthier" they said. The discussion was lively with some students maintaining that green plants needed light. As a group they decided to continue the investigation and see what happened over the following weeks and try the same thing with different kinds of seed.

A class is engaged in a unit on the properties of materials and conducting experiments on the "mixing of solids and liquids". At the end of the session, several groups present their findings, concluding that "water and salt do not mix" whereas others have evidence to claim that it does. (The students had used the same amount of salt but very different amounts of water!) The teacher does not react to the "students' findings" but asks what is to be done? The students discuss the possible problems, including different amounts of water and in a subsequent session, with guidance from the teacher gradually increase the amount of liquid leading to the "correct" conclusion, that there is a limit to how much salt can be dissolved in a certain quantity of liquid at a given temperature.

Practical suggestions

- It may be useful to distinguish between claims supported by student gathered evidence ("Water evaporates more quickly from the containers with a larger surface area.") and explanations which are attempts to explain why or generalize from the specific claims ("I think this is because the water evaporates from the surface and therefore can escape at the same time if there is more surface. It goes faster").
- The effectiveness of the discussions depends not only on the students' skill at talking about their work and expressing themselves orally, but also on their ability to listen carefully to one another and debate, rather than simply respond to you. (See the section on leading discussions.)
- Discussions take time. One way to use time more efficiently is to have teams share their data on a class chart or post their claims and evidence around the room before the discussion begins. In this way the discussion can start with the key question and not with sharing from each team.

- Your role is essential in keeping students focused on the original question or problem, insisting on the use of evidence from their science notebooks, and providing a clear summary at the end of the session. The students need to understand that evidence and scientific reasoning are what will 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.

Comparing and contrasting with "established fact"

Students "discover" nature's phenomena and properties; they experiment and compare their conclusions amongst themselves, like a community of scientific researchers might do. However, unlike the researchers, students are not discovering phenomena and laws that are unknown to the scientific community; rather what they learn in school is established scientific understanding. Therefore comparing and contrasting is essential. The example above is one way. Here the teacher guides the students to a new and quite structured investigation. In another situation the teacher might instead suggest referring to other sources such as books, the Internet or local scientists. In both cases, students are eventually guided towards an understanding that reflects scientific knowledge, although at the level appropriate to the students.

Formative assessment

Formative assessment has its own section here; however, many would consider this to be one of the most essential pedagogical strategies in IBSE. This is not a section about "summative" assessment that takes place at the end of a unit or year. The latter often means testing that gives rise to grades and rankings and can make students very anxious. Rather this section is about so-called "formative" assessment, meaning assessment the purpose of which is to guide teaching and learning. In formative assessment the teacher is looking at how and at what level students understand a concept and how they are thinking about their work. By observing all aspects of student inquiry – e.g. how they make their observations, the questions they raise, the investigations they design, their predictions and explanations and experimental protocol – teachers often are able to see what is clear to students and where their confusions lie, as well as the extent of their understanding of inquiry and of their abilities to reason scientifically.

What teachers learn from formative assessment is primarily used to guide instruction. It may be evident from the assessments that students need more time to work on a particular concept or skill. Assessment 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. Formative assessment is useful not only to teachers to guide their instruction but also to students to guide their learning. 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.

There are many different places and situations in which the teacher can gather information. The science notebook is one very useful source. So are observations of students as they work in teams, their presentations, and the questions they ask each other. Large group discussions are also rich in information about student thinking, as are tasks designed to reveal student thinking. Whatever the source, an efficient strategy for recording data is clearly needed.

Example

The following are examples of possible formative assessments. They are not presented in any order or systematically. In a unit focused on electric circuits, formative assessments might include the following.

- A sheet asking students to indicate which of a number of drawings of a battery and light bulb would work and which would not and why. Having answered these questions, they test the set-ups, identify their successes and failures, and explain what has happened.
- A challenge to the groups to draw as many ways as possible of connecting a battery, bulb, and wires in simple electric circuits, including those that they think will not work. After checking their drawings with materials, they explain why their predictions were correct or not.

In a study of shadows with young children, formative assessments might include the following.

- A challenge to the students to make their shadow outside taller/shorter/disappear
- Setting up a shadow puppet theatre and observing how the students make the shadows do what they wanted them to do.

Practical suggestions

- Designing useful formative assessment tasks is not easy. In good curricula they are provided and can be used or adapted. The Internet can provide useful examples as well.
- 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. Be careful not to assume that students who have trouble writing or speaking do not understand science. They may have learning needs in communication but not in understanding science.
- Systematic recording of data is part of formative assessment. For written data this is less difficult. Student work can be collected, read, and responded to outside of class. Observational data is harder to manage because it must be collected on the spot. Many teachers have developed a variety of strategies. One is a table with the concepts and skills across the top and student names down the side and space for a comment or two. Another is a notebook with pages for each student where brief notes, comments and sticky notes can be collected for later analysis. Yet another is simply the use of index cards to be organized at another time.
- Data must, of course, be analyzed and used to guide instruction in order to be useful. What does it mean that student X responded in a particular way to a challenge? How do I adapt my instruction? Many teachers have found it to be valuable to examine student work together to seek answers to these questions.

Summary

Inquiry-based science education (IBSE)

inquiry-based science education is grounded in the belief that it is important to ensure that students truly understand what they are learning, and not simply memorize content and information.

It is an approach to teaching and learning science that comes from :

1. An understanding of student learning

- Students attempt to make sense of the world around them - to make it predictable - by looking for patterns and relationships in their experiences and through interaction with others.
- Students construct their understanding through reflection on their experiences.

2. The nature of science inquiry

The process of science inquiry can be represented here as a set of 4 stages:

- Explore: students become familiar with the phenomenon they will study
- Investigate: students plan and carry out investigations
- Draw final conclusions: students synthesize what they have learned and come to some final conclusions.
- Communicate: students communicate their new understanding to a wider audience.

It is important to note that: 1 the process of inquiry is not a linear process or set of steps to be followed; 2 depending on the content, and the nature of the investigation, the teacher may emphasize different stages; and 3 a single session almost never includes all of the stages.

3. A focus on content

An overview of important concepts often appears in country or district frameworks and standards. But the specifics depend heavily on the local context and the interests of students and teachers.

Important principles of the inquiry-based approach

Direct experience is at the core of learning science.

Students need to have direct experience with the phenomena they are studying because:

- direct experience is key to conceptual understanding
- students build their understanding of the world around them, naïve or accurate, from their experiences;
- words alone often have little power to change these ideas.

Students must own and understand the question or problem that is the focus of their work.

For students to become engaged and invested in science investigations they must understand the question or problem they are working on and it must be meaningful to them.

Doing science inquiry requires that students be taught many skills.

There are many important science inquiry skills including making observations, asking questions, making predictions, designing investigations, analysing data and supporting claims with evidence. Of these many skills, one of the most fundamental is observing closely and determining what is important to observe.

Learning science is not only acting on and with objects, it is also reasoning, talking with others, and writing both for oneself and for others.

In order for direct experience to lead to understanding, students need to think about their hands-on work, discus and debate it thoughtfully with others, and write about it.

The use of secondary sources complements direct experience.

Students will not and cannot discover all they need to know through inquiry. The use of secondary sources in IBSE is important in the service of students' explorations, not as a substitute for them.

Science is a cooperative endeavour.

Science investigation is usually collaborative. When students work together in small groups or teams, they are sharing ideas, debating, and thinking about what they need to do and how to do it.

Some important pedagogical considerations in IBSE

Organizing the classroom

If students are to engage in hands on investigations in teams, the classroom must be set up to make this possible with appropriate materials accessible to students and adequate space. If students are to work and learn together, all must feel comfortable and have the opportunity to participate in all aspects of the science work - the hands on, thinking, talking and writing.

Creating and asking questions

The questions teachers ask play a very important role in IBSE. Productive questions 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.

Using students' prior experiences and ideas

Students generally have ideas about the phenomena they encounter in their day to day lives, some of which are incomplete or contradict scientific ideas. Teachers need to take these ideas seriously and adapt classroom activities to allow new and more coherent explanations to emerge.

Holding group discussions

Discussion amongst students provides opportunities to make ideas explicit; hear, discuss and debate the ideas of others; and agree on conclusions. They take place throughout the inquiry process between pairs, among team members, and as a whole class.

Guiding student recording

When students record their work they learn, realise the progress they have made, remember what has been accomplished, and note the development of their thinking. Records of science work include text, drawings, flowcharts, graphs, charts, posters, etc., Students keep science notebooks, produce written documents for presentation, and prepare reports. Teachers, as they read students' work, can assess their development and note the nature of their thinking.

Pedagogical strategies for specific stages of inquiry

Guiding students as they design an investigation

Learning to design an investigation is an important part of understanding the nature of science. The process often begins with a full class discussion to clarify the question or problem and determine what elements of the phenomenon are important to study. In an experimental investigation, the next step is to discuss how to test the factors, one after another, using the equipment available. If the investigation is observational rather than experimental, students discuss what would be important to observe, how they will observe, and how they will collect their data.

Helping students analyze their results to reach valid conclusions

Analysis of the findings from investigations and the drawing of valid conclusions are critical for students to build reliable and meaningful knowledge from their investigations. This process occurs at the class level following each investigation and at the end of a part or the whole of a unit.

Comparing and contrasting with "established fact"

As students investigate natural phenomena, they develop and compare their conclusions amongst themselves and construct new understanding. But unlike scientists, students are not discovering new phenomena and laws; rather what they learn in school is established scientific knowledge. Therefore they need to compare and contrast their work with the known by referring to other sources such as books, the internet or local scientists.

Formative assessment

Formative assessment goes on continuously throughout a unit of study. It is a tool for both teachers and students whose purpose is to guide teaching and learning. It is different from "summative" assessment that takes place at the end of a unit or year.

PART TWO

Designing Inquiry-Based Science Units

Introduction

Given the approach to teaching science described in Part 1, the question now is, "What does this look like when it is all brought together in the form of a unit of study?" It is important to note that IBSE units are not likely to be the only way students learn science. Some concepts may be addressed through more text-based units; others may be thematic. What is important is that students experience IBSE units every year in order to develop a deep understanding of certain basic science concepts and, equally importantly, what it means to do science and to construct an understanding of science concepts from direct experience.

There are several basic characteristics of an IBSE unit. 1 It requires students to engage in a process of scientific inquiry using objects and materials. 2 It focuses on a small number of basic ideas or concepts. 3 It is relatively long so that the concepts can be elaborated upon for several weeks. A unit may have anywhere between 10-20 sessions depending on the content. 4 Learning experiences follow one another in a carefully designed order. Each is designed as a follow-up or prelude to others in a sequence.

Regardless of the details, all IBSE units reflect the fundamental principle that in science education, it is not enough to teach the results of science, students must do science and have opportunities to express their ideas, expose their reasoning, test their predictions and engage in rigorous scientific investigation. The inquiry performed by the students may include a range of methods including direct experimentation, the production of an object or model, the use of instruments for observation and recording, document-based research, and the development of a presentation using a variety of media.

There now exist many units, both published and on the internet that reflect these characteristics (e.g. the Pollen web site, **www.pollen-europa.net**, Learning Units section; the *Main à la pâte* site, **http://www.lamap.fr**). Many other resources describe single science activities or series of activities on the same topic. While these may provide good ideas to use in an IBSE unit or as short enrichment activities, they do not by themselves equal an IBSE unit because they are lacking all or most of the characteristics described above.

There also exist many thematic or integrated units such as a unit on water or air pollution or health. These too often do not reflect the characteristics described above. They generally cover many concepts that are linked to the theme and often consist of demonstrations of the science involved rather than of student inquiry. Such units introduce students to important issues and information and may lead to an IBSE unit as described here.

The following pages provide some guidelines for the development of an IBSE unit, using adaptations of two existing units to illustrate the ideas (see examples, pp 42-56). The content and topics of the two units selected are very familiar so as to be able to focus on the structure and design of the unit, not the content itself. The full units are not provided; rather they are described in some detail in order to illustrate the guidelines. Following each description is a single learning experience to illustrate guidelines more specific to the design of a learning experience.

Many terms are used in describing a unit and its parts. In the following pages we write about a unit, a learning experience and sessions. By unit is meant an in depth study of a few selected concepts over an extended period of time. A unit is made up of learning experiences generally focused on a single investigation. A learning experience may be made up of one or more sessions (lessons).

Designing the overall structure of the unit

Designing or adapting a unit of study is a complex process. The five steps described here make a logical sequence. However, in reality, development is an iterative process in which the developer returns often to previous steps. For example, as you begin to select learning experiences, you may need to revise part of the conceptual structure or storyline or that you have found a better starting point. A revision in the storyline of the unit may influence the assessment. A different revision may lead to the decision that another learning experience has no place and must be abandoned.

Selecting the content

The starting point is to think about the basic content of a unit in relation to the students for whom it is designed. Questions to consider include the following:

- What phenomena and basic science concepts will be the foci of the unit?
- What are likely prior ideas and experiences students will bring to this unit?
- What level of understanding of the selected concepts do we expect students to achieve? What are possible assessment questions and tasks we might use and what outcomes would we anticipate?
- What science inquiry and/or technology design skills will be emphasized?
- What attitudes about science should be identified?

Examples from the two units

The descriptions of the two units used as examples, begin with the answers to these questions. We provide a description of the learning experiences, a list of the basic concepts, and a diagram of the storyline. Notice that there are only a few basic concepts presented in the 5 learning experiences (14 sessions) of A Seed? A Plant? The unit focuses on the role of the seed in the life cycle of a plant, the conditions needed for growth, and the stages of germination as defined by the development of parts of the seed and seedling, but leaves for another time such things as photosynthesis and how water reaches the leaves of the plant.

In the 5 learning experiences (12 sessions) of the Clown with the Bright Nose, the focus is on the characteristics and functioning of simple electric circuits, and topics such as complex circuits, motors, or electromagnets are not included. This narrow focus reflects a knowledge of students' misconceptions and the need to provide a range of experiences around the concept of the complete circuit. (**See footnote 1, p. 32.**)

With only a few concepts and this many sessions, the students have the time to design and conduct investigations, respond to some of their questions and ideas, and reflect, discuss and write about how they are thinking and what they are learning.

Practical suggestions

- When considering the level of understanding you wish students to achieve, it may be helpful to think about what you would hope students would be able to say (in their own words) or do at the end of a unit.
- As you begin to design or adapt a unit, it can be interesting to talk with small groups of students about the phenomenon and possible topics, questions, and/or challenges. What seems to spark their interest? What do they appear to be familiar with? This can help you determine the knowledge and experiences they or other students are likely to bring to the unit and possible interesting and meaningful contexts.

- Any science theme or issue is complex and can be considered from many different perspectives. For example, a study of an ecosystem such as the forest could include the study of the concept of habitat and the needs of different organisms, interdependence between living things and the idea of a food chain, populations and how they are controlled, adaptation, and evolution. The list could go on and on. Selecting one or two as central to a unit is essential.
- Even at this stage of the development, you might think about the nature of investigations students might do to be sure that inquiry-based work is possible.

Selecting the context

Once the concepts are clear, the next step is to decide the context in which they will be explored. For example, a unit on levers and other simple machines might have as a context the construction of a local building, the pyramids of Egypt, or a study of playground equipment. Some phenomena are intrinsically interesting in and of themselves, and need no other context (e.g. the study of the properties of water, the systems of the human body). The context can influence how meaningful the unit is to the students as well as the kinds of connections and applications they will make to their daily lives or to other areas of study.

In selecting a context or theme, some questions to consider include the following:

- Where in the day-to-day world of the students are the phenomena, objects, and materials through which the concepts might be addressed to be found?
- What context allows for significant investigation, in-depth and over time?
- What is likely to be engaging and/or of particular interest to the students?
- What materials and resources are available?

Examples from the units

The context for the unit on electrical circuits is a technological problem – how does the nose of the clown light up. The students might also have approached the concept by focusing on how a simple toy can be made to move or simply with a question: *How can we light a bulb using batteries and wires?* The problem is set at the very start of the unit and the students return to it at the conclusion.

When studying seeds and germination, there also are many contexts to choose from. In the seeds unit, it is the seeds students find in their surroundings. Planning and starting a small school garden might also have been an appropriate context for this unit. The unit opens with a field trip and the question, *what is a seed?* This is followed later in the unit with another question – *what does a seed need to germinate?* Finally there is a third question for the fourth learning experience – *how does a seed grow?*

Practical suggestions

- Once again, you are likely to get some interesting ideas if you talk with groups of students and listen to the questions they have and the experiences they bring up from their daily lives.
- If the content can be related to something that is happening locally (the construction of a bridge, the growing of a particular crop) or to the local environment (seashore, river) students are more likely to connect and apply their growing understanding to the world in which they live.
- IBSE requires resources, materials and often people. Your decision about context may well depend partially on who and what is available to support in-depth study.

Developing the storyline

The progression of ideas and learning experiences in a unit is very important. A unit cannot simply be made up of sets of activities on a topic. Learning experiences must follow one another in a carefully ordered sequence that is organized to allow the students to construct particular understandings. This is not to say that there is only one sequence or one best one. Nor does this mean that one should not spend time on a student-generated question that may arise during the unit. But for the teacher and student alike it should be clear why one learning experience comes before or after another and how students are developing their understanding and skills. Questions to consider include the following:

- What is the progression of learning for each concept?
- What misconceptions might students have?[1]
- How will each learning experience build on what came before it and lead to the following learning experiences?
- What do we assume has been experienced/understood at the end of each learning experience that will inform the next?
- How is understanding deepened as the learning experiences progress?

Examples from the two units

Each of the two sample units includes a diagram of the conceptual storyline written in the language of students. This is not necessarily the logical sequence a scientist might construct. You will notice that the central boxes and arrows are in bold. This is the core progression or development of the basic ideas of the unit. The boxes and arrows that are not bolded are the supporting ideas.

You also will notice that the learning experiences may be identified more than once in different boxes. This is because a specific idea may be started in one learning experience and followed up in another. In the seed unit, for example, the students germinate seeds several times, thus gradually developing their understanding of the necessary conditions for germination. What seeds need to germinate, however, is the specific focus of learning experience three and is bolded. In the clown unit, the idea that certain materials will conduct electricity arises in a session in the 2nd learning experience when students examine the inside of a light bulb, but it becomes a central focus in learning experience five.

Practical suggestions

- It can be helpful to look at sample units[2] and try them out in order to become familiar with this approach. Later on, you can adapt or design your own units.
- Reviewing common student misconceptions may help in the design of the storyline, in particular in thinking about supporting ideas.
- Once developed, the storyline is a very useful guide to the design of formative assessment strategies throughout the unit.

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1 There is a great deal of research on this topic. These websites represent three of many sites that attempt to synthesize this research. **http://www.eskimo.com/~billb/miscon/opphys.html**, *Children's Misconceptions in Science*, American Institute of Physics: **http://www.newyorkscienceteacher.com/sci/miscon/index.php**, *Science Misconceptions*, New York Science Teacher; **http://homepage.mac.com/vtalsma/misconcept.html**, *Children's Ideas in Science*.

2 See Pollen web site (**www.pollen-europa.net**), "Learning Units" section.

Designing the end-of-unit assessment

Given a clear set of goals (concepts, skills, and attitudes,) a context, and the storyline, we strongly suggest that there be a return to the consideration of how student progress will be assessed. The assessments designed at this stage may need revision later in the development process, but they are an essential part of the early development process as they insist on an understanding of exactly what is meant by the major goals of the unit and the level of anticipated understanding.

Many final assessments include both a written component and a performance component. This provides students with at least two ways to demonstrate what they have learned, one of which is less language-dependent. In addition performance assessments are often far better at assessing student skills than paper and pencil ones.

The final assessment does not stand on its own as a strategy for looking at student progress. The information it provides is simply added to the information collected by the teacher and students through the on-going formative assessment process. In many instances, IBSE units include a pre-assessment similar or identical to the final assessment so that the teacher and the student can reflect on progress made.

Assessments are difficult to develop and this brief section is designed simply to raise awareness of this component of unit design and to suggest that thinking about assessment can help the process of developing or adapting a unit. Following are a few questions to think about in the development of unit assessments:

- What are the main ideas of the unit to be assessed? What are the skills?
- What questions and tasks will allow students to demonstrate their understanding rather than what they remember or have memorized?
- How will the task or question differentiate between students' language skills and their understanding of science?
- Do the tasks or questions allow for responses at different levels rather than simply a right or wrong answer?
- Do the questions or tasks deal with experiences that are accessible to all students?
- How will the results be analyzed and evaluated?

Examples from the two units

In the two sample units, the final assessments are only briefly described. In the clown unit students first construct their own circuit to light the nose of a clown and then are challenged to take a second bulb and light one eye. In each, they are asked to write an explanation of how the circuits work.

In the unit on seeds, students are asked to make a small poster that describes the stages of development of the seed during germination and includes a brief statement of why each stage is important. They are also asked, in pairs, to write a short note to another class about how they should plant seeds so that they are likely to grow well, and why the specifics of the directions are important.

Practical suggestions

- Many times you will find that a task or question you design is interpreted by students very differently from the way you anticipated. For this reason it is very helpful to talk with students and try out the questions or tasks as you design an assessment.
- Performance assessments often can be designed as end of unit projects where students work in pairs or small groups but contribute individually through written or graphic elements. If the task demands individual interpretation and explanation and you circulate among the groups, you will be able to assess the individuals within the group.

- There are more and more resources available for assessing student understanding and skills. There are websites that offer large selections of assessments, although you need to be careful as the quality varies enormously. The TIMSS (Trends in International Mathematics and Science Study) project has released items that may be of interest.
- As you develop the assessments, we suggest that you develop an accompanying rubric that defines several levels of response.

Identifying the learning experiences

Once all of the above has been accomplished, or analyzed in the case of an adaptation of a unit, the next step is to determine the individual learning experiences – the specifics of what the students will actually do. A learning experience will usually take place over more than one session depending on what it is about and the length of the session.

The starting point of the unit is critical. Whether it is a question or a problem, it needs to capture the students' interest and set the stage for the work to come. It is more than a quick motivator or "magic trick" as it will be a continuous point of reference as the unit proceeds. In some cases, a new but related question, challenge, or problem may initiate a new part of the unit.

Questions to think about when selecting or designing the activities include the following:

- What will engage and motivate the students?
- How will the unit begin?
- What types of experiences allow them to investigate as independently as possible?
- How many learning experiences might be needed to address a concept?
- How does the experience focus students' attention on the important concepts and illuminate them most effectively?
- What materials will be needed?

Examples from the two units

Included with each of the sample units is a short description of each of the learning experiences. Several things are worth noting. 1 The number of learning experiences is quite small and the number of sessions of each learning experience varies from one in learning experience five of the clown unit, to four or five in the first learning experience of the seed unit. In reality most learning experiences will take more than one session to complete. 2 Each learning experience in both units is more than a short activity and sometimes represents a stage of the inquiry process such as the Engage stage or the Design and Conduct Science Investigations stage (see A framework for science inquiry, p.8). Two learning experiences in the clown unit and one in the seeds unit are designed as assessments as well as serving to move the students forward.
3 Both units open with a question or problem and an engaging activity (the clown, the field trip).

Practical suggestions

- There are many sources of activities for students on the web and in published curricula and activity books. These can help at this point, when you are looking for very specific details, good materials, helpful instructional strategies, things to watch out for, etc.
- Be sure to keep in mind possible naïve student conceptions as you design learning experiences. You may want to plan for several different experiences in an area where students are likely to have misconceptions.
- It goes without saying that you will want to try out all the activities you include in your learning experiences. Even those found in publications may have hidden problems and things that don't work. Other activities may seem appropriate, but turn out to be more confusing than they are illuminating.

- In any experience, consider the time it would take students to set up the selected investigation versus the time devoted to the investigation. The clown is a good example. If the students draw, cut out, and decorate the clown face, that is time during which they are not addressing the challenge itself. On the other hand, their motivation and enthusiasm may have to do with the construction of the clown. Here the decision might be to have the faces already cut out, leaving the decoration and wiring for the students.
- When adapting or designing a unit, you may find it useful to prepare a chart such as the portion of the Sample Unit Development Chart included at the end of the clown unit, page 56.

Designing the learning experiences

Once the elements of the overall structure of the unit have been determined, the specific learning experiences can be designed. There are many ways to present a learning experience and it is, of course, not the presentation that is important but rather thoughtful design and attention to some key elements of inquiry-based work. This section of the guide identifies some essential elements and draws examples from each of the two detailed learning experiences to illustrate how these elements might be included. There are other elements such as time, materials, and vocabulary that are included in the examples, but these are more straightforward and therefore are not discussed in any detail here.

Clarifying the goals and objectives

It goes without saying that each learning experience should have a clear goal (often the same across several learning experiences) and a set of objectives that are shared with the students. The goals and objectives relate both to the placement of the learning experience in the storyline and to the stage(s) of inquiry. Designing a brief assessment focused on what a student might know and be able to do at the end of the learning experience can help clarify and guide the design of the learning experience. (See Assessment section below.)

Examples from the two units

Clown unit: The goal of the sample learning experience, *The bulb is far away*, is to develop student understanding of a complete circuit. This concept is central to the unit and has been addressed in earlier experiences, in which, however, the bulb has always been in contact with the battery. The objectives are focused on how to set up the circuit when the bulb is not touching the battery and what it is important to know.

Seed Unit: Having completed their study of the seed itself, the goal of learning experience 3, *What does a seed need to germinate?* is to determine the basic conditions necessary for a seed to germinate. There are three sessions each with specific objectives related to content and inquiry skills.

Practical suggestions

- The storyline already addresses the goal and the identification of the learning experiences should have begun to address the objectives, but you may need to adjust them to fit the detail of the learning experience.
- The more precise and succinct the objectives are, the easier it will be to keep them in mind as you teach.
- The basic questions to ask of each learning experience and session are; *"How does this build on student current understanding? How will this build towards the desired understanding?"*.

Developing the structure of the learning experience

Clearly it is important to describe in some detail the overall structure of the learning experience and what will happen in each session. There are many possible questions to consider:

- What is the sequence or mini-storyline of the learning experience?
- How will students connect the work of the learning experience with what has come before? Where are they in the stages of inquiry?
- In each session, what types of activity will take place – hands-on work, discussion, writing, reading, etc.?
- What stage(s) of inquiry will they be doing in each session?
- How will the session and learning experience come to a close – with a discussion, a group presentation, the writing of a text?

The amount of detail for each session will vary a great deal. Brief descriptions of each step of an activity may be fine for the very skilled IBSE teacher but less useful for others.

Examples from the two units

In the seed unit, Learning Experience 3 is three sessions. Note that the second session, where students design and set up their experiments, is actually one session followed by a series of observations over approximately a week's time. Thus the students move from discussion in session 8, to designing and setting up an investigation and collecting data. In this learning experience, students work on many of the parts of the Design and Conduct Science Investigations stage of inquiry (sessions 1 and 2) and end with the Draw Conclusions stage (session 3).

The clown learning experience is shorter. It is a problem that grows directly out of the work the students have done before and thus can be done in one session. It moves from a statement of the problem to the whole class, to the planning and testing of possible solutions by pairs of students, to a sharing that reinforces the concept of a complete circuit. In terms of inquiry, the students are completing a final investigation in the Design and Conduct Science Investigations stage and move on to the Draw Final Conclusions stage.

Note that in both learning experiences the brief opening statements by the teacher linking this experience to the work they have done before as well as, at the closure, previewing what is to come.

Practical suggestions

- There is no single perfect balance among the various activities, but making a chart such as the example in the clown unit may reveal an imbalance between, for example, direct experience and reflection on that experience.
- Sessions within a learning experience as well as learning experiences within a unit reflect one or more stages of inquiry. A session may be entirely devoted to experimentation (Design and Conduct Science Investigations). Another session may focus exclusively on developing a conclusion through discussion and writing (Drawing Final Conclusions). It can help in the design of the learning experience to consider the implications of the inquiry stage for the students' activities.

Designing formative assessment (See Part One, Formative Assessment)

Each session of a learning experience offers opportunities to assess student skills, reasoning, and understanding. Identifying what might be important and possible to assess, strategies to use, and methods of documentation are all part of the design of the learning experience and of the individual sessions. These assessments are, of course, informed by the goals and objectives of the session. Some assessments may target the group as a whole, while others will be more focused on the individual. Some assessments may simply take the form of questions to ask students informally, behaviours to watch for, and comments to listen for. Others may be more structured, such as examining student notebooks or asking a particular question of the group. Finally, it is important to have a strategy for recording assessment data. Following are questions to consider:

- What are the goals and objectives of the session?
- Which ones are particularly important to focus on?
- In which part of each session will students be using a particular skill or developing a specific understanding? What questions might give insight into the students' thinking and understanding?
- How will the data be analyzed and used by you? By the students?

Examples from the two units

Clown unit: There are two suggested formative evaluation points in the clown unit learning experience. One identifies the point where students are designing their solutions as a time to circulate and informally assess their understanding of a complete closed circuit. The second is at the end of the session when students are discussing their solutions and are expected to have made progress towards meeting the goals and objectives.

Seed Unit: Each session includes suggestions for what to focus the assessment on, as well as possible questions to consider at certain points during the session.

Practical suggestions

- It can be helpful to start by examining the flow of the experience and asking at what point objectives are likely to have been worked on. Then you might look at the nature of what the students are doing in order to determine where their understanding is likely to be best demonstrated, e.g. in their science notebooks? Discussions? Team work?
- Writing down the questions you might ask will help keep the focus on key objectives amidst the activity of the classroom.

Determining the grouping of students (See Part One, Science is a cooperative endeavour)

There are many ways to group students, and decisions around grouping are heavily influenced by the local context – the number of students in a class, their cooperative skills, the age level, etc.. However, there also are considerations directly related to the content of the learning experience and the stage of inquiry. These influence the decisions about when to have students work individually or in pairs, in small groups or as a whole class. Consider the following questions:

- What experience do students have working together? How well do they work on their own?
- What size group would work best with the specific materials?
- How much space will be required?

Examples from the two units

In the clown unit learning experience, the students do their hands-on work in pairs. Because it often requires more than one pair of hands but usually no more than two to set up the circuits, working in pairs means every student will be working with materials. The presentation of the challenge and the discussion are conducted with the whole group.

In the seeds unit, the students are in teams of four when working on the investigation. In this case, there are a number of tasks for the setup, giving every student a chance to take part. The data are collected individually in the science notebook, but the students are encouraged to discuss the data within their team.

Practical suggestions

- You are likely to have other factors to consider as you decide on how to group your students, such as quantity of materials available, space for on-going work, and how advanced your students are in being able to work together.
- Consider establishing roles for the team members in order to help them organize their team work.

Planning the discussions and questions

(See Part One, Holding Group Discussions, and Crafting and Asking Questions)

Time for students to discuss and debate their work must be built into each session of the learning experience. Depending on the session and stage of inquiry, the talk may take place between working pairs and teams, or as a full class. The time also will vary from a few minutes in a team to on-going discussion as teams engage in their investigations, to a lengthy debate as a class. Of particular importance for the class discussions are the questions and comments posed by the teacher during these times. Questions to think about include the following:

- When is a full group discussion important?
- What do the students need to do/have ready for the discussion?
- What question(s) will provoke a productive discussion?
- What type of closure will there be?

Examples from the two units

In both the clown and the seed sample learning experience, all three types of discussion are to be found. There are three elements of particular note. 1 The purpose of each large group discussion is clearly stated. 2 Specific questions are included. While there are many questions that a teacher asks spontaneously in direct response to what students say or do, preparing key guiding questions ahead of time will ensure that they get asked. 3 There are brief descriptions of the closure of each session. While these may well need to change if the session has ended in a different place, the nature of the closure is too important to leave unplanned.

Practical suggestions

- Full class discussions are the hardest to facilitate. You will probably not have such discussions in every session, but rather plan them carefully when students are at a point in their work where such a discussion will be truly valuable (e.g. starting point, investigation design, and conclusion).
- In crafting questions, it can be helpful to try to answer them yourself to see how open and productive they might be. Just as in these sample lessons, you may want to develop several rather than just one, as even the best of questions can fall flat!
- There is a difference between sharing and discussing. Students often prefer to share their work and ideas rather than really discuss them. However, it is hard to listen to reports from every team. You may want to consider how work can be shared before discussion (e.g. posters made by the team and posted, a class chart for student data that each team contributes to). In this way, the actual full group discussion can focus on issues raised by the work and possible conclusions to be drawn rather than on the sharing of the details or data.

Planning the writing/recording (See Part One, Guiding Student Writing)

Just as with discussion, writing in the science notebook takes time. It is easy to say that students should write, but making clear when and how students record is important for them and for the teacher. This does not preclude additional writing; it simply makes sure that the necessary recording is done. It is also important to include in each session the nature of the writing the students will do. Questions to consider include the following:

- What stage of the inquiry process have the students reached? What are the implications for the writing?
- Do the students have the appropriate skills?
- Is the writing focused on the science and not only on writing skills?
- Is the writing individual or is it carried out as a group?

Examples from the two units

In both sample lessons, there are indications on when to emphasize student recording and on the nature of such recording.

Practical suggestions

- When students are in the midst of an investigation, it can be hard to get them to stop and record. It can be helpful to plan times for students to pause and record.
- Consider providing students with structures for data recording. Discussing them is important, but they do not need to spend time drawing lines for charts and graphs.
- Consider carefully when and where you want students to use correct grammar, full sentences, etc., so as not to distract them from data collection or reflection.
- Many teachers keep a class list of important vocabulary students have learned to use.

PART TWO

Examples

AGE LEVEL: 7-8 YEARS OLD

A seed? A plant?

A seed? A plant?*

This is primarily a descriptive unit in which students focus on the initial stages of the life cycle of a green plant. They investigate the seed itself, stages of germination, and conditions necessary for germination and draw basic conclusions about the initial development of green plants. In three of the learning experiences students germinate different seeds. They observe and record this process over periods that may vary from a week to 10 days. The learning experiences themselves may overlap with observations for one learning experience continuing while another investigation is begun.

Learning experience 1: Is it a seed or not a seed?

Session 1/2: Sharing initial ideas and assessment (engage)

The first session both launches the unit and acts as an initial assessment of students' prior knowledge and initial conceptions about seeds. Depending on time and the environment around the school, the teacher either organizes a nature outing for the pupils to collect samples of what they think might be seeds, or provides students with a set of samples he/she has prepared in advance. In teams of 4, students are asked to observe one or more of the seeds, draw them in their science notebooks and write their ideas about what a seed is.

Session 3: Sorting of the material and designing an investigation (engage)

In preparation for the session, the teacher makes sure each set of samples includes both seeds and non-seeds. The students are asked to sort them into categories, first in any way they wish and then into two groups, seeds and non-seeds. Students discuss how they might find out whether something is a seed or not and plan their investigations.

Session 4: Investigating using seed trays (design and conduct science investigations)

Teams of students set up seed trays with samples from their seed and non-seed groups. They describe what they have done in their science notebooks and determine what data they will record and how they will record it.

Session 5: Observing and recording changes in the seed trays; interpreting the data (design and conduct science investigations)

The student teams observe the seed trays over a period of approximately 10 days, entering their observations and reflections in their science notebooks. After enough change has happened they return to the initial question and draw conclusions from their data recognizing that: seeds change and begin to grow; two seeds that look alike produce two shoots which look alike; and objects that look like seeds but do not grow are probably not seeds.

Learning experience 2: What is inside a seed?

Session 6: Sharing initial ideas (engage)

This session both begins a new phase of the unit and serves as an initial assessment. Having observed the external appearances of seeds and concluded that seeds are things that grow and develop, students turn to the question of what is inside a seed. They children share their ideas in a whole group discussion and write their ideas in their science notebooks.

Session 7: Discovering the anatomy of the seed (design and conduct science investigations, draw final conclusions)

In their teams, the students dissect and observe the interior of various seeds using a magnifier. They draw what they see and write other observations and reflections in their science notebooks. In a full group discussion they conclude that

* This work is based on a unit that can be found at: http://www.pollen-europa.net/?page=Prj0nqpx9f8%3D

there are common basic elements in all the seeds they have observed – the embryo, the food reserves, and the protective coat. They then make a definitive distinction between seeds and non-seeds in the collection.

Learning experience 3: What does a seed need to germinate?

Session 8: Sharing initial ideas (engage, design and conduct science investigations)

Having completed their study of the seed itself, the students turn to the question of what seeds need to germinate. The session serves as an initial assessment as well as a time for the students to talk about and write in their science notebooks their thinking about the needs of plants in general and the specific needs of a seed to germinate successfully. They are reminded to look back in their notebooks at their records from their recent experiences with seed trays. (See Sessions 3, 4, and 5.) They discuss their list of possible needs and identify one for further investigation.

Session 9: Investigating one basic need (design and conduct science investigations)

The next sessions are about the need for water (other needs could be investigated as well as or instead of this one). The students clarify the question, 'Does the seed need water to grow or not?' discuss possible experimental designs, agree on a procedure (including a control), and decide which teams will do what. They implement their plans, and record observations and reflections in their science notebooks over approximately a week's time.

Session10: Analyzing data and drawing conclusions (design and conduct science investigations, draw final conclusions)

In teams, the students review their work, analyze their data, make inferences, and write their thoughts in their notebooks. In a class discussion they come to the conclusions that a seed needs water to germinate, and that without water it does not germinate.

Learning experience 4: How do seeds germinate?

Session 11: Investigating germination (design and conduct science investigations)

The students have seen seedlings grow and discussed and investigated the basic needs for germination. In this learning experience they once more set up seed trays to observe closely how the seed 'wakes up' and how it becomes a seedling. The session begins with a discussion that also serves as an initial assessment of student ideas. Students then plan how they will set up their trays and how they will record their data. They write their plans and their predictions in their science notebooks.

Session 12: Analyzing data and drawing conclusions (design and conduct science investigations, draw final conclusions)

Students record their observations regularly over the time it takes for the seedlings to begin to develop real leaves. As they observe, record, and discuss what they are seeing, they discover that the parts of the plant they have observed in the seed emerge in a clear sequence. As a class they come to the conclusion that all have a well-defined role: the root develops first, it grows downwards and takes in water; the stem then develops upwards; the two halves of the seed (the cotyledons) serve as a 'food-reserve' when the seedling emerges. Once the first true leaves emerge the cotyledons drop off.

Learning experience 5

Session 13/14: Evaluation

Students are asked to draw and label the stages of the seedling from seed to first leaves and describe the importance of each stage. When they are finished they work in their teams to develop a guide for another class.

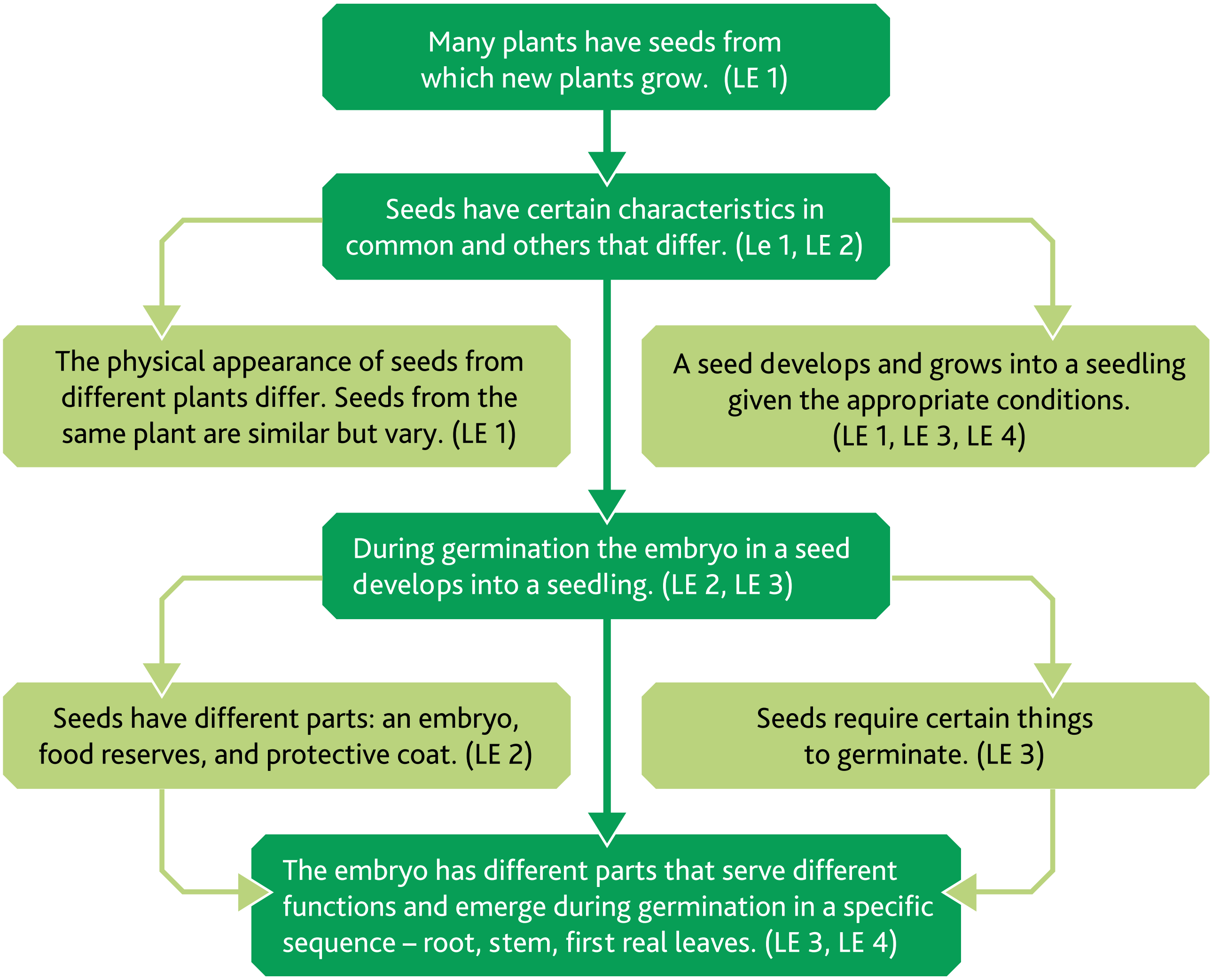
A seed? A plant?

Goal: Students will develop an initial understanding of the role of the seed in the growth and development of the plant. They will become familiar with the initial stages of the life cycle of a green plant.

Basic concepts of the unit

1. Many plants have seeds from which new plants grow.
2. All seeds are alike in some ways and different in others.
3. Given appropriate conditions, the embryo in the seed develops into a seedling.
4. Different parts of the embryo and seedling have different functions.

Conceptual storyline



Learning experience 3: What does a seed need to germinate?

The students have investigated the seed itself. They have gathered seeds from the environment and looked closely at the external and internal structures and characteristics of seeds. In the next learning experiences they investigate germination – what is required and the stages of development.

Session 8: sharing initial ideas

Having completed their study of the seed itself the students turn to the question of what seeds need to germinate. They talk and write about what they think are the needs of plants and what a seed needs to germinate successfully. They discuss their list of possible needs and identify one for further investigation. The session also serves as an assessment of prior knowledge.

Objectives

- student will describe and discuss their ideas about basics needs for germination
- students will suggest a list of basic needs for investigation

Assessment

Using what students say in the discussion and write in their notebooks, record:

- what most students understand about the basic needs of plants
- what confusions the class or individuals within the group seem to have

Opening of the session

- The teacher asks each student to open their notebooks, date the new page, and write about the following: *"What do you think every seed needs in order to start to grow?"*
- He/she reminds them to look back at their entries from sessions 3, 4, and 5 to see what they were thinking then and whether any records they made of their observations might help.

Core of the session

- After a few minutes the class comes together to discuss the questions:
  "What do we think seeds need in order to germinate?"
  "Why do we think that?"
- They create a class list on a poster and discuss why they think each might be important, referencing any data from their notebooks that might be relevant.
- Students discuss the questions:
  "Which factors might we be able to investigate in the classroom?"
  "Which ones are we most interested in?"

Note: The students are likely to want to investigate many of these factors. Depending on the time available, and the particular group of students, you may choose to have different groups pursue different questions, let the students decide on one for the class, or chose one yourself. The process of finding a question that can be investigated is an important one for students. It requires them to think and talk about what is observable and what is possible in the classroom.What follows is an example of an investigation of one factor.

Closure of the session

- The session ends with a quick review of the list of factors, and a review of the factor(s) to be investigated.
- The students are asked to think about the question *"How could we find out whether this factor matters?"*. This will be discussed at the next session.

Materials: science notebooks

Additional vocabulary:

- germination
- soil

Note: *Depending on the review of the assessment data, you may choose to move forward quickly to the next session or spend a little more time discussing possible factors.*

A sample of what the pupils might suggest: *"Perhaps they shouldn't be planted too deeply", "Perhaps they should be put in the light", "Perhaps they shouldn't have too much water", "Perhaps they shouldn't be pressed on too heavily".*

Assessment: Do the students have a generalized knowledge of what plants need in order to grow? Can the students distinguish between something that could be tested and something that could not be tested?

Session 9: Investigating one basic need

The next sessions are about the need for water.Students clarify the question, *'Does the seed need water to grow or not?'*. Discuss possible experimental designs, and agree on a procedure (including a control). They implement their plans, and record observations and quick reflections in their science notebooks every day for approximately a week.

Objectives

- Students will clarify the question they are going to investigate and make predictions
- Students will design an experiment (including a control)
- Students will set up their experiment and collect observations and ideas in their science notebooks

Assessment

- Using your observations from the discussion of experimental design and how students set up their experiments, look for the extent to which students understand the need to have a control and keep all but the water the same.
- Using the student notebooks, look for detail and accuracy of recording and interesting reflections about seeds and germination.

Opening of the session

- In the full group, the students review the list and talk about the factor they have chosen, in this case water, and discuss the question, "What do we want to find out?"
- They clarify and agree on their questions: *"Does the seed grow or not when it is given some water?"*, *"Does the seed grow or not when it is not given any water?"*

***Note:** In one class the students became involved in a discussion about the wording based on the initial statement on their list: "Perhaps they shouldn't have too much water." The discussion turned around the expression "not too much water". Some pupils suggested that "not too much water" does not mean "a great deal". Others said, "We don't know how much "not too much water" is!" The exchange continued and an idea was suggested: "We shouldn't talk about water, but about some water". This type of discussion pushes students to think clearly about their investigation...*

- *The teacher tells the students what materials they will have available.*

Core of the session

- The students move into teams to develop their predictions and a plan for the experiment.They write their predictions and plan in their notebooks.
- The teams return to the larger group to discuss the various plans:
  "How will you set up your experiments?"
  "What do you think is needed to make this a good experiment?"
  "What do you think it is important to observe and record?"
- If necessary, the teams revise their plans in their notebooks explaining the plan and labelling any drawings.(See one example below).They review their predictions and why they think they are true.They decide as a team how each will record observations.

Materials: seeds, containers (The container must allow for two germination trays, one of which can be kept wet and the other dry[1]), labels, soil.

***Note:** It is preferable to choose two or three different types of seed. This allows students to note that the requirements for germination are common to more than one kind of seed. Some seeds (e.g. bean, wheat, pea) can be chosen as 'reference seeds' used by all to be sure the results are comparable. Students may choose others from their collections.*

Additional vocabulary:

- variable
- control
- seedling

Assessment: What do students know about setting up an experiment?What are they missing?

***Note:** The teacher moves from group to group during this time, commenting and asking questions to be sure that the teams have a workable plan and enough specificity (what seeds they will use, and how many. How often, how much they will water, etc.).*

1 It is important to ensure that the watered sectors of seeds do not suffer from evaporation. One can either install an element to limit the evaporation, or top up withwater to a level which will be regularly monitored.

Example of a student's notebook page showing the experimental design

"This is the experiment of my group on March 7^{th} 2000"

[Left] *I put water in.*
Water is put in, a plant should grow.

[Right] *I did not put water in.*
Water is not put in, nothing should grow.

Closure of the session

- The teacher asks teams who have different experimental designs to share them and discuss them with the class.If the students do not raise questions, these may serve to start the discussion:
  "How will you be sure your results will be only about the water?"
  "What is the difference between this team's plan and that one's?"
  "Do you think they will both work?"
  "Do you think we will be able to compare results? Why/why not?"
- The teacher asks one team to state its predictions. He/she asks for any different ones and then guides the students in a discussion (*Why do you think that will be true?*).
- The teacher then goes over what the students are to do over the next week: actions, observations, and recording of data. He/she reminds them to stick to their designs and to make sure every recording is dated, clear, detailed, and includes numerical data where appropriate.

Assessment question: To what extent are students' predictions based on their experience?

Assessment question: As students observe their seeds, are they recording important data?

Session10: Analyzing data and drawing conclusions

When the results are clear, the teams review their work, analyze their data, make inferences, and write their thoughts in their notebooks.In a class discussion they come to the conclusion that based on their evidence, seeds need water to germinate: that without water they do not germinate.

Objectives

- Students will review their data and develop an initial synthesis and conclusion
- Students will present their ideas to the class
- Students will defend their results and debate the results of others
- Students will develop an understanding that seeds need water to germinate and to develop and grow

Materials

- Science notebooks
- Experimental set-ups

Additional vocabulary

- Evidence
- Conclusion

Assessment

Using your observations of the team discussions, record:

- How students use data from their notebooks.
- Whether they stay focused on the question asked.
- How well they support their ideas.

Opening of the session

- The teacher invites the students to analyse the results of the experimentation. He/she reminds them that each member of a team has data and ideas in their notebooks from their investigation. They are to work together and develop a claim and identify the evidence for their claim. They are to think in their teams about how they might explain the results. He/she asks them to pursue the questions, *"What can you say about your seeds' need for water? What evidence do you have? Why do you think this is true?"*.

Core of the session

- Students work in their teams to prepare a team response on a small poster as well as noting their individual ideas in their notebooks (see one example below). They make inferences from the results they have obtained from their experimentation and write down their conclusions and put up their posters.
- Once all the posters are up, the teacher asks the class to circulate and look at each one. He/she might ask *"how are they the same? Different?" "What might explain any differences?"*.

Assessment: Are students using the data they collected in their notebooks?How rigorous is their reasoning about the question?

Closure of the session

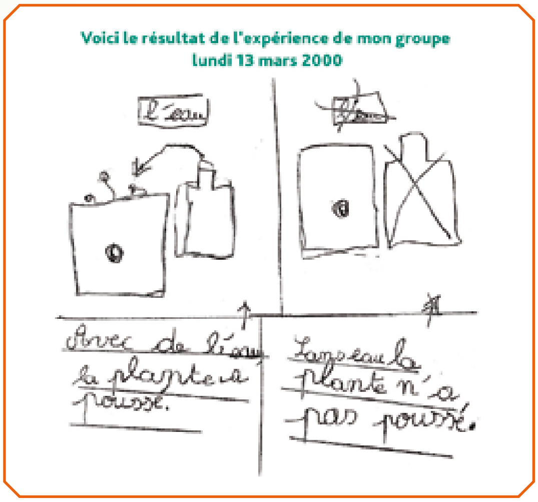
- The class comes together and the teacher asks students to discuss what conclusions can be drawn after looking at all the posters. Questions might include
  "What patterns do you see? What do you think those patterns mean?"
  "Do you think all of our evidence supports a single conclusion for our question? What makes you think that?"
  "What else might we do to be sure if the evidence isn't clear?"
- If the evidence is there, the teacher guides the discussion towards the conclusion that seeds need water in order to germinate, because none of the seeds in the sectors in which there was no water have germinated and, conversely, in the watered sectors, shoots have appeared.

Assessment: How do students defend their ideas?To what extent is their conclusion a reasoned one?

Note: *Some seeds that are watered may not germinate. This is important to discuss. There are a number of possible reasons but it is important that students realize that they have evidence to support the statement that no seeds germinate without water and many germinate with water, but not that all seeds germinate with water.*

- The teacher (or a student) then summarizes the final conclusion that is written on a class chart, and inserted into the student notebook.He/she also makes a list of questions that may have been raised.
- The teacher closes the session by telling the students that they are now going to take a close look at what happens to the seed from the moment it is given all it needs in order to germinate.

Example of a student's notebook page showing the experimental design



“Here is the result of the experiment of my group on Monday 13th 2000“

[Left] With water the plant has grown.

[Right] Without water the plant did not grow.

AGE LEVEL: 7-8 YEARS OLD

The clown with a bright nose

The clown with a bright nose *

This unit explores the basic concept of a simple electric circuit as a continuous pathway along which electricity travels. Students work with a battery, a bulb and wires and test the conductivity of different materials. They apply their understanding to the design of a circuit for a clown face that allows them to turn the bulb that is the nose of the clown on and off.

Given the nature of electricity, students are not observing electricity directly; they are observing its effects. They may be familiar with terms such as electricity, electric current, voltage, and energy but it is unlikely that these are really understood. This session is not about terms or the nature of electricity it is about continuing to develop the idea of a complete or closed circuit.

Learning experience 1: Initial assessment

Session one

This session is designed as an initial assessment to determine the experience and understanding students already have of electricity, and in particular of the need for a complete circuit. This evaluation will also serve as a reference point at the end of the unit.

Session two (engage)

The teacher shows the class the clown face that has a lit bulb for a nose. He/she does not show the circuit on the back that makes it work. The students are asked to imagine how it works and to draw what they think and write why they think so in their notebooks. The teacher then asks what materials they might need to light a bulb like the one in the clown face and the students make a class list.

Learning experience 2: Lighting the bulb

Session one (design and conduct science investigations)

The teacher brings in the materials the students have asked for. He/she divides the class into teams of two and asks them to look again at their drawings from the day before, revise them if they wish, and try out their ideas of how to light a bulb with the materials. They share results, select other materials if needed, and eventually all the students light their bulbs.

Session two (design and conduct science investigations)

The teacher asks the students to try to light the bulb in as many different ways as they can, using only a battery, wire, and a bulb. The students try different ways and record with diagrams in their notebooks what does and doesn't work. In groups of 4, students discuss what seems to be important in getting the bulb to light.

The teacher then introduces the names of the parts of the bulb, and the students look closely at a bulb that has had the glass broken off. As a class, they discuss the path of the electricity which goes from one terminal of the battery through the bulb, and on to the other terminal of the battery - a complete circuit.

Learning experience 3: The bulb is far away

(design and conduct science investigations, draw final conclusions)

Referring to the clown, the teacher asks the students how one might design the system so that the battery is on the

* This idea was presented by Josiane Favrot at the colloquium of *La main à la pâte*, *Les Sciences et l'École Primaire*, January, 1999. Various versions can be found on the Internet.

table and the bulb at the height of the nose. In their teams, the students discuss and draw their ideas and write why they think they will work. When ready, using a battery, a bulb, and wires of different lengths, they try out their designs, and in a full group discussion review and reinforce their understanding of a complete circuit.

Learning experience 4: Turning the light on and off

(engage, design and conduct science investigations)

The teacher again presents the clown, this time turning the nose on and off. He/she asks, "How does this happen?" The students discuss, draw, and try out a mechanism to do this – a switch. For this work, the teacher provides materials including battery holders and bulb holders, discussing with the students how the electricity moves through them. The students make their switches and the teacher asks them to try different objects as the part of the switch that opens and closes the circuit. In the process the ideas of conductor and insulator are introduced and the idea that a complete circuit can be made up of a variety of different objects and materials. The session closes with a group discussion about how to make a switch and initial ideas about conductors and insulators.

Learning experience 5: Conductors and insulators

(design and conduct science investigations)

The teacher follows up the previous session by asking the students to try out two different materials – one that works and one that doesn't - to complete a circuit that has been broken (opened). The students then look for a variety of possible connectors and classify them as conductors and insulators. The session closes with a full group discussion and initial conclusion about the nature of conductors and insulators and their role in a circuit.

Learning experience 6: Final assessment

Session one (draw final conclusions)

In their teams, the students decide how they will construct their own clowns with a bulb as a nose and a switch to turn it on and off. They first draw their designs in their notebooks indicating why they think it should work and then construct the clown.

Session two (draw final conclusions)

In this final session, the teacher asks that the students add a second bulb to their clown face so one eye can light up as well. The switch must turn both on and off at the same time. Here too the students write in their notebooks why their circuits work. This activity and the previous one provide evidence of the students' understanding of a complete circuit and how to make one.

The clown with a bright nose

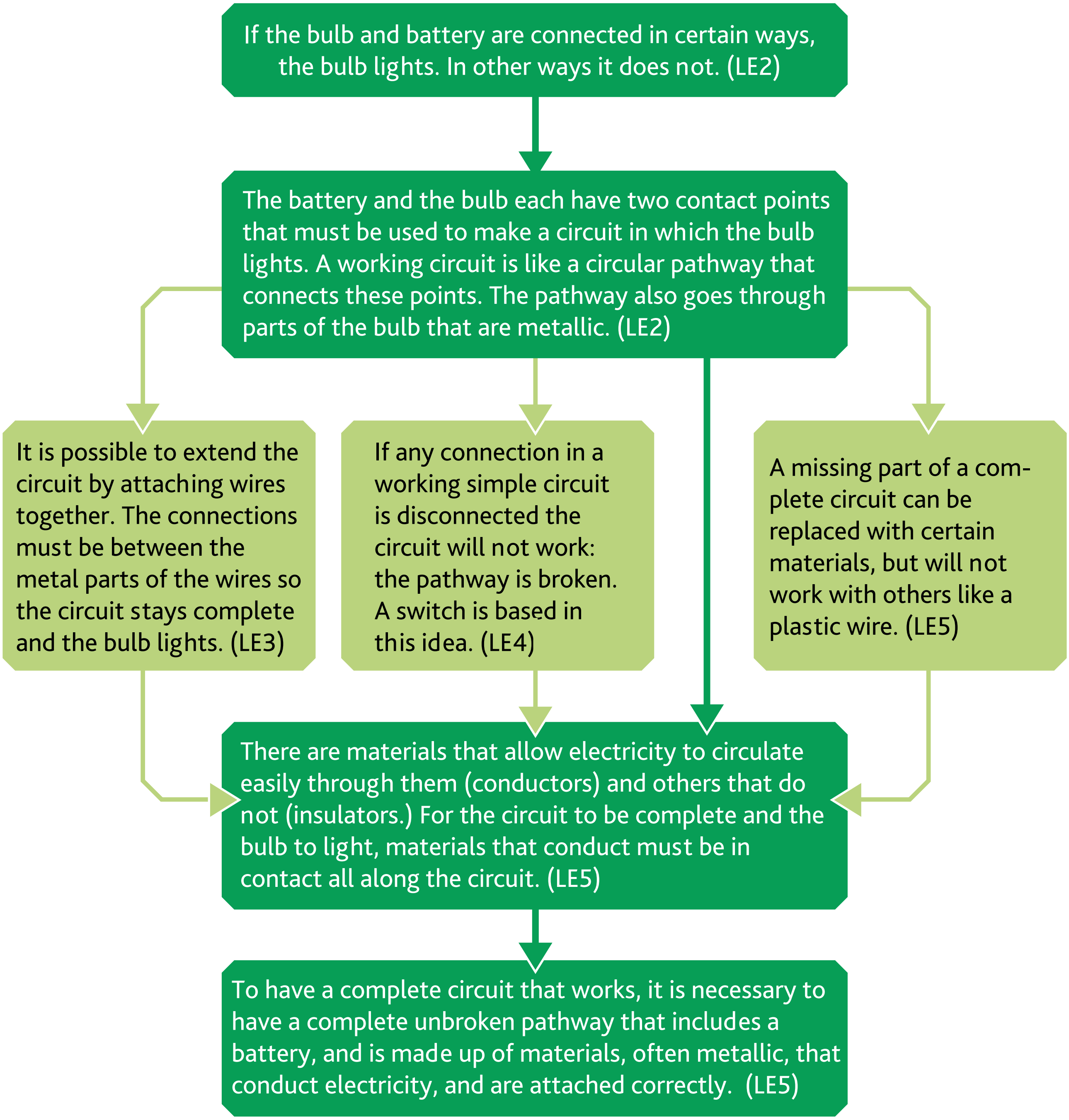
Goal of the unit:

Students will develop a basic understanding of a simple circuit and the nature of insulators and conductors.

Basic concepts of the unit

1. A complete simple circuit through which electricity flows is a continuous pathway made up of materials that conduct electricity and includes a battery.
2. Some materials conduct electricity and can be used in a working circuit.
   Others do not and cannot be used to make a complete circuit.

Conceptual storyline



Unit 3: Lighting a bulb that is at a distance from the battery

Time: 45 minutes

What do we know now?

At this point it is expected that students are able to make the bulb light up, and have identified ways that work and ways that do not. The students are able to draw approximate diagrams of the set-ups.

The students also have explored the idea that there must be a path for electricity made up of metallic materials. This was reinforced by their work on the bulb. They are beginning to understand the idea of a complete circuit as a closed path through which electricity can move.

Brief description

Until now, the bulb has been lit using a direct contact between the bulb, one of the battery terminals, and a wire that is in contact with the other terminal. The learning experience focuses on the problem of how to make a circuit to light the bulb when the bulb is not near the battery. In this case the bulb is to be placed at one end of the desk and the battery at the other (at least 40 cm.)

The teacher presents the problem and pairs of students try to solve it. They plan how they will do it and make drawings. When they have drawn and explained their circuits, they try them out.

At the end of the session, students reflect on the different solutions they have found and reaffirm the elements and importance of the continuous complete circuit.

Objectives

- Students will solve the problem of lighting a bulb that is at a distance from the battery.
- Students will connect the battery, two or more wires and the bulb to form a closed circuit so the bulb will light up.
- Students will explain the importance of the continuous path, appropriate materials, and proper connections.

Teaching comments

The role of teacher questioning is fundamental. Sample questions to consider are included in the following sections.

It is important to be sure that students' conclusions are based on evidence. For example, students might think that the length of wire has no effect. If they bring this up, it is important to tell them that in this instance they do not have any evidence to suggest there is an effect. But they would need to experiment with much greater distances.

Preparation

For each pair of students the teacher prepares a box with one battery and one bulb. In a separate box he/she prepares plenty of wires of different lengths and colors with the ends stripped. It is best not to use thick wires as they are difficult to handle. Students will decide on the wires they need.

Material:

- One bulb
- one battery for each pair of students
- A box with wires (several of different lengths for each team)

Note: *No battery holders or bulb holders are used in this session so that students can see the pathway very clearly. These elements are going to be used in the next session.*

Safety: It is important to remind students that experimenting with electricity must never be done at home and never with other materials or sources of electricity such as the wall socket or different batteries.

Opening of the session

- The teacher opens the session with the full class by asking students to describe how they have lit a bulb in previous sessions.
- The teacher shows the clown again without showing the circuit behind and describes the problem. The bulb cannot touch the battery as it is high up on the clown's face and the battery is at the base.
- A few students are asked to suggest some solutions that the teacher writes on the board.

Notebook: Although working in teams, both students use their science notebooks through out the session. They draw their own initial design, designs that did not work, and the final working designs in their note-books along with their explanations for why the circuits did or did not work.

Core of the session

Designing a solution:

- Working in teams of two, students discuss a solution to the problem. They both make a drawing in their science notebooks and explain why they think it will work. These may be the same or different.

Trying solutions:

- Once students have discussed and drawn their ideas; one student picks up two batteries, two bulbs, and a box with wires.
- If the two designs differ, the students work together to set up one design and then the other. Questions the teacher might ask while moving from group to group include:
  "What happens when you use differently colored wires?"
  "What difference did you notice between using several short wires or one long wire?"
  "What would happen of you change the order in which you connect the wires?"
- If a circuit does not work, the teacher suggests that the students think about what might be the problem and how to solve it. It is best not to intervene too soon and let the students find their own solutions. Questions that might help include:
  "How have you set this up? Why do you think it should work?"
  "Where do you think there might be a problem?"
  "How might you go about checking your circuit?"
- If students are stuck the teacher can suggest some possible problems asking questions like these:
  "Have you checked the bulb? Why would that matter"
  "Have you checked all the connections? What needs to be touching?"
  "How can you be sure the wires are all touching?"
- Before discussing their work with other teams, the teacher asks the students to draw and explain in their notebooks what did and did not work.

Assessment: The teacher circulates among the teams observing:

- How are the students understanding a complete circuit?
- Do they mention a continuous closed pathway?

Note: Make sure students record circuits that do not work and show how they fixed them. The detection of mistakes not only develops technology skills, it also pushes students to think about what makes a circuit that works.

Communicating findings:

- When all (or most) of the teams have managed to light the bulb at a distance from the battery, the teacher asks one team to describe a solution and show their diagram. He/she asks the rest of the teams whether they did it the same way. One team is asked to describe the continuous or complete circuit for this solution.
- The teacher continues this process asking for different solutions until all the successful strategies have been shared. He/she then asks
  "How does this pathway go from the battery and back again? Trace it."
  "What are the critical elements in these circuits?"
  "What are some of the important connections you had to make?"

Assessment: Are the students expressing an understanding of the need for a conti-nuous closed path as a condition for the electric circuit to work?

- The teacher then asks for descriptions of circuits that did not work and the class discusses the reasons why:
  "What were some problems you encountered? How did you fix them?"
  "How might you avoid these in the future?"

Closing the session

- The teacher continues the group discussion guiding the students towards a conclusion based in their work:
  "How did we solve the problem of lighting a bulb at a distance from the battery?"
  "What is important to do to light a bulb using a battery whether or not the bulb is touching the battery?"
  "What were the critical elements in making the complete circuit?"
  "How would you tell someone else to do this?"
- He/she tells them for the next session to think about how they could make something to turn the bulb on and off without having to disconnect one of the connections.
- Finally, the teacher asks the students to write their own response in their notebooks to the question: "*What is important to do to light a bulb using a battery whether or not the bulb is touching the battery?*"

Note: During the next sessions, the students will make a switch and think about the properties of conductors and non-conductors. Their experiences and conclusions in this session about their circuits and what happens when they were not well connected will be important to recall.

Sample Unit Development Chart

LE f (session)	Title	Questions	Activities	Recording	Evaluation	Materials	Notes
2 (2)	The bulb is lighting	What is inside the bulb? Is the path continued inside the bulb?	• Using a magnifying lens, students observe and draw a bulb, labeling different parts. • With help from the teacher, students explore the inside of the bulb and complete their drawings. • Students present and discuss any necessary adjustments. • Class discussion: Using their knowledge of the inside of the bulb, students discuss and describe the complete circuit.	• drawing of a bulb indicating parts and names • group conclusions	• drawings that show the continuation of the circuit inside the bulb • comments during discussions	magnifying lens bulb bulb with glass broken	To avoid accidents, the glass of the bulb has to be broken by the teacher.
3 (1)	The bulb is far away	The bulb is far from the battery. How can we complete the circuit using wires?	• The teacher presents the problem: the bulb is not touching the battery. • In groups, students try to light a bulb that is on the opposite side of their desktop. • Students present their designs. • In a final discussion, the concept of a complete closed electrical path is reinforced.	• drawings that include several wires connected appropriately • presentation of designs and discussion • conclusion	• circuits work correctly • closed path circuit descriptions that students produce	bulb battery enough wires	None of the wires should be long enough to reach all the way across the desk so that students have to connect pieces.
4 (1)	Turning the light on and off	How do we turn the bulb on and off?	The teacher presents the problem of how to turn the bulb on and off. Students try to figure out the solution to the problem. Class discussion: students present their ideas and discuss solutions. Final class discussion: the switch opens and closes the path.	• student drawings with switch • explanations	• written explanations of switch • drawing of circuit with switch • comments during discussion	bulb battery wires, round head fasteners (prong paper fasteners)	The original clown now has a switch visible on the front of the face.

Summary

Designing Inquiry-Based Science Units

Definitions

- **Unit:** a full study of a few selected concepts over an extended period of time.
- **Learning experience:** generally focused on a single investigation
- **Session**: lessons

Characteristics of IBSE units

- engage students in a process of scientific inquiry using objects and materials.
- focus on a small number of basic ideas or concepts.
- take place over a number of weeks in 10-20 sessions depending on the content.
- have a carefully designed conceptual progression –a storyline- in which each learning experience is designed as a follow-up or prelude to another.

Designing the overall structure of the unit

Step one: the content

Determine the basic content of a unit in relation to the students for whom it is designed.

- What are the phenomena and basic science concepts the students will focus on?
- What are likely prior ideas and experiences students will bring to this unit?
- What level of understanding of the selected concepts do we expect students to achieve? What is a possible assessment we might use and what outcomes would we anticipate?
- What science inquiry and/or technology design skills will be emphasized?
- What attitudes about science should be identified?

Step two: the context

Decide the context in which the content will be explored and the starting point.

- Where in the day to day world of the students are there phenomena, objects, materials through which the concepts might be addressed?
- What context allows for significant investigation, in-depth and over time?
- What is likely to be engaging and/or of particular interest to the students?
- What materials and resources are available?

Step three: the storyline

Design the conceptual storyline of the unit. Concepts and experiences must follow one another in a carefully ordered sequence that is organized to allow the students to construct a particular understanding.

- What is the progression of learning for each concept?
- What misconceptions might students have?
- How will each learning experience build on what went before and lead to the following learning experiences?

- What do we assume has been experienced/ understood at the end of each learning experience that will inform the next?
- How is understanding deepened as the learning experiences progress?

Step four: end of unit assessment

Determine the nature of the end of unit summative assessments focusing on the level of understanding of the concepts students have attained, the skills they are able to use, and their ability to apply the knowledge and skills in new situations.

- What are the main ideas of the unit to be assessed? What skills?
- What questions and tasks will allow students to demonstrate their understanding rather than what they remember or have memorized?
- How will the task or question differentiate between students' language skills and science understanding?
- Do the tasks or questions allow for responses at different levels rather than simply a right or wrong response?
- Do the questions or tasks deal with experiences that are accessible to all students?
- How will the results be analyzed and evaluated?

Step five: learning experiences

Determine the learning experiences –what the students will actually do.
Questions:

- What will engage and motivate the students?
- How will the unit begin?
- What types of experiences allow them to investigate as independently as possible?
- How many learning experiences might be needed to address a concept?
- How does the experience focus their attention on the important concepts and illuminate them most effectively?
- What materials will be needed?

Designing the learning experiences

Step one: goals and objectives

Clarify the goals and objectives in relation to the position of the learning experience in the storyline and the stage of inquiry.

Step two: structure of the learning experience

Develop in detail the overall structure of the learning experience and what will happen in each session.

- What is the sequence or storyline of the learning experience?
- How will students connect the work of the learning experience with what has gone before?
- What part(s) of the inquiry will they be doing in each session?
- In each session, what types of activity will take place – hands-on work, discussion, writing, reading, etc.?
- How will the session and learning experience come to a close - with a discussion, group presentations, writing?

Step three: formative assessment

Designate opportunities in each session to assess student skills, reasoning, and understanding.

- What are the goals and objectives of the session?
- Which ones are particularly important to focus on?
- In which part of the sessions will students be using a particular skill or understanding?
- What questions might give insight into students' thinking and understanding?
- How will the data be used by you? By the students?

Step four: grouping of students

Determine when students will work individually, in pairs, in small groups or as a whole class based on the local context as well as the content of the learning experience and the stage of inquiry.

Step five: discussion and questions

Build time for discussion into each session of the learning experience. Depending on the session, the talk may be in working pairs and teams, or as a full class. Develop possible questions to guide the discussion.

- When is a full group discussion important?
- What do students need to do/have ready for the discussion?
- What question(s) will provoke a productive discussion?
- What type of closure will there be?

Step six: writing/recording

Determine when and how students will record in their science notebooks in each session.

- What is the nature of the writing the students will do?
- At what stage of the inquiry process are they at?
- Is the writing individual or group?

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Notes

www.pollen-europa.net

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