Kingdom of Cambodia

Nation - Religion - King

Student Centred Approaches for Science Education

Part 1

Chapter 1: Developing Active Reading and Writing Skills

Chapter 2: Developing Reasoning Skills

Chapter 3: Teaching the Scientific Method

Teacher Training Department 2012

Part 1

Chapter 1: Developing Active Reading and Writing Skills

Chapter 2: Developing Reasoning Skills

Chapter 3: Teaching the Scientific Method

Published by the Ministry of Education, Youth and Sport of the Kingdom of Cambodia

Printed in Cambodia, 2012 (First edition)

The development and publication of this document has been funded by the General Directorate for Development Cooperation and Humanitarian Aid (DGD) with technical support from the Flemish Association for Development Cooperation and Technical Assistance (VVOB). The Flemish and the Belgian governments cannot be held responsible for the content of this publication.

Prologue

Capacity building and human resource development are one of the crucial angles in the rectangular strategy of the Royal Government of Cambodia. Qualitative science education is an important factor in creating a well-educated workforce. Not only is there a strong need for people with degrees in scientific domains, but science education also contributes to developing students into well-informed, critically and creatively thinking citizens.

In cooperation with development partners and international organizations, the Ministry of Education, Youth and Sport (MoEYS) has developed educational materials to fulfil the needs of teaching and learning. The process of material development and capacity building consisted of joint efforts of the technical expertise of both the MoEYS and VVOB educational experts. This enabled us to design materials that focus on basic knowledge and teaching methodology for science subjects.

This manual focuses on the theory and practice of science education and the promotion of problem solving skills, reasoning skills, reading comprehension, creativity and deeper understanding of science. The manual also offers solutions to make science lessons more connected to students' daily lives.

MoEYS strongly hopes that all teacher trainers will use this manual to teach science in the teacher training centres, and thus contribute to improving the quality of science education in Cambodia.

On behalf of MoEYS, I would like to express sincere thanks to the team and educational advisors of the Flemish Association for Cooperation Development and Technical Assistance (VVOB) for their energy, motivation and intellectual spirit to develop these useful manuals.

Phnom Penh, March 15th, 2012
Minister of Education Youth and Sport

H.E Im Sethy
(signature and seal)

Preface

The manual on Student Centred Approaches (SCA) in Science Education has been compiled in order to support science teacher trainers in their teaching. In 6 chapters we present a wide range of tools and techniques to increase the student centred character of science lessons.

A student-centred approach means literally that the student is placed in the centre of the learning process. Some characteristics of a student-centred approach include:

- Active involvement of the students in the lesson;
- Students learn from each other, not only from the teacher.
- Students are more responsible for their own learning.
- Differences among students are taken into account.

The tools and techniques in this manual were first introduced at RTTC Kandal. A team of teacher trainers and teachers tried out the techniques, discarded some and changed others and provided suitable examples from the local curriculum.

This manual consists of 6 chapters:

Chapter 1: Developing Active Reading and Writing Skills presents techniques to stimulate active and strategic reading and writing skills with students in science lessons.

Chapter 2: Developing Reasoning Skills presents discussion and argumentation techniques for science topics.

Chapter 3: Teaching the Scientific Method introduces ways to make students familiar with the various stages in the scientific method.

Chapter 4: Conceptual Science Teaching focuses on techniques to stimulate conceptual thinking with students.

Chapter 5: Models and Analogies introduces techniques and examples of models and analogies in science lessons.

Chapter 6: Educational Games explains how to integrate educational games in science lessons and gives a range of examples.

We hope that teacher trainers will try out the methods in this manual. We are looking forward to receiving your comments. We wish you an inspiring experience and many satisfying science lessons.

Editorial Committee,

July 2011

Manual Development Committee

1. Management Committee

H.E. Im Sethy	Minister, Ministry of Education, Youth and Sport
H.E. Nath Bunroeun	Secretary of state, Ministry of Education, Youth and Sport

2. Approval Committee

Mr. Leang Seng Hak	Director, Teacher Training Department
Mr. Eng Kimly	Director, Department of Curriculum Development
Mr. Eung Ngor Hok	Director, General Secondary Education Department

3. Committee of Authors

Mr. Stefaan Vande Walle	SEAL Programme Coordinator, RTTC Kandal
Mrs. Veerle Cnudde	SEAL Programme Coordinator, RTTC Kandal
Mr. Uon Virak	Technical Advisor/Facilitator – Science & life skills RTTC
Ms. Nget Sokhany	M&E Officer/Facilitator – SEAL Programme

Teacher Trainers – RTTC Kandal

Mr. Mam Pha Ol	Mr. Meng Phirun	Mr. Thak Sophea
Mr. Be Bra	Mr. Sok Saroeun	Mrs. Long Punthiny
Ms. Hou Chansara	Mrs. Som Dany	Mr. Oeur Sokmeng
Mrs. Srey Chansophea	Ms. Veng Sreymon	Mr. Seang Bunthoeun

Teachers – Hun Sen Sereypheap High school – Kandal Province

Mrs. Kong Sovannra	Mr. Pang Sienghay
Mrs. Sun Chanmoly	Mrs. Pen Raksmey

Teachers – Anuwat Lower Secondary School – Kandal Province

Mrs. Loch Sotheany	Mrs. Mam Metboran
Mrs. Morn Sokha	Mr. Phan Ny

Teachers – Hun Sen Takhmao High school – Kandal Province

Mr. Prum Vannara	Mrs. Tuon Vannak	Mrs. Phon Socheat

Teachers – Hun Sen Kampong Kantuot High school – Kandal Province

Mr. Men Nimol	Mrs. Ek Amara
Ms. Tim Bunthen	Mrs. Chea Yeth

4. Editorial Committee

Mr. Men Vannary	Officer, Teacher Training Department
Mr. Sok Saroeun	Officer, Teacher Training Department
Mr. Sin Vath	Officer, Teacher Training Department
Mr. Chan Sopheap	Officer, Department of Curriculum Development
Mrs. Ean Sarin	`Officer, General Secondary Education Department

5. Technical Advisor

Mr. Chea Phon	Vice-director, Teacher Training Department

6. Translator

Mr. Keo Mono	Technical Advisor/Facilitator – Science RTTC

Table of Contents


Chapter 1:
Developing
Active Reading
and
Writing Skills

Chapter 1 Developing Active Reading and Writing Skills

Introduction

In this manual we present 10 techniques to stimulate reading comprehension and writing skills with your students. On average students spend a lot of time reading or writing during science lessons. These techniques will enable teachers to turn these moments into active learning opportunities for students.

More specifically, the methodologies in this chapter will teach students to:

- Read a text actively instead of just decoding words;
- Select main ideas and key words from a text
- Take notes in a strategic way
- Reflect on their learning and formulating it.
- Write about science in their own words
- Use their creativity when writing about science.

Active reading and writing are important components in a student-centred classroom. The techniques stimulate students to engage more actively with the lesson content and to reflect on their learning process.

1. Concepts Covered

Strategic reading

Many students believe that they are good readers, when in fact they are simply good decoders of text. This means that they can transform the letters into words; reading a science text is more than that. It also requires comprehension. Therefore, if students have poor comprehension, they are poor readers even if they can decode fluently. This chapter discusses techniques to help poor readers become strategic readers. The table below contrasts the habits of poor readers with strategic readers. It is important for teachers to recognize these characteristics so they can diagnose reading problems and help their students to improve.

		Poor readers…	Strategic readers…
Before reading	Structure	Do not review the structure established by the author	Review structure before reading
	Goals	Do not have specific goals for what they hope to accomplish	Set specific goals before reading
While reading	Notes	Do not take notes	List the key points and summarize major ideas
	Vocabulary	Ignore words they do not understand	Try to determine meaning of new words
	Re-reading	Continue reading even if they do not understand key points	Re-read confusing sections
	Synthesis	Do not relate new information with prior knowledge	Integrate new material with prior understanding
	Reflection	Do not reflect on what they have read	Generate questions from the reading
	Highlights	Highlight and underline too much or not at all	Highlight or underline only key points
	Assessment	Do not assess understanding or only at the end of the passage	Assess understanding by outlining and solving problems
After reading	Evaluation	Do not have any goals to evaluate	Determine if they have reached their goals
	Memory	Memorize material verbatim or not al all	Express key points in their own words
	Discussion	Do not "self-talk" or discuss the material with others	Discuss material with others
	Review	Do not review the material they have read	Integrate new information with prior knowledge

Science writing

Writing is very important in science. Scientists communicate with each other through writing. Science writing is a particular style, such as a novel or a newspaper article, with its own rules and vocabulary. For example, science texts have a logical structure, they avoid using unnecessary words and they focus on precise and standardized formulations.

Secondly, writing is an important component of science lessons. Students write down definitions, notes, procedures, conclusions… However, note taking during science lessons is often limited to copying from the whiteboard without any accompanying thinking activity going on. We present in this manual techniques to turn this copying time into active learning activities.

2. Activities

1. Activity 1: Flash cards

1.1 Introduction

Flash cards are cards with on one side a scientific word or concept and on the other side its description. It is a technique to activate reading assignments and develop strategic reading skills with students. Cards made during one session, are still useful in later lessons. Students can also use them at home to study.

1.2 Objectives

- Students learn to actively read scientific texts
- Students learn to select keywords and main ideas from a text.
- Students learn new science vocabulary
- Students learn to formulate science concepts in their own words
- Students apply prior knowledge and experience to their reading

1.3 How to use this technique?

- Explain students which text they have to read and why. Inform the students about the topic of the text and situate the text in the lesson or the theory.
- Let students read the text individually a first time. Then they read it a second time, more slowly and focusing on the keywords of the text. They mark the words they think are keywords.
- Alone or in small groups, students make flash cards of the key words, using information from the text and their prior knowledge. For every keyword they try to formulate a good description that captures the meaning of the key term well.

You may specify before the assignment how many flash cards the students need to make. You may also check which keywords students marked after the second reading and, if necessary, make some suggestions or changes.

Afterwards group students together to check the quality of the flash cards or organize a class discussion. When you give them a "correct" description, discuss

- The importance of specific words,
- why some descriptions are correct or not,

Finally make sure that every student has a set of correct flash cards. If the students' flash cards are correct, stimulate them to use these. If necessary, they may need to copy the correct description.

Let students keep their flash cards in an envelope. During review lessons ask the students to bring all their flash cards, mix them and use them to review their lessons in small groups.

1.4 Material

Flash cards can be made by cutting an A4 paper in six parts. With thicker paper cards will keep longer. It is best to make cards big enough, so students are not restricted for their descriptions by the size of the cards.

If you plan to use this technique during the whole school year, it's useful to take <u>different colours</u> for different topics, e.g. blue for fluids and pressure, yellow for optics ….

1.5 When to use this technique?

This technique is best applied <u>during *stage 3*</u> of the lesson. You can easily combine it with a 3-2-1 sheet activity.

You can use the set of flash cards <u>during *stage 2*</u> of the next lesson to review the key-words of the previous lesson. Have students use their set of flash cards at various times during the school year. Regular review of key-terms strengthens understanding of core concepts.

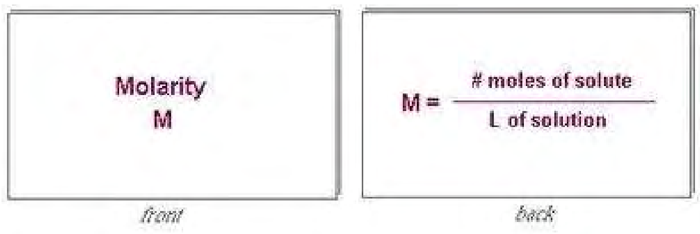
1.6 Examples from curriculum

Biology

- Integrated pest management (grade 8, chapter 7, lesson 1, 2010): cards for terms like pesticide, fertilizer, nitrification, DDT…
- The digestive system (grade 7, chapter 4, lesson 1, 2009): cards with the different parts and their function.

Chemistry

- The Greenhouse Effect (grade 7, chapter 3, lesson 2, 2009): cards for terms like greenhouse effect, greenhouse gas, CFC, atmosphere, global warming…



Earth and Environmental Science

- The Earth's Crust (grade 8, chapter 1, lesson 1, 2010): ideas for flash cards include lithosphere, asthenosphere, magma, convection, volcano…

Physics

- Gravity (grade 11, chapter 1, lesson 3, 2009): cards for terms like gravity, escape velocity, free fall…
- Heat Transfer (grade 7, chapter 2, lessons 1 - 3): ideas for flash cards include conductivity, convection, radiation, heat, temperature …

Newton's First Law	In the absence of external forces, when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity (that is, with a constant speed in a straight line). When no force acts on an object, the acceleration of the object is zero
(Front)	(Back)

1.7 Variations

You can let students decide about the number of flash cards or impose a fixed number.

1.8 Important Tips

Make sure that students have correct flash cards at the end of the lesson. However, if students know beforehand that they will get a correct set of flash cards anyway, their motivation to make good flash cards by themselves may dwindle. Explain why making an effort to construct good flash cards is a much stronger learning experience than just copying the "right" answer.

Select the text carefully so that students can formulate descriptions themselves as much as possible.

Monitor the process of selecting and describing keywords closely. The objective of this technique is not (only) the set of cards but the process of reading a text actively, looking for key terms and formulating a correct description.

At the end of the semester you can organize a review lesson during which students use their complete set of flash cards to review the concepts they've learned.

2. Activity 2: Three – Two – One sheets

2.1 Introduction

3-2-1 sheets are an interesting and easy-to-apply way to stimulate active reading with students. Students get three topics to find in the text. These topics question students about the reading content, but also, more importantly, about their own learning experience. For the first topic they have to find three answers, for the second one two and for the last topic one. Together with flash cards, 3-2-1- are excellent instruments to turn a reading assignment into an active learning opportunity.

3	Things you found out
2	Interesting things
1	Question you still have

2.2 Objectives

- Students learn to read scientific texts actively
- Students learn to identify main ideas in a text.
- Students think and discuss with their peers about science concepts
- Students learn to evaluate their learning

2.3 How to use this technique?

- Distribute the empty 3-2-1 sheets before the reading activity or write the structure on the board and let students copy the format into their notebooks.

- Students read the text a first time. Then they read it a second time, focusing on the 3 items of the 3-2-1 sheet. After reading give students sufficient time to complete the 3-2-1 sheet.

- Let students compare their 3-2-1 sheet, first with their neighbour or in a small group.

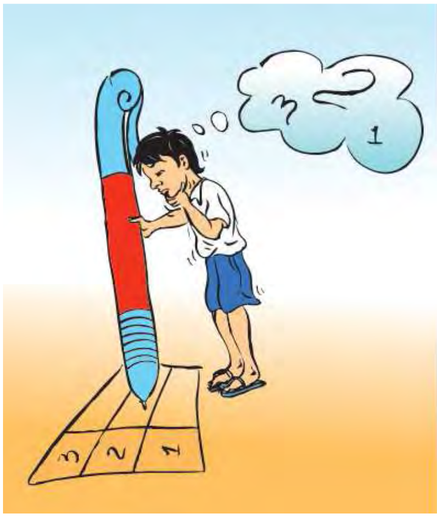
- Organize a short class discussion to capture the variation in responses. From this discussion students can gain new insights or ways to look at the text.

Items you can use on the 3-2-1 sheet:

- things you didn't know before
- interesting things from the text
- question you still have
- keywords
- things you agree upon
- thing you don't agree upon
- arguments in (dis)favour of
- things you want to tell someone else
- thing you want to know more of
- things important for yourself
- thing you still struggle with

2.4 Material

Provide the students with an empty 3-2-1 sheet (half A4 paper) or write the structure on the board and let students copy it into their notebooks.



2.5 When to use this technique?

Use 3-2-1 sheets <u>during *stage 3*</u> of the lesson. You can combine the technique with flash cards.

2.6 Examples from curriculum

Earth science: The greenhouse effect (grade 7, chapter 2, lesson 3)
Let students think about what they still find difficult to understand about the greenhouse effect.

Earth Science and Biology: Integrated Pest Management (grade 12, chapter 6, lesson 1 or grade 11, chapter 6, lesson 3 in the biology curriculum)
Let students try and find arguments for and against IPM.

Integrated Pest Management

Before 1990 agriculture chemicals were not readily available in Cambodia, but as the country opened up to the outside world this changed. Between 1989 and 1999 pesticide imports more than doubled. No policy existed and dangerous chemicals banned in other countries were imported.

A 1999 study of toxic residues in fish found DDT levels were low with the highest values recorded from Kompong Chhnang. The researchers concluded that residue levels were lower than in other parts of Asia, and that Cambodia was one of the cleanest countries in the region. But it may be difficult for Cambodia to keep its enviable status, as a recent report by an UK NGO, the Environmental Justice Foundation, found the use of hazardous pesticides to be increasing across the country.

An alternative way forward is being provided by integrated pest management (IPM), the objective of which is to encourage natural pest control methods. It involves minimizing the use of pesticides by adopting a range of approaches and interventions to pest management, some chemical, but others biological, cultural or temporal. An example is the promotion of rice-fish culture systems, as fish are both beneficial in pest control and increased fish production raises farmers' livelihoods.

Source: Poole, 2005

3	***Things you found out*** *1. Between 1989 and 1999 pesticide imports more than doubled.* *2. In 1999 Cambodia's residue levels were lower than in other parts of Asia* *3. FAO wants Cambodia to manage pest by using natural pest control methods*
2	***Key-words*** *Pesticide* *Integrated pest management*
1	***Question you still have*** *How can the government increase the awareness on integrated pest management with its citizens?*

IPM	*Integrated pest management* *It aims at reducing chemical usage and increasing natural pest*	DDT	*A poisonous pesticide* *It is banned in many countries*

2.7 Variations

You may let students close their books or put away the text to avoid that students copy. The objective is that they formulate the 3-2-1 sheet in their own words.

You can draw the structure on the board big enough to contain all the findings of the students, so they can easily see what they missed or what others noticed. This can inspire the class discussion.

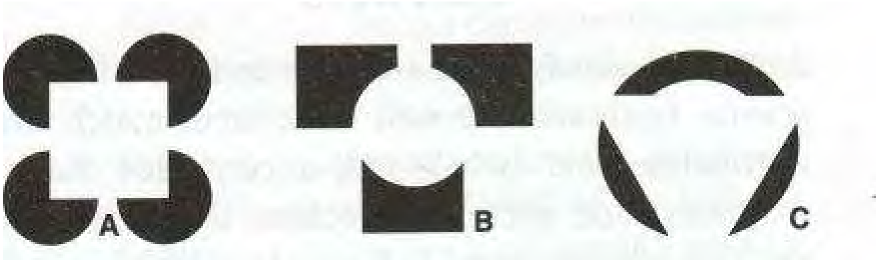
2.8 Important Tips

Stimulate students to write in their own words, instead of copying from their textbook.

3. Activity 3: Cloze Worksheets

3.1 Introduction

In the figure below most people will see a square, a circle and a triangle, but if you look again, you will note that none of these shapes is actually found in the diagram. Your mind sees clues and provides "closure" to the partial patterns it detects. Similarly, your mind provides closure if you don't decode every word when you are reading.
The ability to provide closure is a measure of reading comprehension. This activity helps to develop this skill.



Source: Herr, 2008

3.2 Objectives

- Students read scientific texts in an active way.
- Students get a better understanding after reading science texts.

3.3 How to use this technique?

Students work individually or in small groups. They read the texts while trying to fill in the missing words. They write the missing words on a sheet of paper. Afterwards students compare their results in small groups. Different words can be correct, as long as they respect the meaning of the text.

Finally, the teacher discusses the answers and lets the students complete the text. In the discussion the teacher can ask following questions to the students:
- What percentage of the terms did you guess correctly?
- What percentage are synonyms for the missing words?

In order to correct or discuss fluently, it is best to give each blank space a number.

3.4 Material

How to make a cloze worksheet exercise?

1. Select one or two paragraphs from the MoEYS science textbook or other science text.
2. Copy the first sentence intact.
3. Copy all but the last sentence, replacing <u>every fifth word</u> with a blank of equal length. The type of words that is omitted can be anything, both key-words, verbs, adjectives…
4. Transcribe the last sentence intact.
5. Make a list of the missing words on a separate sheet of paper.

3.5 When to use this technique?

Apply the technique together with a reading assignment in **stage 3** of the lesson. Choose a text that is not too difficult for students to understand.

You can also present a summary of the lesson as a cloze worksheet text in **stage 4** of the lesson.

3.6 Examples from curriculum

Biology

- The lymphatic system (grade 9, chapter 3, lesson 7, 2008)
  Students read a summary on the characteristics of the lymphatic system.

Chemistry

- Oxygen (grade 9, chapter 2, lesson 2, 2011): students read a summary of the lesson, describing the characteristics of oxygen.

Earth and environmental science

- Marine Life (grade 11, chapter 2, lesson 3, 2011): students read a cloze worksheet text on marine life.

Physics

- Newton's Laws (grade 8, chapter 21, lesson 3, 2010): students read a cloze worksheet text summarizing Newton's Laws.

Biology: Diffusion (grade 8, chapter 2, lesson 5)

I. What is diffusion?

Here are the examples of the diffusion of molecules;

- At the 2-meter distance, we can smell someone's perfume in one room. The smell of the perfume …(1).. from that person (2).. the other parts of the room. …(3)… we put a …(4)……..of sugar in the tea water, the (5) will become …(6).. without stirring the solution. The sugar …(7).. spread throughout the glass of tea water.. (8)… the living room, we …(9)… smell food that …(10)..cooks in kitchen. Of course, the …(11)… of food spreads …(12)… the kitchen to …(13)..room. If you drop a small amount of …(14)….. ink in a glass of water, …(15).. few minutes later, we…(16).. that the solution in a glass will become red…(17)..completely. It is because the molecules of…(18)..diffuse in the…(19).. molecules.

According to each of the above examples, it shows us that molecules tend to move from a place which contains more molecules (high concentration) to a place which contains few molecules or no molecule (low concentration).

Answer Key

1. Spreads
2. To
3. When
4. Piece
5. Water
6. Sweet
7. Molecules
8. In
9. Can
10. Someone
11. Smell
12. From
13. Living
14. Coloured
15. A
16. Note
17. Coloured
18. Ink
19. water

3.7 Variations

Students can prepare cloze worksheets in groups. Afterwards, the worksheets are exchanged among groups and the groups try to read (and fill in) each other's worksheets.

3.8 Important Tips

Don't confuse closed worksheet with a test. In a test, students have to fill in missing key words, whereas in a cloze worksheet exercise, random words are omitted to stimulate students' attention.

This technique does not replace the need for practical activities such as experiments or group discussions where possible.

4. Activity 4: Jigsaw technique

4.1 Introduction

A proverb says:

"Tell me, and I'll forget.
Show me, and I may remember.
Involve me, and I'll understand."

One of the most effective ways to be involved in the learning process is to share your understanding with other students. In the process of explaining to others, you develop a deeper and more comprehensive understanding. In this activity, students study a science passage and explain it to other students.

This technique is one of the most powerful reading techniques available, because students really need to read actively and be involved. It is also one of the most popular techniques with teachers.

4.2 Objectives

- Students achieve better understanding of science
- Students are actively involved in the learning process
- Students acquire better science communication skills
- Teachers identify difficult items for the students

4.3 How to use this technique?

- The teacher divides the class in expert groups and home groups.
- All students are member of an expert group and all students are also member of a home group.

- First, students sit together in the expert groups and study their (parts of the) science text. This means that they identify the key-words, make a summary and search for questions and their answers. The teacher circulates and gives explanations and tips to the groups.
- Students go to their home groups. Each member of the home group was a member of a different expert group. Now they explain to each other what they have studied in their expert group. They use their key-words, summary and questions to help the other students to understand the content of the text without reading it themselves.
- The teacher checks understanding in a class discussion. He should ask questions to students who did not study the topic themselves but received explanation from other students.
- Afterwards the teacher should spend some time letting the students tell which problems they had and what was hard to explain to others.

What are expert groups and home groups?

- In the expert group students read and study a part of the science lesson
- In the home group students explain to each other the part they studied in the expert groups.
- The science lesson is divided into as many sections as there are expert groups.

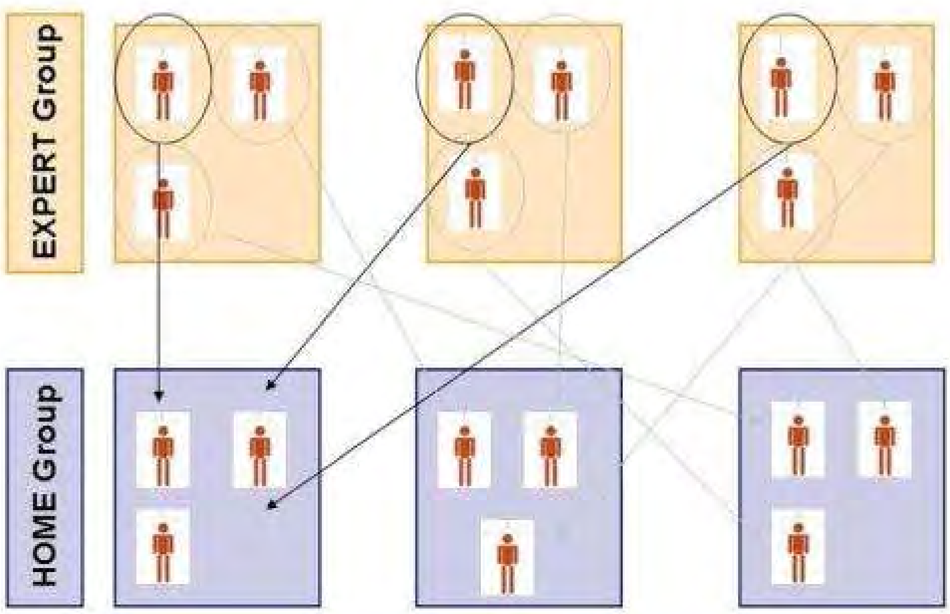
Student activities in home group and expert group

In the expert group	*In the home group*
Reading the text	Explaining to their fellow students using the material prepared in the expert group
Making a summary	
Making a list of key terms	
Searching for questions	
Formulating the answers to the questions	

How to divide the class in expert and home groups?

- First decide in how many parts you want to divide the text
- Determine the number of expert groups. There should be at least as many expert groups as there are parts in the text. In classes with many students there can be twice as many expert groups as there are parts in the text.
  For example you divide the science lesson in 3 parts and there are 25 students in the class. You can divide the class in 5 expert groups of 4 students and one group of 5 students. Each part will be studied by two expert groups. There will be 4 home groups (3 of 6 students and one group of 7).
- Determine the number of home groups. Each home group should contain at least one and sometimes two students of every expert group. In that case each part of the science text is explained by one (or two) “experts”..
- Groups should preferably contain no more than 6 students to ensure that every student is involved.

- Expert groups can be numbered (1, 2, 3…) and home groups can be given a letter (A, B, C…). Each student receives a code (for example A1) that indicates to which home and expert group he belongs. Instead of letters and numbers also science concepts or pictures related to the lesson can be used. For example the experts groups are identified by the main parts of the plant.
- Give each student a code. Current class setup can be used for expert groups so that students only have to change place once.



4.4 Material needed

- Each expert group should have paper to write the key-words, summary etc. When the group agrees on the result, every student can copy it into his notebook and use it in the home group.
- You may use small papers with codes, key-words or pictures to divide the class in expert and home groups.
- If available, students can use science books or internet to find more information.

4.5 When to use this technique?

- This technique should be used in **stage 3** of the lesson. The first time foresee sufficient time to explain the technique to the students.
- The technique can be spread over two lessons. The first lesson covers the expert group stage and the second lesson the home group stage and the class discussion.
- Choose a topic that is not too difficult for students and allows for self-study.

		1 hour lesson	2 hour lesson
• Stage 3	EXPERT group	15’	30’
	HOME group	20’	40’
• Stage 4	CLASS DISCUSSION	7’	15’

4.6 Examples from curriculum

Biology:

- The respiratory system (grade 8, chapter 4, lesson 1, 2010)

Chemistry:

- The speed of chemical reactions (grade 12, chapter 1, lesson 1, 2010)

Earth and environmental science:

- Plate tectonics (grade 9, chapter 2, lesson 1, 2011)

Physics:

- Electromagnetic radiation (“Visible and Non-Visible Light”) (Grade 12, chapter 5, lesson 5, 2011)

4.7 Variations

You can provide guiding questions for the expert groups (what, why, how…) that allow them to structure the information.

4.8 Important Tips

Divide the science lesson in parts of approx. **equal study length** or give additional questions to the expert groups.

As a teacher it is important to be **well prepared** for this technique. You need to have a clear idea on how you will coach the expert groups. Have tips ready that you can give to the students without telling too much.

This technique can only if the lesson parts can be studied **independently**. A lesson where the understanding of one part is required to understand the next part is not suitable for Jigsaw technique.

5. Activity 5: Cornell Note Taking

5.1 Introduction

Note taking is an important skill in science education. A fixed format can help students to take notes in a structured and consistent way. The Cornell system provides such a structure. This activity turns lectures into active learning opportunities.

5.2 Objectives

- Students learn to take structured notes.
- Students learn to distinguish important from unimportant information
- Students learn to process information by formulating questions, identifying keywords or making tables and drawings.
- Students learn to review and complement their notes after a lecture
- Students learn to use scientific vocabulary and write in a scientific way

5.3 How to use this technique?

Select a topic for a lecture. The lecture should be well structured and begin and end should be announced clearly. Write down some key-words on the board during the lecture to ease note taking. Remind students not to write down whole sentences but key words and short phrases and stimulated to write down as much as they can. The length of the lecture is best kept between 10 and 15 minutes. The first time, explain the structure for note taking to the students:

A page is divided in three main areas:

- cues: contains the main ideas, key-words, questions and action points
- notes: contains the record of the lecture: brief phrases, words and diagrams
- summary: contains the main points of the lecture

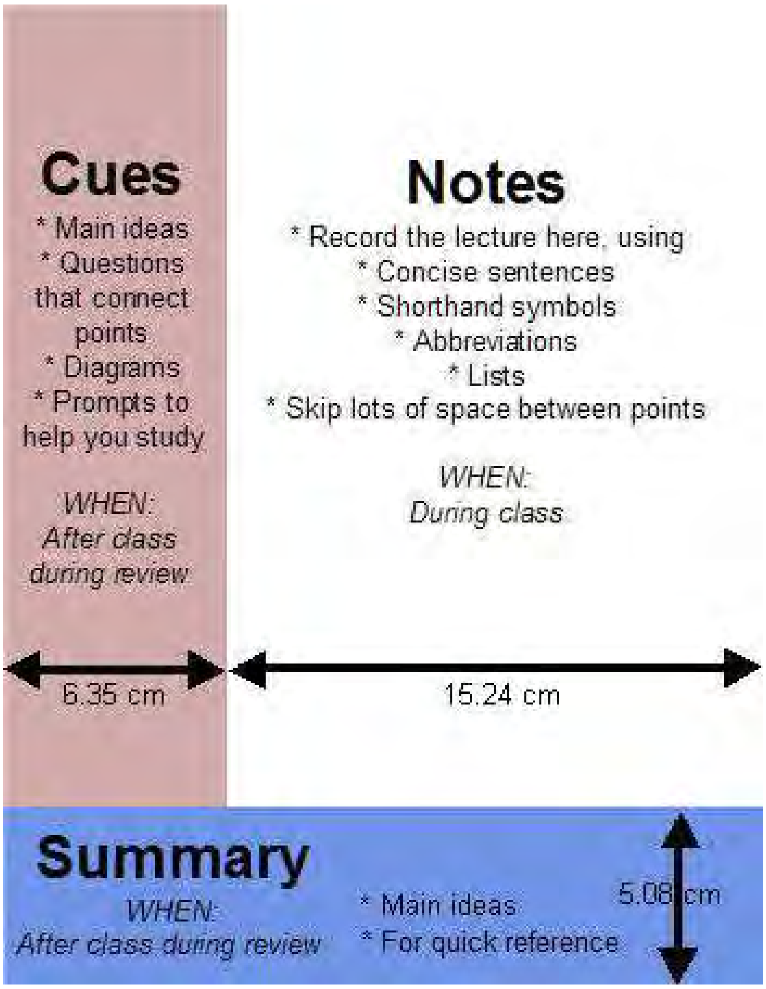
During the lecture students only write in the “notes” part.

After the lecture provide 5 to 10 minutes for the students to complete the “cues” and “summary”. This review can also be organized as homework assignment. During the review phase walk around and try to get an impression on the student’s ability to take notes.

Afterwards you can let students review their notes in pairs (see: Note Taking with Peer Review) or organize a class discussion, focusing on issues as:

- What are the key issues in the lecture?
- What should be included in the summary?
- What questions did you write down?
- Did you find it difficult to take notes?

The notes and the discussion afterwards reveal which key issues the students have difficulty with understanding.



5.4 Material

Students take notes in their notebooks or on a separate sheet of paper.

5.5 When to use this technique?

The technique is best applied during *Stage 3* of the lesson. It stimulates students to think during the lecture and to review their notes after the lesson. If combined with peer review, it stimulates students to review the lecture with their peers.

5.6 Examples from curriculum

Earth and environmental science:

- Ozone in the Stratosphere (grade 12, chapter 4, lesson 8, 2011)

Biology:

- Enzymes (grade 12, chapter 4, lesson 3, 2010)

Chemistry:

- Application of Acids and Fertilizers (grade 9, chapter 4, lesson 2, 2011)

Physics:

- Kinetic Theory of Matter (grade 10, chapter 2, lesson 2, 2009)

5.7 Variations

You can also use Cornell note taking as an active reading activity. Let students make a summary of a text using Cornell notes.

Let students make notes in Cornell note taking format while watching a video.

5.8 Important Tips

Make the **objective** of the lecture clear before note taking starts, so students know on what to focus during note taking. For example, writing down a complete procedure for an experiment is not necessary when the students only have to understand the conclusion.

Circulate in the class during the lecture You may collect notes after the lecture for assessment.

6. Activity 6: Note Taking with Peer Review

6.1 Introduction

Note taking activities can be followed by a peer review activity. Students exchange their notes with their peers and review each other's notes. They complement the notes and write a short comment on style and content. This process is similar to the peer review process scientists use when they want to publish research articles.

6.2 Objectives

- Students get inspired and learn from other student's notes
- Students learn to formulate a brief comment on other students' notes.
- Students are more motivated to take notes because other students review them.
- Students learn to think actively about the content and structure of the notes they're reviewing.
- The teacher can assess the note taking capabilities of the students. Students' comments may reveal misconceptions on the topic or identify problems that need further instruction.

6.3 How to use this technique?

After taking notes (see Cornell Note Taking activity) and review each student passes his notes to the student at the left. Students review the notes from the student on their right and write comments without using the textbook. Circulate and check the quality of the notes. Let students present good examples. You may also participate in the process, reviewing some student's notes.

The first time the teacher needs to give some examples of constructive comments. After the first time the merits of using peer review can be discussed with the class.

6.4 Material

Notes taken on a separate sheet of paper are easiest to transfer between students.

6.5 When to use this technique?

Apply this technique during **stage 3** of the lesson.

6.6 Examples from curriculum

See: Cornell note taking

6.7 Variations

Two rounds of passing notes can be organized, so each student receives feedback on his/her notes from two students. The second review should only add new elements, not repeat the same comments.

Students may work in pairs, if some students have difficulty formulating comments.

6.8 Important Tips

Tell students to avoid making quick and vague comments. They should get enough time to review the notes thoroughly and formulate a comment. The first time the teacher can provide some examples of good comments.

Comments should be constructive and not entirely negative. The teacher should explain that constructive comments are more useful and motivating and provide some examples.

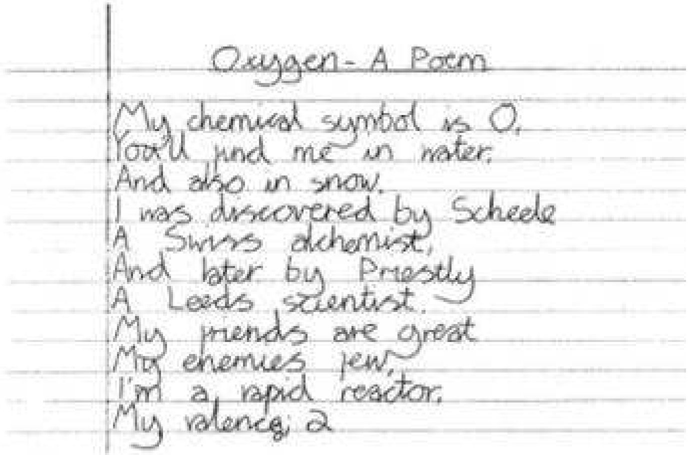
In order to obtain good reviews you can put the main goals of the task on the whiteboard so that whenever a student - reviewer hesitates in writing a comment, he or she can take a look at those main goals.

7. Activity 7: Creative Writing

7.1 Introduction

Creative writing is a collection name for writing activities that stimulate students to write about science in a creative way. Students translate the content of a lesson or part of a lesson using language and examples appropriate for a specific writing style and audience.

Oxygen – a poem



Oxygen - A Poem

My chemical symbol is O.
You'll find me in water.
And also in snow.
I was discovered by Scheele
A Swiss alchemist,
And later by Priestly
A Leeds scientist.
My friends are great
My enemies few,
I'm a rapid reactor.
My valency 2

Source: Year 8 pupil

7.2 Objectives

- Students learn how to formulate knowledge so that others can understand.
- Students increase their understanding by learning to summarize what they learned **in their own words**, using correct scientific terms.
- Students improve their communication skills
- Creative thinking is stimulated

7.3 How to use this technique?

Present students with a topic and/ or a writing style. Topic and/ or writing style can be formulated broadly, giving the students room for selection. However, students should be familiar with the characteristics of the format. For example, a newspaper has a limited amount of words, is intended for non-specialists, has a catchy title and begins with a summarizing topic sentence. If necessary, explain the characteristics of the style and write them on the whiteboard.

Select an appropriate time for the writing assignment. You may let students start the assignment during class and finish it at home.

Below are some possible formats and audiences.

Format	***Audience***
Letter	Parents, grandparents
Newspaper article	Director of a company
Poem	Your friend
Manual	Readers of a newspaper
Advertisement	Government
Opinion article	Scientist
Story	Younger sister or brother

7.4 Material

Students can write in their notebooks or on a separate sheet of paper.

7.5 When to use this technique?

Usually this technique is applied at the end of a series of lessons on a topic. The writing activity provides students the opportunity to review the topic in a creative way.

It is best done in **stage 3** of the lesson or organize it as a homework assignment.

You may let students present their writings to each other in front of the class.

7.6 Examples from curriculum

Biology:

- Imagine you are a chloroplast. Write a diary of a typical day spent in the Sun (Photosynthesis, grade 9, chapter 1, lesson 1-3, 2011)
- Write a story with as title “The day I was swallowed” (Digestive System, grade 7, chapter 4, lesson 3, 2009)
- Let students compose (and sing) a song that deals with “Water safety”.

The lyrics of the song could be as follows:

Tak Ting Nung Nung; while bathing in the lake, we catch 5 chunks of clay, two of which be used to
make fish paste, three for processing with pickles;
All the five will be processed on wooden board.

Tak Ting Nung Nung; drinking later water might upset our stomachs
Drinking unclean water brings in diarrhea and harm to health;
Don’t water without boiling;

Tak Ting Nung Nung, we must do the best to use boiled or filtered water;
Only this way can we get rid of fear
Our children can enjoy good health

Earth and environmental science:

- Imagine you’re making a journey to the centre of the Earth. Write a letter to your parents describing what you have seen. (Structure of the Earth, grade 8, chapter 2, lesson 1, 2010)

Physics:

- Write a letter to grandma explaining why our weight is less on the Moon but our mass still the same (Gravity, grade 11, chapter 1, lesson 3, 2009)

Chemistry:

- Report the discovery of a new unknown chemical element (atomic model, table of Mendeleev, grade 9, chapter 1, lesson 1, 2011).

All subjects:

- Write a letter to your grandfather explaining what you have learned today.

An example from *Nature of Our Country, in "I Want to Know" series*

Please help us

My name is dolphin. I live in Mekong River, but I am not a fish. I am pregnant for 9 months and usually give birth to one offspring at a time and twin babies sometimes. Our babies are breast-fed like human. People say I am a mammal. When we are fully grown, we may weigh up to 200 kg and 2.8 meters long. Our village located in Mekong River, specifically in Steung Treng and Kratie. Before 1975, our population was thousands and we used to swim downstream to Kampong Cham and Kandal. Unfortunately, humans keep hunting for us. Today, our population is only 70 to 100. Please help to protect us so that we can enlarge our family.

7.7 Variations

You may give students a list of words to include in the writing, for example the key-words of the lesson.

You can organize a brainstorming activity before the creative writing (see chapter on Scientific Method), in order to give inspiration to students.

7.8 Important tips

When a teacher gives freedom to a student to be creative, it must be clear to the students that there are some main goals that the text must fulfil but the creativity part can be neither wrong nor right. Students need to feel safe before they can be creative.

When the teacher gives the task to a certain public (e.g. grandmother), it's preferable to let that public read the text and give comments.

8. Activity 8: Ten – Two

8.1 Introduction

This is a small and short activity helping the students to process large amounts of information during instruction. After 10 minutes of instruction, students take two minutes to reflect on and summarize what they have learned so far.

8.2 Objectives

- Students learn to summarize frequently and reflect on their learning. This is in particular useful when large amounts of information and difficult ideas are presented.
- Students' attention and involvement will increase by providing variation in instruction.

8.3 How to use this technique?

Explain the purpose of the technique to the students. Start the lesson. After 10 minutes of instruction (during stage 3 of the lesson), give the students two minutes of time to quietly think, summarize or discuss their ideas with a partner.

After the two minutes ask if the students are ready to move on. When you circulate in the class try to get a sense of students' summary notes. They may reveal that students are struggling with the information and are not ready to proceed without further help from the teacher. Resume instruction and repeat again after 10 minutes. The teacher may ask for feedback on this technique from the students.

8.4 Material

Students may write questions or a summary in their notebooks.

8.5 When to use this technique?

Use the technique **in stage 3** of the lesson, to break long periods of instruction.

8.6 Examples from curriculum

Biology:

- Sexual Reproduction in Animals (grade 11, chapter 2, lesson 1&2, 2009)

Earth and environmental science:

- Instruments Used by Earth Scientists (grade 7, chapter 1, lesson 1, 2008)

Chemistry:

- Polarity of Bonds (grade 11, chapter 3, lesson 2, 2007)

Physics:

- Lasers (grade 12, chapter 5, lesson 3, 2008)

8.7 Variations

Other time intervals may be used, such as 5-1, 7-2, 10-3, 15-5…

You may combine this technique with Concept Tests (see chapter about Concept Test)

8.8 Important Tips

Make sure that the flow of the lesson is not broken. Breaking at certain intervals without taking into account the structure of the lesson may cause inconsistency.

9. Activity 9: Two-Minute Papers

9.1 Introduction

The Two Minute paper is a quick and simple way to collect feedback from students about their learning at the end of an activity, field trip, lecture or other learning experience. Give students two minutes to write about a statement that you give them.

9.2 Objectives

- Students learn to think what they have been learning.
- The teacher collects instant feedback on students' learning.

9.3 How to use this technique?

Provide half a sheet of paper to students. Write two questions on the board that you want the students to respond to. Examples are:

- What was the most important thing you learned today?
- What did you learn today that you didn't know before class?
- What important question remains unanswered to you?
- What would help you learn better tomorrow?
- …

Give students two minutes time and collect their papers. After analysis, share the results with the students, letting them know that you use their feedback and showing them how you will use it.

9.4 Material

(Half) a sheet of paper per student.

9.5 When to use this technique?

Apply this technique in *stage* 4 of the lesson.

9.6 Examples from the curriculum

*Physics**:** Magnetism (grade 8, chapter 5, lesson 1, 2010)*

- What did you learn today about magnets that you didn't know before?

*Chemistry**:** Air Pollutants (grade 7, chapter 3, lesson 2, 2009)*

- In 2 minutes, write down what you have learned today about the impact of human activities on the environment.

9.7 Variations

It can also be used at the beginning of a lesson to reflect on the previous lesson.

For older students it can be turned into a One-Minute Paper. For younger students Three-Minute or Four-Minute Papers can be used.

9.8 Important Tips

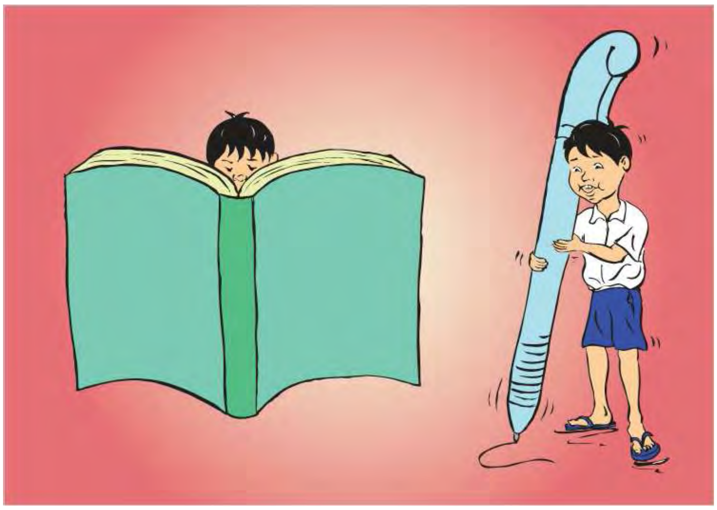
Adjust the time to your students' writing abilities so that slower students also have the opportunity to give feedback.

Don't overuse the technique to avoid that students get bored with the technique.

10. Activity 10: Read-Write-Read-Write

10.1 Introduction

This methodology stimulates students to actively read a text and extract its main ideas. It is used to teach students how to make a summary in their own words.



10.2 Objectives

- Students learn to read actively
- Students learn to write a summary in their own words
- Students learn to identify key ideas in a text

10.3 How to use this technique?

- Distribute the text to the students or assigns a text from the student book
- Students read the text individually.
- Students put the text away (or close their book) and try to write a summary of the text.
- Students put their summary away and get some time to read the text again.
- Students put the text away and get some time to update their summary.
- (optional) students compare and improve their summary in small groups
- Teacher discusses the main elements of the text. Students compare with their summary.

10.4 Material

The teacher may provide a paper with the text for the students or he can select a text from the book. If not all students have a book, students can do the reading activity in groups of 2.

10.5 When to use this technique?

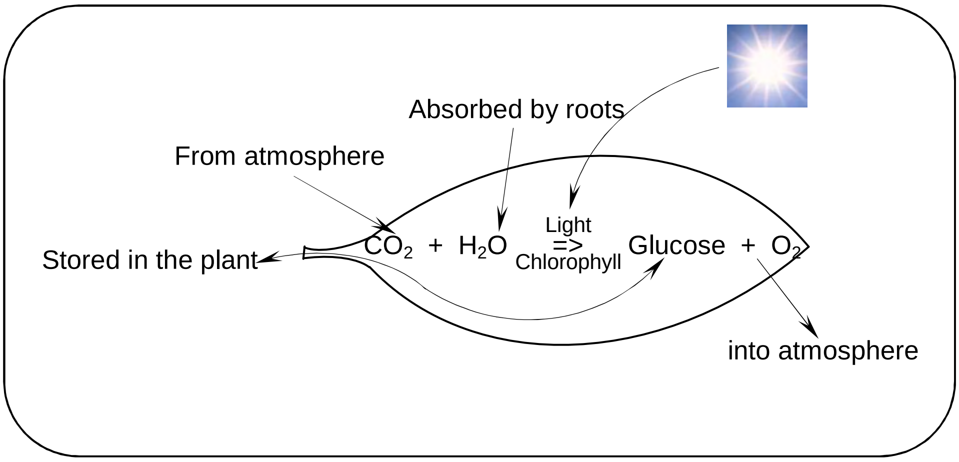
Use this technique in stage 3 of the lesson, when students have to read a text. The technique does not replace the need to explain the content or to include practical activities in the lesson.

10.6 Examples from the curriculum

Biology: Photosynthesis (grade 9, chapter 1, lesson 1-3, 2011)

Photosynthesis

The process used by green plants to produce their food is called photosynthesis. This process requires energy. The plants use chlorophyll, the green pigment in their leaves, to absorb energy from sunlight. This energy is used in a chemical reaction between carbon dioxide and water in which sugar is produced. This sugar is called glucose. In this reaction also oxygen is produced. Plants don’t use oxygen and emit it back into the atmosphere. Some plants such as sugar cane break down the produced glucose into another type of sugar. Other types of plants convert glucose to starch. The presence of starch in plant leaves indicates that photosynthesis takes place there.



Leaf (food manufacturing location for green plants)

10.7 Variations

Students can write the summary in small groups, if they find it difficult to write a summary.

10.8 Important Tips

Explain new or difficult vocabulary before the activity. Students should be able to understand the text when reading it.

Specify whether students need to make a summary in full text or in bullet points, or whether they can choose the format.


Chapter 2:
Developing
Reasoning Skills

Chapter 2 Developing Reasoning Skills

Introduction

This chapter introduces a set of techniques to help you developing reasoning skills with your students. The techniques stimulate students to express what they have learned in their own words and to form their own opinion about scientific issues. In this way, the techniques promote deeper understanding of the science content.

We hope that you will find this manual useful. We do realize however that it may still contain inaccuracies. We are grateful to receive any comments or suggestions to improve the manual.

1. Concepts Covered

Reasoning in science

Reasoning in science lessons encompasses techniques that aim at stimulating students to deepen their understanding on science topics by engaging them in scientific argumentation. In this way, they apply their knowledge in new contexts, using their own words. Allowing students to reason about science can reveal pre- and misconceptions with students that will help the teacher to teach more effectively. At the beginning of a unit of instruction reasoning helps the teacher to assess the prior knowledge of the students, while students refresh their memory.

2. Activities

1. Activity 1: Agreement Circles

1.1 Introduction

This technique stimulates student thinking and interaction and doesn’t require expensive materials.

1.2 Objectives

To stimulate students to think and formulate explanation to support their own idea.

1.3 How to use this technique?

- Place students in a circle and read aloud the statement about the topic of the lesson.
- Students who agree with the statement step forward to the centre of the circle.
- Make small groups with a mix of students who agree and disagree.
- Let students discuss for a few minutes to justify their answers.
- Give the students an opportunity to reposition themselves, if they changed their mind.
- Repeat the process a few times. The aim is to get everyone either inside the circle or on the outside.

The technique can be done with several rounds with statements related to the same topic. Good arguments will be adopted by other students and spread fast throughout the class.

If the technique was used in the beginning of the lesson, then the next step is providing a lesson that will allow students to explore these ideas further. If the technique was done near the end of the lesson, the teacher can organize a class discussion to synthesize the concepts.

1.4 Material

The classroom needs to be big enough so the students can form a big circle. If space is limited, a variant called corners technique can be applied (see 1.7) or the activity can be done outside.

1.5 When to use this technique?

Use Agreement Circles at the start of stage 3 (assessing prior knowledge) or at the end of stage 3 (reviewing the concepts of the lesson).

1.6 Examples from curriculum

Biology: Statements on HIV/ AIDS

Grade 7, chapter 8, lesson 3, 2008
Grade 9, chapter 6, lesson 16
Grade 9, chapter 3, lesson 2, 2011
Grade 9, chapter 6, lesson 17, 2008

Below are statements about HIV/AIDS. Decide for each one if it is true or false and argue why.

1. *HIV is the same as AIDS.*

FALSE. HIV is the name of the virus. Once HIV infection has weakened the immune system sufficiently, the body is susceptible to a whole range of infections. It is this weakened state which we call AIDS.

2. *There is no cure for AIDS*

TRUE. HIV cannot be eliminated from the body and the progression of AIDS cannot be reversed but there are drug treatments which can slow the progression of the disease and treat the symptoms.

3. *A mother can pass HIV to a baby in the womb*

TRUE. Yes, and at labour and delivery time too but if the mother takes antiretroviral drugs during pregnancy, the risk to the baby is reduced a lot.

4. *A mother can pass HIV on through breast milk*

TRUE. It is advisable therefore for an HIV+ mother not to breast feed her baby but to use formula milk.

5. *HIV+ people with no symptoms cannot transmit the virus*

FALSE. Many people in the early stages of infection will seem totally healthy and show no symptoms but they can still pass on the virus.

6. *All people with AIDS show the same symptoms*

FALSE. HIV weakens the immune system, leaving the body open to many different infections and leading to AIDS. The infections and symptoms will vary between people with AIDS.

7. *A negative HIV antibody test confirms that a person does not have the virus.*

FALSE. Particularly in the first few months after infection, the body has not produced enough antibodies to be detected by the test.

8. *HIV can be transmitted by insect bites.*

FALSE When a mosquito sucks blood, all it introduces is saliva which does not contain viruses from any previously bitten person.

9. *HIV survives for a long time outside of the body.*

FALSE HIV quickly disintegrates outside the body or body fluids.

10. *HIV only affects humans.*

TRUE. Whilst there are similar viruses which effect cats and monkeys, they cannot infect humans nor can HIV infect any animal other than man. This is good as it means the virus cannot be transmitted by animals but is also a disadvantage as animals cannot be used in developing treatments for HIV infection.

11. *HIV damages the immune system.*

TRUE. The host cell of HIV is mainly a type of white blood cell. Destruction of these cells damages the immune system, leaving the body open to the infections which may lead to AIDS.

12. *There is a vaccine against HIV.*

FALSE Attempts have been made and are being made to develop a vaccine but so far without success. The changeable nature of the chemical structure of HIV is a problem for vaccine development.

13. *Condoms are an effective barrier to HIV transmission.*

TRUE. Whilst no guarantee against transmission, correctly used condoms are highly effective in reducing spread.

Physics: Statements on Energy

Grade 8, chapter 3, lesson 1, 2008
Grade 7, chapter 2, lesson 3, 2008
Grade 10, chapter 1, lesson 3, 2009
Grade 8, chapter 3, lesson 1, 2010

1. Energy is a material that is stored in an object

FALSE. Energy is not a material but a characteristic of a system enabling it to do work on the environment.

2. The faster an object moves, the more energy it has

FALSE. The energy of an object is not only determined by its speed, its mass, its position (potential energy) or by its chemical structure (for example oil).

3. Energy is a type of fuel, which we should use wisely in order to avoid an "energy crisis"
FALSE. Energy is plentiful, but there are different sources of energy. Fossil energy sources are limited in supply and therefore need to be used wisely.
4. Energy can never be created or destroyed
FALSE: Energy conservation is valid when the total amount of mass is not changing during the process. This is most of the time correct and the energy will be transformed from one state to the other. But there are situations where the amount of mass will change. For instance, during nuclear fission or fusion an amount of the mass will be transformed into energy. This equivalence between energy and mass is expressed by Einstein's formula $E = mc^2$)
5. When energy changes from one form to another, heat is usually given off
TRUE. Machines are not 100% efficient. What we call "energy waste" is in fact a partial conversion to heat energy.
6. Objects with the same speed also have the same momentum.
FALSE. The momentum is determined by the speed and the mass of an object. A small car and a big truck may have the same speed, but they don't have the same momentum.

Earth and environmental science: Planets of the Solar system

Grade 7, chapter 3, lesson 4, 2008
Grade 7, chapter 1, lesson 4, 2008
Grade 10, chapter 4, lesson 2, 2010
Grade 12, chapter 2, lesson 6, 2011

1. The Earth is the centre of the solar system.
FALSE. The Sun is the centre of the solar system.
2. All objects in the solar system orbit the Sun.
FALSE. Moons don't orbit the Sun, but planets.
3. Pluto is the most-distant object in the solar system.
FALSE. There are many objects in orbits further from the Sun than Pluto, such as other dwarf planets and comets. Even Neptune's orbit brings it further from the Sun than Pluto at times.

1.7 Variations

When it's difficult to form circles, you may ask students to form 2 rows, one for the agreeing students and one for the disagreeing students. If possible, go outside to do this technique.

When space constraints don't permit the formation of a circle, the <u>corners technique</u> can be applied. The same statements are used but the teacher indicates which side of the class is the "agree side" and which side is the "disagree side". After each statement students choose to move to one of the two sides.

If all students end up at the same side, have them pair up to explain why they agree or disagree. Often there are differences in the justification of their ideas, even if both students agree or disagree with the statement.

Stimulate students to come up with their own statements.

1.8 Important Tips

Make sure students don't move to the inside or outside because the majority of the students do so. They need to be confident in their thinking when using this technique. Agree on a signal with the students when they all choose their position at the same time.

Statements should be as clear as possible for the students, so they don't have to ask many questions before taking position.

2. Activity 2: Donuts

2.1 Introduction

This great technique stimulates thinking and reasoning with students as they discuss with different people. Keeping discussion times short stimulates students to formulate their arguments in a concise way.

2.2 Objectives

- To stimulate scientific argumentation and listening skills.
- To increase understanding of a science topic and/ or the implications of the topic on society.
- To assess prior knowledge and/ or opinions with the students

2.3 How to use this technique?

- Make two circles with pairs of students facing each other.
- Read aloud a scientific statement or question
- Have students discuss the statement or question during 1 minute
- After one minute (keep **discussion times short**) have every student in one of the circles move on 2 persons so that new pairs are made. The new pairs repeat the exercise with the same question. Repeat the whole process once more, so everyone has discussed the statement or question three times.
- At the end of the exercise organize a class discussion focusing on:
    - Which arguments pro and contra were used?
    - Were scientific terms and concepts used correctly?
    - Did students change their views or arguments the second and third time?

During the discussion **walk around, listen and make mental notes**. You may address some of the arguments during the class discussion afterwards (explain why they are wrong, how they can be corrected etc.)

After the discussion, you may write arguments pro and contra on the whiteboard for students to copy in their notebooks.

2.4 Material

You may write the statement or question for the Donut Technique on the whiteboard or a large sheet of paper. Move outside if there's not enough space inside the class.

2.5 When to use this technique?

Donut technique can serve as an introduction to a series of lessons on a topic with a moral implication. You can also use it to conclude a series of lessons.

It is best applied at the beginning of **stage 3**.

2.6 Examples from curriculum

Biology:

- Should animals have rights?
- Should we experiment on living animals?
- Would you eat genetically modified food?
  Grade 12, chapter 5, lesson 1 and grade 11, chapter 3, lesson 2 (2009)
- Should patients always be told the truth about their disease and prognosis?
- Is there any difference between "good drugs" and "bad drugs"?
  Grade 9, chapter 8, lesson 18 (2008) and grade7, chapter 5, lesson 1 (2009)

Earth and environmental Science:

- Should we invest money in a manned space mission to Mars?
- Should we build dams on the Mekong River to provide hydro-energy?
- Can the rock cycle stop?

Physics:

- Are our observations influenced by our prior knowledge?
- Can we solve our fossil energy problem with technology?
- How can we prove that a physics law is correct?

Chemistry:

- Should we destroy all atomic bombs?
- Should we use chemical fertilizers to improve crop yields?

2.7 Variations

When there is not enough space available, the exercise can also be done with 2 lines of persons facing each other wherever there is space (e.g. in front of the class, in walkways between desks etc.)

The teacher may **add an extra observer** who follows one student during the different discussions. The observer should not intervene during the discussion but take note of the arguments that the student uses. At the end of the exercise the teacher can ask both the observers and the participating students how the students' views have evolved during the exercise.

Try to avoid that pairs of students stand too close to each other. In that case they will influence each other's discussions.

If there are an odd number of students, you may group two students together. One can act as an observer (see above).

2.8 Important Tips

Questions should be broad and related to **daily life**. They should stimulate students to question the implications of science on society.

Do not intervene during the discussion when you hear a wrong argument. Make a mental note and explain it afterwards to the whole class. Also other students may hold this wrong conception.

If a large number of students turn still out to have misconceptions at the end of the activity, you need to plan additional instruction on the topic.

3. Activity 3: In the Fishbowl

3.1 Introduction

In this technique a small group of students discusses a scientific statement in front of the class, while the other students listen and take notes. Afterwards they can comment on the discussion “in the fishbowl”.

3.2 Objectives

- Students listen to each other’s arguments
- Students justify their arguments in a scientific way (using evidence and explanation)
- Students identify inaccuracies and challenge statements that conflict with their own thinking
- Students reflect about what they have learned

3.3 How to use this technique?

- Choose 4 to 6 students who are representative for the class as a whole (see Important Tips) and place them in front of the class.
- Remind students that only the students in the “fishbowl” can talk. The other students listen to the discussion and write down any comments or questions they want to make at the end.
- Read an open-ended scientific statement to begin the discussion.
- One student starts the discussion by sharing his or her answer and the reasoning behind it. Other students join in, agreeing or disagreeing, building on each other’s arguments. If necessary, the teacher can facilitate the discussion (See Important Tips).
- Encourage all the students in the “fishbowl” to participate in the discussion and to focus on each other, not on the other students in the class.
- After the discussion allow the other students to comment.

- Make a synthesis of the discussion. If wrong arguments or misconceptions were used, explain why they are wrong and what the correct statement is.

3.4 Material

Write the statement for the discussion on the whiteboard or on a large sheet of paper. Students may use educational materials such as posters, models or experiments to support their arguments.

3.5 When to use this technique?

Use this technique in stage 3 of the lesson. Use it to let students practice what they have learned and deepen their understanding.

3.6 Examples from curriculum

Physics

1. Is air necessary for gravity to act on an object?

Grade 8, chapter 2, lesson 3 (2008)
Grade 10, chapter 1, lesson 3 (2009) and
Grade 8, chapter 3, lesson 1 (2010)
Gravity does not need air to act on an object. Recall the moon orbiting the earth or the earth orbiting the sun. Gravity is a force that doesn't need a "medium" to work.

2. Does the wind have energy?

Grade 8, chapter 3, lesson 1 (2008)
Wind is moving air. The air molecules have kinetic energy, but also potential and heat energy.

3. Would you prefer to carry an amount of water with one bucket or with two buckets? Why?

Grade 11, chapter 1, lesson 6 (2009)
Two buckets are easier because you may stand upright while carrying a bucket in each hand. With two buckets the centre of gravity will be in the centre of the support base provided by your feet. The same can be accomplished by carrying one bucket on your head.

Earth and environmental science

1. Life would be impossible without the greenhouse effect.

Grade 12, chapter 4, lesson 5 (2011)
(The greenhouse effect is necessary for the life (as we know it) on Earth. Without it the Earth would be about 20 degrees colder.)

2. Are humans capable of organizing a manned space mission to one of the outer planets?
   Grade 7, chapter 3, lesson 4
   Grade 7, chapter 1, lesson 4 (2009)

(No. 1/ travel time would be several years 2/ We don't have rockets that can carry enough energy to come back (to escape the strong gravity of the outer planets) 3/ Outer planets lack a solid surface to land on.)

3. Convince an extra-terrestrial visitor that the Earth orbits the Sun.

Grade 7, chapter 3, lesson 3 (2008)
Grade 7, chapter 1, lesson 3 (2009)
(At different times of the year you can see different stars at the same time at the same location. The Sun has a much higher mass than the Earth, so according to the laws of gravity it must orbit the Sun.)

Chemistry

1. Why doesn't oil mix with water? (see experiment 17 in Chemistry experiment manual)

2. Do chemical reactions continue until all the reactants are exhausted?

Biology

1. Should we experiment on living animals?

2. Do you think we should pay local people for protecting their forest?

3. How can we stop deforestation?

3.7 Variations

You can repeat the activity several times, each time with other students in the "fishbowl".

To structure the discussion you can use a fixed format. The first student gives his/her opinion to the statement. From then on, the students may only interfere using the following format: I agree (or disagree) with student x because. This way the students have to formulate decent arguments and interact with each other. The teacher can stop the discussion when the arguments are not clear.

3.8 Important Tips

Make students in the “fishbowl” feel at ease before you start the discussion. Make sure they know there is no right or wrong during the discussion. Every argument is valid as long as it is built on reason.

The first times you apply this technique choose students with strong conversational skills. They will act as examples for the other students.

During the discussion, write down problems and misconceptions that may need to be addressed during subsequent instruction. If many students still have misconceptions at the end of the activity, you may plan more instruction on the topic.
Prepare additional questions and tips that you can use when the discussion stops.
Statements that are too difficult or too easy will not generate a lot of discussion. After the activity evaluate the statements. Were they at the right difficulty level?

4. Activity 4: Moral Continuum

4.1 Introduction

This short activity can be done to stimulate students to consider the moral or societal implications of science. It can be done with large classes and still have all students involved.

4.2 Objectives

- Students learn to clarify their arguments and to listen to others.
- Students learn to consider the moral and societal implications of science.

4.3 How to use this technique?

- Have students stand in a U-shape.
- Explain that one side of the U-shape represents "do agree fully" and the opposite side means "disagree fully" . Students in the middle neither agree nor disagree. Draw the U-shape on the whiteboard the first time.
- Read the statement aloud and have students position themselves. The students need to be able to see each other and form a single line.
- Ask some students why they are standing at that point in the line.
- After hearing some arguments allow students to reposition themselves.

Repeat the process with another question. Start with a general question. The second question can be a more personal question, related to their daily live, to see how the students respond to a case more related to their own moral choices.

For example, the first question could be whether they agree with surrogate motherhood (women carrying someone else's child). The second question would be whether they would do it themselves (or approve their sister doing it).

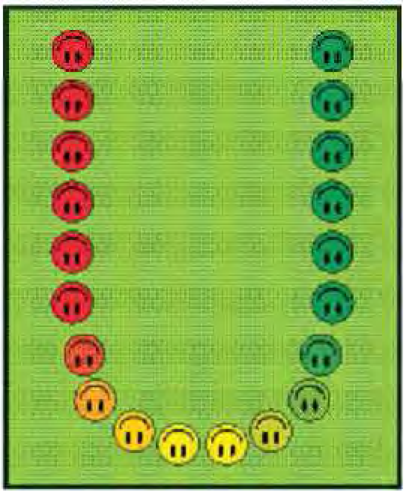
4.4 Material

For this technique you only need enough space to form a U shape. Maybe you can do the activity outside?

4.5 When to use this technique?

Use this technique in stage 2 or 4 of your lesson. Use it to let students practice and review what they have learned and deepen their understanding. Allow 10 to 15 minutes to do this activity.

Alternatively use the technique to introduce a topic and to collect students' prior knowledge.



4.6 Examples from curriculum

Biology

- Should we use animals for dissection in class?
- Who is responsible for water pollution?
- Do you approve that women carry someone else's child?

Chemistry

- Do you think it is okay for farmers to use chemical fertilizers? *(grade 10, chapter 4, lesson 5, 2008)*
- Would you buy vegetables that you know have been treated with chemical fertilizers? *(grade 10, chapter 4, lesson 5, 2008)*

Earth and environmental science:

- Would you allow building houses on hills that are prone to landslides?
- Would you forcefully remove poor people who have built houses on steep hills that are prone to landslides?

4.7 Variations

If there is not much space in the classroom you can visualize the opinions of the class on the whiteboard. Draw a horizontal line on the whiteboard (at the left you write: do agree fully, at the right: disagree fully). Let the students write their name at their position on the continuum.

4.8 Important Tips

Choose **questions that are likely to generate different opinions** with the students. Let them give suggestions for new questions or statements.

Stimulate students to use concepts that they have learned during the lesson in the discussion.

The U-shape stimulates discussion because all students face each other. You can use this class setup for other activities such as class debates.

5. Activity 5: Odd-One Out

5.1 Introduction

This technique combines apparently similar items and challenges students to reason which item doesn't belong in the group. Odd-on-out stimulates students to use the lesson content in a creative and engaging way.

5.2 Objectives

- To stimulate understanding and scientific reasoning
- To let students apply the lesson content in a new context

5.3 How to use this technique?

- Choose items and a relationship that is <u>not immediately obvious</u> to promote deeper thinking.
- Present the list on the whiteboard or on a paper.
- Let students think individually for a few moments, then group them in small groups
- Tell students to <u>focus on the arguments</u>, not on guessing the correct answer.
- Let students discuss their results. Tell them that different correct answers may be possible, as long as their argumentation is valid.
- Have students copy the odd-one-out table and let them write down their own arguments before discussing their ideas in groups.
- Ask the students:
    - o "Who chose the first word as the odd-one out? What arguments did you use?" If there are more groups with the same answer, ask whether they used the same arguments.
    - o Then repeat the questions for the second, third and fourth word.

- o Afterwards, discuss which arguments were correct and incorrect. Give additional possibilities if any.

5.4 Material

You can prepare the odd-one-out lists on a large sheet of paper.

5.5 When to use this technique?

Use it at the start of stage 3 to find out what students already know about a topic. Alternatively, use it near the end of the lesson (in stage 4) to strengthen students' understanding.

5.6 Examples from curriculum

Physics: Properties of matter

Which is the odd one?	Why?
Weight	
Density	
Length	
Colour	

Earth and environmental science: Planets of the Solar System
Grade 7, chapter 3, lesson 4 (2008)
Grade 7, chapter 1, lesson 4 (2009)
Grade 10, chapter 4, lesson 2 (2010)
Grade 12, chapter 2, lesson 6 (2011)

Which is the odd one?	Why?
Earth	
Jupiter	
Mercury	
Mars	

Note: you can use different combinations of the eight planets!

Chemistry: Chemical structure of elements

Which is the odd one?	Why?
Water	
Dry Ice	

Iodine	
Sulphuric Acid	

Biology: Structure of the Cell
Grade 10, chapter 2, lesson 1 (2011)
Grade 7, chapter 3, lesson 1-3 (2009)

Which is the odd one?	Why?
Cell Wall	
Chlorophyll	
Photosynthesis	
Vacuole	

5.7 Variations

A possible variation is to present groups of 4 to 5 students with 3 terms that match together. In groups they try to find one "odd-one" and an explanation. Next, the groups exchange their "odd-one out" exercises with each other and try to find the correct answer and argumentation. Groups will try to make a difficult exercise in order to test their peers.

5.8 Important Tips

Make sure all the words listed in the "odd-one out" exercise are well understood by the students before the exercise.

6. Activity 6: Thought Experiments

6.1 Introduction

A thought experiment is a prediction about what would happen in a situation that cannot be easily carried out as a real-life experiment. Students think together and provide an explanation to support their prediction. It is a useful technique to stimulate deep thinking and increasing students' understanding. The thinking process is more important than the final answer.

6.2 Objectives

- Students deepen their understanding
- Students develop reasoning skills
- Students learn to make connections between different topics

6.3 How to use this technique?

- Present students with a thought experiment. If possible, use pictures, stories, text or video to illustrate the thought experiment.
- Students are divided in small groups and discuss their ideas. Students should be stimulated to draw diagrams and pictures to support their ideas.
- Provide time for groups to present their ideas afterwards. Stimulate scientific discussion.

6.4 Material

You can support the thought experiment with audio-visual material to help students imagining the experiment.

6.5 When to use this technique?

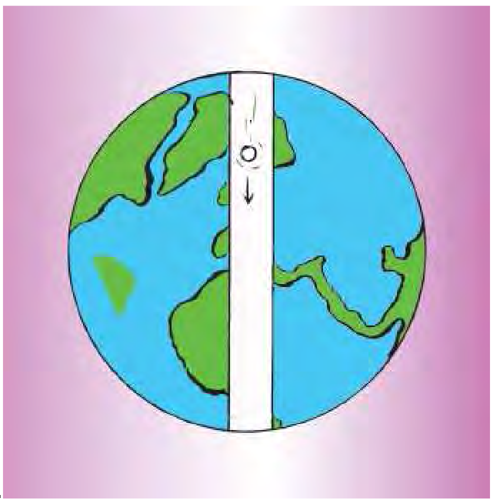
Use this technique during stage 3 of the lesson. This technique can be helpful to let students apply their knowledge in new situations in order to strengthen their understanding. Use it for abstract topics, where it is not possible to do hands-on activities.

6.6 Examples from curriculum

Earth and environmental science: Structure of the Earth
Grade 8, chapter 2, lessons 1-3 (2008)
Grade 8, chapter 1, lesson 1 (2010)

“How would a ball fall if it were possible to drop a heat-resistant ball through a hole drilled all the way through the Earth, starting and ending on opposite sides of the Earth?”

(Solution: Its acceleration would decrease as its falls down, reaching zero at the centre of the Earth. Across the centre of the Earth the now negative acceleration increases again and its speed would gradually decrease reaching zero when it appears at the other end of the Earth. Then it would fall back. Friction being zero, it would fall back and forth forever. This assumes an equivalent mass distribution throughout the Earth)


.

Physics: A thought experiment from Galileo
Grade 8, chapter 2, lesson 1 (2008)
Grade 8, chapter 1, lesson 1 (2010)

"a. Imagine a ball gliding downward from a slope (without any friction). It starts with an original speed $v_{(0)}$. How will this speed change?
b. Imagine a ball gliding upward on a slope (without any friction). It starts with an original speed $v_{(0)}$. How will the speed change?
c. Imagine a ball gliding on a horizontal plane; It starts with an original speed $v_{(0)}$. How will the speed change?
(Solution: a. increase, b. decrease (until standstill and then it will increase downwards.) c. speed will not change anymore, this is the limit case of a or b when you keep reducing the slope.)

Biology. Why aren't we giants?

Draw the shape of a human bone. Make a drawing of how the bone must look like if our linear size was doubled. Take care of the fact that our mass (and volume) will be around 8 times higher.
(Solution: the length of the bone can be doubled but the doubling of the bone diameters will not be sufficient to take care of the higher weight (times 8). That's why smaller animals are stronger than bigger animals. A small dog can easily carry 2 or 3 times its weight, a horse will have it already very difficult to carry only one time its weight).

Biology: How to survive for days on the sea?
(Osmosis)
Grade 8, chapter 2, lesson 6 (2008)
Grade 7, chapter2, lesson 3 (2009)
Grade 12, chapter 2, lesson 1 (2010)

While cruising on the sea, your boat was damaged in a storm and you were set adrift in a rescue boat. The only things on board were a large piece of tarpaulin, empty jerry cans and nylon thread. What can you do to obtain potable water?

6.7 Variations

Have students come up with their own ideas for thought experiments.

6.8 Important Tips

Explain students that the experiment is imaginary. Otherwise they may develop misconceptions.


Chapter 3:
Teaching the
Scientific Method

Chapter 3 Teaching the Scientific Method

Introduction

The scientific method is generally described as a body of techniques for **investigating phenomena** and **acquiring new knowledge**, as well as for correcting and strengthening existing knowledge.

An effective integration of a scientific method in class is an important objective of science education. Students learn that scientific knowledge is not a static collection of facts, but a dynamic network, where new connections are being laid, tested and strengthened or discarded. They learn to see science as a way to gather knowledge about the world.

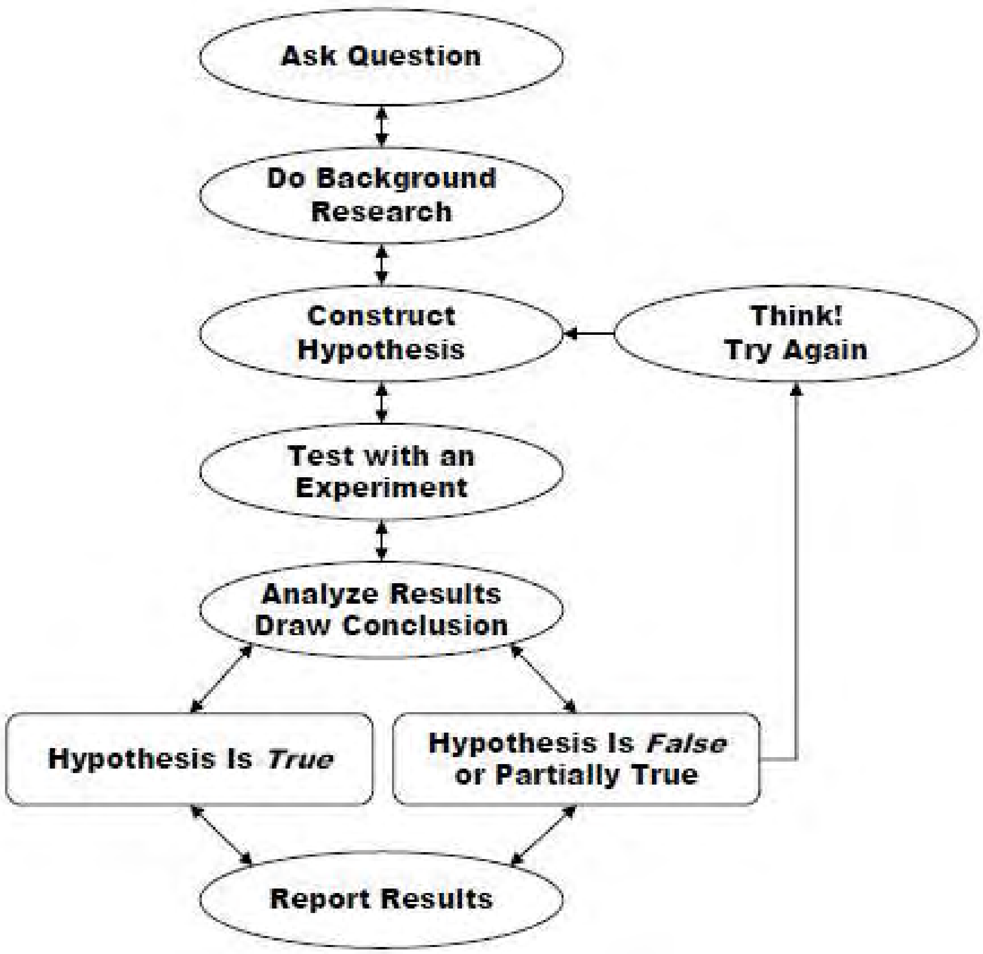
In reality, the work of scientists is rather complex, difficult and time-consuming. Scientific investigations in science lessons will always be performed in a simplified and pedagogical way. In this way science teachers stimulate methodical competences and problem-solving skills.

Although words such as observations, experimenting, research questions, hypotheses … are mentioned in science curricula these words seem to generate a lot of confusion and misconceptions, not only with students but also with teachers. That's why a general framework on the introduction of the scientific method in science lessons is necessary.

I. Concepts Covered

1. The scientific method framework

Although there is no commonly applied scientific method (see important remark further in this text), a lot of science lessons and projects use a fixed sequence of steps during this process. The steps can vary from text to text but they usually include the following steps:



- *Ask **questions** and define the **problem***: The field of study for natural sciences is nature itself. Out of the millions of observations, one (or several) must be brought to the attention of the learners. It makes them think and generates further questions about the problem. Eventually this problem must be defined in clear research questions.

- *Do background **research***: The hardest part (certainly for younger students) and which is often forgotten is the need for further information and research. The learners' prior knowledge and the access to several sources are essential.

- *Construct a **speculative theory** of hypotheses*: Often this term is used as hypothesis or an educated guess[1]. In fact, we try to explain several phenomena we notice during the first step of the scientific method. Therefore we need to construct research hypotheses, based on our prior knowledge and research. These should then be tested in the next step.

- *Testing by **designing** and doing **experiments***: A challenging step with many things to consider is the design of an experiment. By imitating the phenomena in class, learners can investigate their assumptions. We need to control as many variables as possible. A good experiment must be repeatable and clearly measured by instruments, thereby showing that the results are consistent.

- *Analyse and draw **conclusions***: Based on observations and/or data conclusions are drawn in relation with the hypothesis. These conclusions can be qualitative or quantitative, depending on the measurement instruments used during the experiment. If possible, you can translate your results into a formula or other quantitative conclusions.

In this step new insights and problems may arise, that require additional experiments. Depending on the results adaptations in the previous steps (new questions, new research, and new theories of new experiments) may be needed.

- ***Report** results*: Scientists publish their final report in a scientific journal to communicate with colleagues. In class, when learners communicate and discuss about their conclusions, methods and experiments, valuable skills can be developed.

2. Examples

Example: Hang out the laundry to dry

- You notice the laundry hanging out to dry. Some questions come into your mind, such as: 'Why is the laundry hanged out at this moment? When will it dry faster? Why does it take up so much space? These observations make you think.

- Of course, based on what you know and have seen in the past, you can already summarize several factors such as temperature, sunshine, wind and surface area. You also look for extra information about drying laundry. Maybe there are other factors that you don't know about yet. New questions arise, for instance: What is most important: a windy or a warm day?

- We construct possible theories/hypotheses: The bigger the air replacement, the faster the laundry will dry. Alternatively an alternative hypothesis could be, the higher the temperature, the faster the laundry will dry.

- To test your assumptions/hypotheses with experiments there are several difficulties. In the real world you cannot investigate the phenomena in identical circumstances,

1 See myth 2: A hypothesis is an educated guess McComas, William, *Ten myths of science: Re-examining what we think we know....*, Vol. 96, School Science & Mathematics, 01-01-1996, p 10. (http://amasci.com/miscon/myths10.html)

because there are too many variables that influence the process of drying laundry. Therefore you need to ‘copy’ these phenomena in the classroom to control the variables. For example, the laundry can be simulated by strips of small (filter) paper that are dipped in water. These strips can be dried.

- It is also important that the process can be measured. Therefore you must define the speed of evaporation and think about how you can measure this. During the investigation you can dip two identical strips in the same liquid at the same time. Then you place one strip in front of ventilator while the other is placed in the class (without a ventilator). Another possibility is to dry one strip in the sun and the other in the shadow or a cooled box.

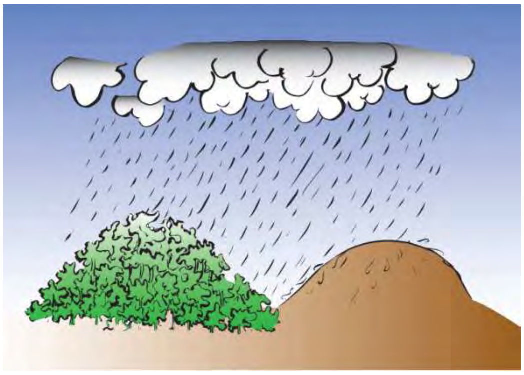
- Draw conclusions based on your observations.
- Because you cannot quantitatively measure the air replacement (only the power of our ventilator), you must conclude a qualitative statement, for example: when the air replacement is larger, the strip will dry faster.
- Finally you report your results to the rest of your class. Not only your conclusions, but also how you have investigated your problems, your way of collecting data and any assumptions that you made. Maybe there are other students who haven’t used strips of paper or a ventilator? Did they reach the same conclusions? Do they support/defend the same speculative theory? Gathering all this useful information can lead to solid scientific knowledge, just like in ‘real’ science.

Other examples to let your students set up a research framework:

- *Effect of soil characteristics on water run-off*

Earth and environmental science (Grade 12, chapter 1, lesson 3, 2011)

Biology (Grade 8, chapter 2, lesson 1, 2010)



Which characteristics of soils affect the way they absorb water? Factors that can be investigated are the type material, the humidity of the soil, the vegetation of the soil. These factors could be investigated by preparing various soil plots on an inclined plane.

- *Factors affecting the dissolving rate of sugar in water*

Chemistry (Grade 8, chapter 3, lesson 3, 2010)

Which factors affect the rate with which sugar (or salt) dissolves in water? Factors that can be investigated are the grain size of the sugar, the temperature of the water, the amount of stirring in the water and the amount of water. This investigation is discussed in detail in the **chemistry manual**.

- *Factors affecting the sense of taste*

Biology (Grade 12, chapter 3, lesson 2, 2010)

Which factors affect the way we taste substances? Factors that can be investigated are the amount of water, the size of the particles and the type of foodstuff. This investigation is discussed in detail in the **biology manual**.

3. Important remarks

Although this common series of steps is very clear and may seem applicable in class, some important remarks need to be made.

First there is **no generally applied scientific method** in real science[2]. This idea of a single scientific method is so pervasive that many students may be confused when they find out that scientists do not always strictly follow these steps.
Many common science teaching methods serve to work against the creative element in science. The majority of lab exercises, for instance, are verification activities. This means that the teacher discusses what will happen in the laboratory, provides step-by-step directions and the student arrives at a pre-defined answer. On the contrary, science should be an exciting and creative pursuit. There is no such thing as a single correct path to follow when doing a scientific investigation.

Summarizing, scientists approach and solve problems with **imagination**, **creativity**, prior **knowledge** and **perseverance**. These, of course, are the same methods used by all problem-solvers. Therefore this manual provides assistance to integrate the scientific method in class focuses on skills necessary to do scientific research, rather than strictly following the steps of the scientific method.

Every activity can be done separately or as a step within a wider application of the scientific method. In this way the teacher is more flexible and chooses some activities depending on available material, needs and time. The activities are illustrated by **an open ended and inquiry based approach on plasma (spheres)**.

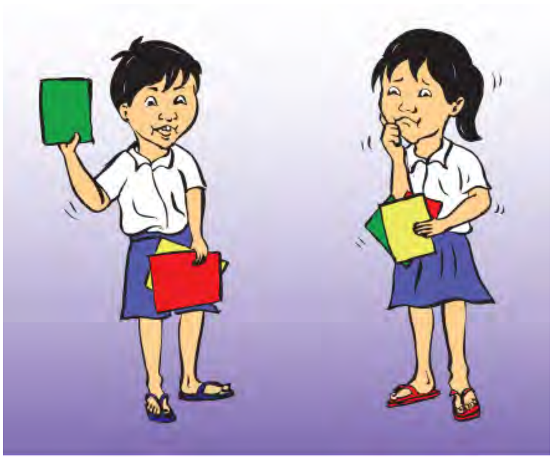
2 McComas, William, *Ten myths of science: Re-examining What We Think We Know....*, Vol. 96, School Science & Mathematics, 01-01-1996, p 10. (http://amasci.com/miscon/myths10.html)

2. Activities to integrate the scientific method in lessons

1. Activity 1: Starter or Reflection Activity: What is the scientific method? (Traffic Light cards)

1.1 Introduction

‘Traffic light cards’ is an enjoyable student centred activity that provides teachers instant feedback on the students’ level of understanding. You can apply this technique to find out what students think/know about the scientific method. Usually students have incomplete or incorrect understanding about how science works.



1.2 Objectives

- Students reflect on the scientific method in class (reflection activity).
- Students learn to clarify their arguments about the scientific method.
- Teachers receive instant feedback on student understanding of the lesson

1.3 Material needed

Three cards per student are needed, one red, yellow and green card. The cards should be big enough in order for the teacher to see clearly, laminated cards are more durable.

1.4 When to use this technique?

As 'starter', this activity must be done **before** students have done activities of scientific method. The objective is then to find out students' prior knowledge of the scientific method. It is possible that this exercise is too difficult for students who haven't come into contact yet with real science or haven't got any idea how a scientist works. In that case, it is better to do this activity **at the end** of an integration of the scientific method in class. In this way, a teacher can evaluate and **reflect** on the method used in class.

1.5 Procedure

The teacher reads a statement aloud. After a few seconds of thinking time students hold up the card that represents their agreement on the statement.
Students should raise the cards simultaneously independently from each other on the signal of the teacher.

- Green card = I agree
- Yellow card = I have some doubts
- Red card = I do not agree

Statements about the scientific method

- Objectivity in science is not possible since all scientists are influenced by their world view or past experiences.
- With the scientific method you can prove anything, solve any problem or answer any question.
- The best scientists are those who follow the steps of the scientific method.
- An experiment can never prove that something is true; it can only prove that something is not false.

If the majority of students holds up the same colour (red or green), it indicates that there is a consensus. If many are holding up a yellow card, there is a need for clarification of the statement. Alternatively, a mixture of cards indicates that a lot of different ideas are present, which can cause interesting discussions (for example for a *brainstorming* or *thought shower* activity). In all cases, it is important that you <u>ask for arguments</u>, by posing questions such as “Why are you (not) agreeing?”, “Why do you have doubts?”

Make sure that students listen to each other’s arguments and that the discussions aim at clarifying the statements. After the discussion the teacher can ask the students to raise cards again and ask those students who have changed “colour’ to explain their reasoning.

The teacher may group students who raised different colours together and have them discuss their answer. During the group discussions the teacher can walk around and write down good arguments or misconceptions. In groups where discussion stops, he can give extra arguments.

1.6 Variation

The traffic light cards method is a powerful technique to acquire instant student feedback on your teaching. After each key concept or part of the lesson you can probe students to evaluate their understanding and vote.

- Red card means: I didn't understand this part of the lesson
- Yellow card means: I still have a few questions
- Green card means: I understand the concept well; you can go on with the next concept.

Make sure that students who raise a green card really understand the topic. You can do this by asking them a question or letting them explain the concept in their own words to their fellow students.

1.7 Important Tips

Make sure that discussions don't **drift away** from the topic.

The contribution of the teacher is restricted to providing **guidance** (asking additional questions, summarizing students' ideas, ending the discussion). The main objective is to find out students' own ideas about the scientific method, not to find the 'correct' answer. Most statements can result in different acceptable answers, depending on the validity of the arguments.

2. Activity 2: Brainstorming

2.1 Introduction

Brainstorming is a powerful **group** problem-solving technique that involves the spontaneous contribution of ideas from all members of a group. Scientists regularly hold brainstorming sessions. Often the comments of one group member **inspire** another, generating a chain reaction of ideas.

2.2 Objectives

- To collect prior knowledge and associations to the topic.
- To stimulate creativity
- To transform curiosity into scientific questions.
- To generating possible answers/solutions to a problem
- To generate many ideas in a short period of time.

2.3 When to apply this technique?

Brainstorming sessions can be held **at different stages** of the scientific method (see different objectives):

- In the beginning of the scientific process brainstorming helps to explore the general field, to **collect prior knowledge** and to **raise** possible **research questions**. In an ideal scientific process, students investigate these research questions themselves in the next stages of scientific method. This kind of open ended inquiry is very motivating. Each group of students selects one research question to investigate.

- Brainstorming can also help to generate possible solutions for difficult problems and in this way construct speculative theories that can later be submitted to experimental investigation.

Usually you will apply brainstorming in stage 3 of the lesson.

2.4 Procedure

Clear and step-by-step instructions are very important. Keep following guidelines in mind:

- Encourage students to think: Write a keyword or question on the board. Sometimes a simple demonstration can help to generate ideas. If the topic is unknown, provide additional information through a short lecture.
- Divide students in small groups. Ask one person per group to write down the ideas
- Limit the time for brainstorming (for example to max. 5 minutes)
- You may give a minimum number of ideas the students need to find, to ensure quantity.
- After the brainstorming allow time for the groups to order or prioritize their ideas.

2.5 Variation

Nominal group technique is a type of brainstorming that introduces more structure to the process. It is useful in ensuring that all participants have an equal say and can be used to generate a rank-ordered list of ideas. Each group member is asked to write down their ideas. Then a student who is assigned as moderator asks each participant in turn to express one of the ideas that they have written down. The moderator writes down each idea on the flipchart. Then each participant copies the group's final list on a blank page giving each idea a score. The pages are collected from each participant and the scores summed, providing a rank-ordered list. This list can then be discussed in order to reach consensus.

2.6 Examples in curriculum

Physics: open ended and inquiry based approach on plasma

(1) Introduction to the topic

- Brainstorming: Making associations with the word plasma and collecting prior knowledge:

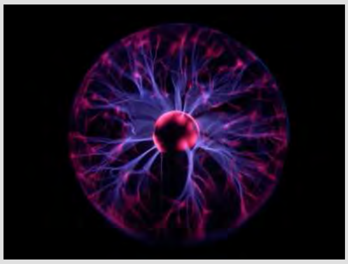
The teacher asks general questions to find out what students know about plasma. Possible answers and ideas are discussed with all students (not in groups).

Possible questions:
What is plasma? What do you think of when you hear the word plasma? What do you know about plasmas? What do you want to know about plasmas?

- Short lecture on key characteristics of plasma:

This topic is not very well known to students and teachers. However plasma occurs in a lot of everyday life experiences. A short overview:

- Plasma in lightning technology:
    - Plasma sphere
    - Television
    - Fluorescent lamps
    - Neon signs



Source: Wikipedia

- Plasma in nuclear fusion research: Because plasma can be heated to extremely high temperatures it is used as fuel in fusion experiments.

- Plasma in nature:
    - Sun
    - Polar lights (aurora)
    - Lightning
    - Flames of a candle.

Source: www.nasa.gov

Plasma is called the 4th state of aggregation.

This information gives students insight about the importance of plasma in physics (technology, nature, etc.). But more importantly, it stimulates further thinking about plasma.

- Raising questions and key ideas about plasma

Students must generate as many questions as possible about what they want to know about plasma. If necessary, the teacher should refer to the phenomena described above. The students are divided in small groups and the teacher asks a ‘reporter’ to write down all questions. Every question related to the topic is a good question; even it is not possible to answer it.

Students must generate **questions** themselves (not the teacher). A possible list:

Polar light: why at the poles only?	Can you touch/see plasma?	What colour has plasma?
State of matter: why 4th?	How can plasma be produced?	Is plasma dangerous? Can it be “misused”?
What is the connection between plasma and TV?	Why do plasmas emit light?	What is it made of?
What can influence it?	Why does it move? Can it stand still?	What is the temperature of the plasma?
Why different colours?	Why does the plasma stay inside the sphere?	How does the plasma sphere work?
Can plasmas go everywhere?	How can plasma be kept?	Can you touch plasma?

Students may produce a lot of different questions that are very time consuming and difficult to answer. Nevertheless, these questions should be collected, fixed and later evaluated by the teacher. It is important to address all these open questions within the instruction unit but not immediately. The concept of an open ended inquiry is that participants work together to answer their questions by themselves during the workshop (see further activities).

Examples of starting questions

Biology:
How can we protect ourselves against infectious diseases? (Grade 11, chapter 8, lesson 1, 2009)
How can we preserve our national resources? (Grade 9, chapter 5, lesson 1&2, 2011)
How can we improve our school's environment?
Why is the local river polluted? Find as many causes as possible. (Grade 11, chapter 6, lesson 3)

Chemistry:
Recall everything you know about acids and bases.
Grade 9, chapter 3, lesson 2&3 (2011)
Grade 12, chapter 3, lesson 1-4 (2010)

Earth and environmental science:
Recall everything you know about the sun. (Grade 7, chapter 1, lesson 2, 2009)
How can we test if oil is present underneath the Earth's surface? (Grade 12, chapter 4, lesson 2, 2011)
Think of an analogy to explain the expansion of the universe to your students. (Grade 12, chapter 3, lesson 4, 2011)
How do we generate renewable energy in Cambodia? (Grade 12, chapter 4, lesson 3&4, 2011)

Physics:
Recall everything you know about heat. (Grade 7, chapter 1, lesson 3, 2009)
What do you want to know about ice? (Grade 10, chapter 2, lesson 3, 2009)
Think of as many examples of Newton's 3rd Law as you can. (Grade 8, chapter 2, lesson 3, 2010)

2.7 Important Tips

Ideas from brainstorming sessions must not be evaluated according to feasibility. Therefore a teacher should give students some guidelines when holding a brainstorming session:

- Do not evaluate ideas until the brainstorming session is finished;
- Focus on quantity, not on quality. The more ideas, the more chance there will be some good ones;
- Maintain a criticism free atmosphere. Encourage even wild and seemingly ridiculous ideas.
- Build on ideas of others, combining or modifying ideas already present.

It is important that students are stimulated to think. If students do not know much about the topic the brainstorming session will end quickly. Therefore additional material must be presented by the teacher (examples of phenomena, short lecture on the topic, pictures etc.)

People engage deeply when they feel they are contributing their thinking to questions that are important to them. Encourage all participants to contribute to the conversation.

See the *Thought Shower* technique for tips on formulating good brainstorming questions.

3. Activity 3: Thought Showers

3.1 Introduction

Thought Shower is a **type of brainstorming** where students write down as many ideas about a given topic as possible on a big sheet of paper. Afterwards there is time for justification and listening.

3.2 Objectives

- To activate student thinking,
- To promote discussion and listening to each other.
- To learn clarifying scientific ideas.

3.3 When to apply this technique?

This activity is best done at the **beginning** of the scientific method to collect prior knowledge. The technique can also be used to help prepare students **to write a report** in a following class.

3.4 Procedure

- Divide the class in small groups of four to six students
- Ask each small group to stand by a large blank piece of paper that could be spread out on tables or on the wall. If possible, provide different coloured marker pens to each group.
- Ask them to write as many ideas as possible about a situation or key question that the teacher reads out. Before they start, emphasize to students that at this stage all ideas should be written down without judging them. Every group may receive a different situation or key question from the teacher.
- After 5 minutes the teacher calls out "Change" and asks each group to move to another piece of paper, that another group had been working on. Ask them to add to the ideas written by the previous group. After another 5 minutes ask the students to change again. This can be repeated a few times.

Bring the class together and stand around each paper in turn as the class discusses it. Read through what they have written on the pieces of paper and ask students to explain anything that is unclear to others.

3.5 Examples in curriculum

Biology
Can you describe any examples of genetic engineering you have heard on?
(Grade 12, chapter 5, lesson 3, 2010)

Earth and environmental science
Discuss reasons why water gets polluted. (Grade 7, chapter 3, lesson 1, 2009)
Design a survey for observation and an interview guideline to collect information on how much and what kind of waste is produced within the school. (Grade 12, chapter 5, lesson 1&2)

3.6 Variation

The **World Café** is a technique where students switch between topics during the brainstorming. Different groups discuss different brainstorming questions. Groups of students start a brainstorming session. After some discussion time the teacher invites students to switch between groups. Students may choose which group they go to. In this way, students can contribute to different brainstorming sessions and groups will change composition.

Each group has one table host who stays with the same brainstorming question and collects the ideas. This person will summarize the conversation of the previous round for the newcomers ensuring that any important points are available for consideration in the upcoming round. They then invite the travellers to add their ideas and suggestions.

This cross-pollination of ideas often produces surprising results that could not have happened otherwise. The system of conversational rounds and asking people to change tables between rounds allows for a dense web of connections to be woven in a short period of time. Each time students travel to a new table they are bringing ideas of the last round and combine them with those brought by other students. As the rounds progress discussion can move to deeper levels. Students who arrived with fixed positions often find that they become more open to new and different ideas.

3.7 Important Tips

For a successful thought shower it is important to construct compelling questions. Find questions that are relevant to real-life concerns of the students. Powerful questions help attract collective energy, insight and action. Depending on the time available and the objectives, you may explore a single question or use several conversations.

A powerful question:

- Is simple and clear
- Is thought provoking
- Generates energy
- Focuses on inquiry
- Surfaces assumptions
- Leads to new questions
- Invites deeper reflection

The questions we ask and the way we construct them will greatly affect the outcome of our activity. For example, if we ask: What is wrong and who is to blame? We already steer the discussion in a certain direction, compared with a more neutral formulation of the question.

4. Activity 4: Classification & Categorizing (card sorts)

4.1 Introduction

Students often have the misconception that knowledge in science is 'discovered' and absolute. However, scientists have always tried to bring order into the multitude of information. For instance **classification systems** are created by people to create some order in the huge diversity of life forms in biology. Scientists develop classification systems based on criteria reached by consensus. Different criteria can result in different classifications.

The same skills can be used by students to **organize ideas and questions** of the first step of the scientific method. They survey the information available and try to reach consensus in groups on the criteria to classify the information into meaningful categories.

A possible methodology is 'card sorts'. Students experience card sorts as different, informal and fun. They represent a quick and ready way to explore or review a topic.

4.2 Objectives

- To understand that not all scientific knowledge fits nicely into groups;
- To understand that classifications are human, based on agreed but modifiable criteria ;
- To learn to structure knowledge;
- To learn to organize scientific information/questions into clusters;
- To learn from each other in groups

4.3 Position in Lesson Plan

This activity can be done to organize the big amount of ideas generated **after a brainstorming session**.

However, also in other stages of the scientific method, categorizing and classifying is very important. Examples are categorizing observations, phenomena, living things and objects (see examples from curriculum).

Usually a cards sort activity will be done during stage 3 of the lesson.

4.4 Procedure

Step-by-step instructions for a cards sort activity:

- The teacher divides the class in small groups
- The teacher gives a set of cards to each group
- Students try to classify the cards and write down the criteria they apply. Meanwhile the teacher walks around the class and helps students where necessary.
- After classifying the cards, the teacher explains which criteria scientists use to classify this topic.
- After the explanation the students try to reclassify the cards according to these criteria.
- The teacher synthesizes the activity.

4.5 Variation

Instead of cards, real objects (stones, minerals, leaves, mixtures) or words/questions written on the blackboard could be used.

The teacher can also provide the students with headings of each category or ask them to determine the headings themselves.

The teacher can provide extra blank cards for students to add ideas.

4.6 Examples

Physics: open ended and inquiry based approach on plasma (spheres)

(2) categorizing questions:

With the list of the questions raised during the brainstorming session (see (1)), a categorization is developed by the students. This means that questions are grouped together that belong to one theme.

Possible topics are heat, light, matter, danger, etc.

In the end, a set of categories with different questions is available. The teacher adds ideas and questions in order to set his planned learning objectives.

Then, students are assigned to groups that work on one of the categories.

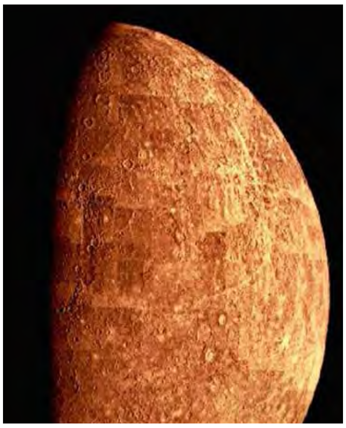
Example earth and environmental science

Planets of the Solar System (Grade 7, chapter 1, lesson 4, 2009)

Galaxies (Grade 10, chapter 4, lesson 3, 2011) and (Grade 12, chapter 3, lesson 3, 2011)

Instructions for students:

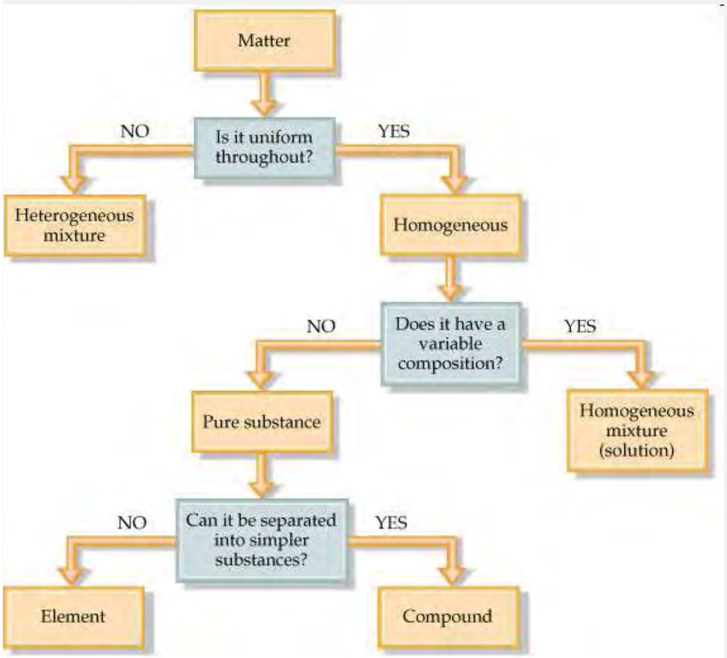
- Observe pictures from planets in the Solar system/ from galaxies
- Make classes based on criteria you define
- Argument your choice
- Compare your classification with the scientific classification




Example chemistry:

Classification of Matter (Grade 7, chapter 1, lesson 2, 2009).

- Observe pictures from various substances
- Make classes based on criteria
- Argument your choice
- Compare the classification with classification outlined in the flowchart



Source: http://www.middleschoolscience.com

Example biology:

Classification of Vertebrates (Grade 10, chapter 1, lesson 6, 2008)

- Observe pictures from various vertebrates
- Make classes based on criteria you define
- Argument your choice
- Compare the classification with the classification scientists use

Source: Wikipedia

Example physics
Fuels (Grade 12, chapter 2, lesson 2) and (Grade 7, chapter 1, lesson 3, 2009)

Let students discuss the items below and classify in three categories: fuels, non-fuels and "not sure". Have them write down as accurately as possible why they put each item in a certain category.

Example Earth and environmental science
Climate zones and vegetation

Students group cards with climate charts with corresponding pictures of vegetation zones (grade 11, chapter 4, and lesson 2). The activity is described in detail in the **earth and environmental science activity manual.**

4.7 Important Tips

- Card sorts are best used in small groups to encourage students to talk about their ideas.
- Make sure cards are big enough so that all students can easily read them.
- Have students discuss each card and come to a common agreement in which category to place it before discussing a new card. Avoid that students put the cards quickly in a category without discussion.
- Consider adding a category called “it depends on” or “not sure”.
- Stimulate students to develop a “rule” that could be used to determine the category.

5. Activity 5: Research Activities

5.1 Introduction

Students often have the misconception that all knowledge in science is found by experimental investigation. This is not correct; rather on the contrary, scientists are working most of the time doing **background research** on the topic or research questions.

In science lessons this research can be imitated and a teacher can activate students' prior knowledge (from previous lessons) or let them search in **external sources**.

5.2 Objectives

- Student teachers learn to search for information in external sources.
- Student teachers understand that the scientific process requires revisiting previous knowledge and searching new information in order to build upon them for deeper understanding.
- Student teachers learn how to do research.
- Student teachers learn to discuss and share ideas.

5.3 Position in Lesson Plan

After the topic and research questions are defined.
If the information has been classified in different categories (see card sorts), groups of students can work on different subtopics.

5.4 Procedure

Depending on the level of understanding of the students and their access to external sources, the results from a background research can be different.

A possible strategy:

- Let students work in small **groups** to do research on a (sub)topic. Concrete questions are distributed to each group.
- Students must discuss and **share ideas** about the topic/questions.
- If students have access to library and/or internet, they can **search** for information in these sources.
- **Limit** the time of research.
- At the end, students present their ideas and information to the whole class.

Variation: focused listing

Focused listing is a student centred approach that helps students to recall ideas from prior topics.

- Select an important topic from the curriculum.
- Have students write the word or phrase at the top of a sheet of paper and list as many terms, facts, ideas, concepts, definitions… that they can remember from previous lessons.
- They can work in small groups.
- Examine the lists or let small groups post their results. The teacher needs to look for similarities, noting which things students readily recall and which things, that are critical for further learning, are missing.
- An important remark: generating these items does not always mean that students understand it.

5.5 Examples

Open ended and inquiry based approach on plasma (spheres)

Students learn how to do research on in a small group. They also discuss and share ideas; distribute and organize work within a group; plan presentations.
Possible topics are:

- definition of plasma
- emission of light, colours
- atomic models and aggregation states

Since plasma is not part of the physics curriculum, additional info is necessary. Besides the prior knowledge of the students, external sources (library, internet) are very useful. Finally, all ideas and research info is presented to the whole class.

A lecture is given that makes relations between the aspects addressed by the participants and addresses new contents that were not covered yet. If they are already covered the objective of this lecture is to structure and resume the findings. (See annex at the end of this manual).

Example earth and environmental science: Research on volcanoes

Grade 9, chapter 2, lesson 3, 2011 and Grade 11, chapter 1, lesson 6, 2011

Students work in small groups to collect all information they can find on **volcanoes**. Possible sub-topics are:

- Where do we find volcanoes?
- What exactly is a volcano?
- Why are there volcanoes on Earth and not on the Moon? How about other planets?
- Why are volcanoes important for human beings (think about both positive and negative roles)

They can use their textbooks to gather the information or, preferably, use additional sources such as books from the library.

Example biology: Research on plants

Grade 7, chapter 2, lesson 1-3 (2009)
Grade 7, chapter 3, lesson 3 (2009)
Grade 8, chapter 3, lesson 1&2 (2010)
Grade 9, chapter 1, lesson 1-3 (2011)

Divide student in groups. Each group will collect information about **plants**. Some sub-topics can be:

- What classification do scientists use to order plants?
- What do plants need to grow?
- Why do we need plants? What would happen if we would cut down all trees and other plants on Earth?
- Why are plants green? Are all plants green?

Students can make more questions related to their topic and look for information to answer their questions.

Example chemistry: Research on acids and bases

Grade 9, chapter 3, lesson 2&3 (2011)
Grade 12, chapter3, lesson 1-4 (2010)

Divide students in groups. Each group will collect information on a different aspect of **acids and bases**.

- What is the difference between an acid and a base?
- What are examples of acids and bases in daily life?
- What are weak and strong acids/ bases?
- What is pH? How is it related to acids and bases?

Students look for information in their textbooks and, preferably, other sources such as books from the library and science posters.

5.6 Tips

- Stimulate students to work on questions that they asked themselves during a previous step. This will be very motivating for them. These questions can be classified and each group researches some of the questions.
- The research topic may not be too difficult or too easy. Clear and well-structured questions can help searching for specific information.
- Access to external sources is very useful (books, articles, posters, and internet).
- The search for information can be very **time-consuming**. Therefore the teacher can give specific tasks/questions as homework to his students. Another possibility is a restriction of the sources to a copy of an article or selected passages in handbooks.

6. Activity 6: Experimental Explorations (observing and making inferences)

6.1 Introduction

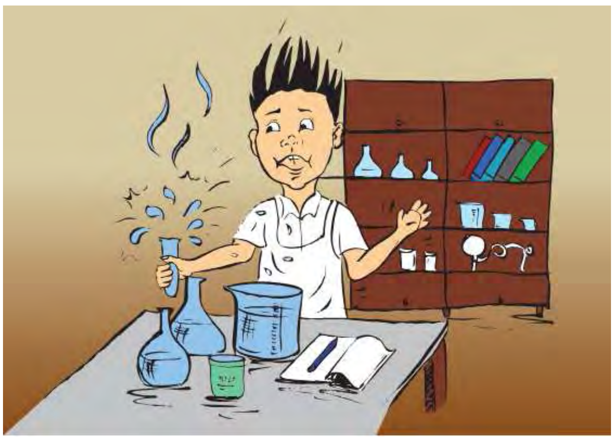
Experiments are used to test and explore assumptions about research questions or topics. These experiments are influenced by the background research and prior knowledge of the students.

Observations and inferences are fundamental parts of good experimenting. An **observation** is a record resulting from the study of an object or an event. An **inference** is a conclusion drawn from evidence or reasoning based on observations. However, observations as well are theory-based and a complete objective observation is not possible. There is always a connection between observations and inferences.

Observations can be done with one of our five senses (sight, smell, hearing, taste, touch). They can be **qualitative** or **quantitative**. Qualitative observations describe what we observe and are usually expressed with adjectives, whereas quantitative observations measure what we observe and are expressed in numbers. Inferences are based on your past experiences and prior knowledge. They can change when you make new observations!

6.2 Objectives

- Student teachers learn to distinguish between observations and inferences
- Student teachers understand the role of and learn to make ‘proper’ observations
- Student teachers learn about the unsystematic and systematic approach of making phenomena visible.



6.3 Position in Lesson Plan

No scientific method is complete without an experimental phase.

Based on prior knowledge and assumptions students can make careful observations about a scientific phenomenon.

New insights and questions can arise that lead to further investigations. These ‘open questions’ are a motivating method to explore different phenomena. In the beginning most of the observations will be unsystematic, but the more observations the more systematic the approach students will apply.

This activity is best done during stage 3 of the lesson.

6.4 Procedure

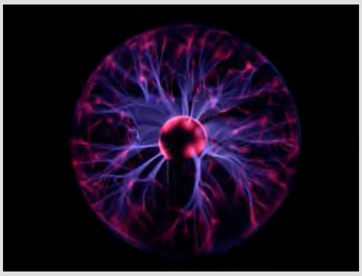
- Ask students to record all their observations about a phenomenon, a demonstration or an image.
- Students record individually on a sheet of paper all the observations they can make or make a drawing. Students compare their lists in groups of 2 (optional).
- The teacher collects and writes observations on the board.
- The teacher points out observations that are in fact inferences and explains the difference between them (depending on the results).
- The teacher points out additional observations that can be made (depending on the results).
- Depending on time and level of understanding, the inferences and explanations can be made by the teacher or students (small groups).
    - The teacher explains the scientific phenomenon referring to the observations of the students.
    - Or students work in small groups on several observations. This is more motivating, but requires a certain level of understanding and is more time-consuming.

6.5 Examples

OPEN ENDED AND INQUIRY BASED APPROACH ON PLASMA (SPHERES):

- **unsystematic and systematic explorations**

Students explore the plasma sphere through concrete observations. It is important they only observe and describe different phenomena without trying to find explanations of inferences. Students are allowed to experiment freely with the plasma sphere.



Instructions:

- Students work in small groups.
- After an exploration phase students write down in detail different phenomena they have seen. It is very important that they try to observe as many things as possible!!
- For a systematic exploration you can give participants different kind of observations:
  - plasma sphere without touching
  - touched by finger
  - touched by hand
  - by lamp

Possible results:

objects	observations
Without touching	lots of streamers, streamers are pink-blue-pink, move around fast, object/ human approaches: streamers change direction and speed the bigger the area of touching the bigger the streamer, buzzing, black field in middle, from bottom up; streamers split up at top;
touched by finger	only one streamer; two fingers: connected by streamer; development of heat; still smaller streamers there, but less than before; streamers headed towards finger; weak prickle/ tingle; streamer jumps between these two fingers; smells like chlorine/ ozone/ solarium; finger smells burned; vibrations; when touching, buzz gets louder; bigger streamer
Fluorescent lamp	lights up at a distance of about 10 cm; it only lights up to where it is touched by human; closer to lamp = brighter; streamer headed towards it; with hand on sphere: even brighter; with hand on sphere, it stops shining; if connected to sphere by cable it doesn't shine; if connected to sphere by cable, it shines

- Finally they can freely explore with lots of objects and different setups. The explorations have no limits. To encourage them, they have access to additional material (needles; cupper wires, paper, aluminium foil, magnets, different gasses, water, multimeter, coins, lamps, LED's, etc.).

Some observations will lead to new experiments, so this is a reinforcing process. It is important that the participants have enough time to do all these experiments.

At the end students present their results. All observations are collected and categorized on the whiteboard. Only observations should be written down. If an explanation has been given, it shouldn't be discussed yet (e.g. instead of streams a participant may talk about electric discharge or movement of electron/ions).

Alternative Example Physics: burning candle (*Faraday's Candle)*

Michael Faraday was a British scientist who invented the first electric motor and dynamo. He demonstrated the relationship between electricity and chemical bonding and discovered the effect of magnetism on light. He was not only a brilliant scientist but also a science educator who gave frequent lectures for non-scientists.

Faraday knew the importance of observation in science and began his lecture by asking to record as many observations as possible about a burning candle. Today this activity is still useful to stimulate observation skills.

Present a burning candle to your students and ask them to list as many observations they can make. The teacher may perform the following activities with the candle:

1. Hold a beaker with water above the candle
2. Put beakers of different size upside down on the candle
3. Blow out the candle and reignite it by placing a match in the smoke near the wick.

Afterwards, explain the difference between an observation and an inference. Discuss which observations are inferences. Give, if possible, additional observations that they didn't observe.

Other examples

Biology: observe a microscope image of an onion root cell (mitosis)
Grade 11, chapter 1, lesson 3 (2009)

Let students observe an image of onion root cells under a micro slide viewer or microscope. Alternatively, you can print a picture of the image. Let them make a drawing of the different stages of cell division that they can recognize. Let them classify the stages and count how many cells are present in each stage of cell division. Let them try to explain their observations (in a next phase).

Onion cells in various stages of cell division (Pearson Education Inc., 2008)

Earth and environmental science: observe an image of the Moon or a planet.
Grade 8, chapter 3, lesson 1 (2010)
Grade 12, chapter 2, lesson 4 (2011)

Project a picture of the Moon, show a poster or give students a printed image. Ask them to make a drawing on which they include as many features as the Moon as they can recognize. Afterwards, you can discuss the different features with them, such as craters, mountains, mares etc. As an extension, you may provide students with an image of the far side of the Moon and let them list the differences.

Source: apod.nasa.gov

Chemistry: observe a scientific reaction

Let students write down in detail their observations during a chemical reaction. Afterwards, collect their observations and add any observations that they missed. In this way, a demonstration becomes an exercise in observation skills!

6.6 Important Tips

- Make sure the object of observation can be seen clearly by all students.
- This activity is time-consuming. Make sure that your students do not stop too fast with explorations. Good observers will always see, hear, smell, feel and taste more! Encourage students to make as many observations as possible.

7. Activity 7: Designing Experiments

7.1 Introduction

In contrast with the previous activity of experimental exploration, this activity is more focused on a **systematic approach** of a research question. Designing good experiments is necessary **to test** our assumptions about possible theories. In literature this is often referred to as 'testing hypotheses by doing an experiment'. Not exploring but testing is the main objective in this activity.

7.2 Objectives

- Student teachers understand the link between real phenomena and experiments.
- Student teachers can design experiments to test hypotheses;
- Student teachers understand the difference between dependent, independent and control variables in experiments;
- Student teachers recognize the difficulties while designing experiments: limitation through conditions, materials, measurement etc.

7.3 Position in Lesson Plan

After defining the research questions and formulating possible theories/hypotheses.

It is usually done during stage 3 of the lesson.

7.4 Procedure

- The teacher writes down a hypothesis on the whiteboard. If possible, hypotheses are put forward by the students.
- First students can freely imagine and invent possible experiments (even if they are impossible to perform). They must ‘copy’ the phenomena in a testing ‘lab’. This means that they have to switch their thinking from a real life perspective to a laboratory perspective. They need to think how they can scientifically prove (or disprove) the research hypothesis.
- They need to consider limitations such as time, space, equipment and environmental conditions. How can they test the hypothesis, taking these limitations into account?
- If possible, the experiment can be performed in class.

7.5 Examples

Law and theory in science:

Students try to design experiments for testing the following theories/hypotheses:

Example Physics: Newton’s Laws
Grade 8, chapter 2, lesson 3 (2010)

- First law of Newton: A moving object will keep on moving (unless an external influence is exerted)
- Falling objects: An object falls independent to its mass.

(These 2 hypotheses are very difficult to test because of factors we cannot restrict like friction. Nevertheless this exercise demonstrates that testing theories in science is difficult and even impossible)

Evaporation *(Grade 10, chapter 2, lesson 3, 2009)*

- Evaporation: the bigger the air resistance, the faster the laundry will dry.
- Evaporation: evaporation is a cooling process.

Example Biology: Growing plants *(Grade 9, chapter 1, lesson 2, 2011)*
- Growing plants: plants always grow opposite to the field of gravity.
- Growing plants: plants always grow to direction of light.

Example Earth science: Erosion *(Grade 12, chapter 1, lesson 3&4, 2011)*

- Erosion: erosion is influenced by the type of soil
- Erosion: erosion is influenced by the vegetation cover
- Erosion: erosion is influenced by the slope of the terrain

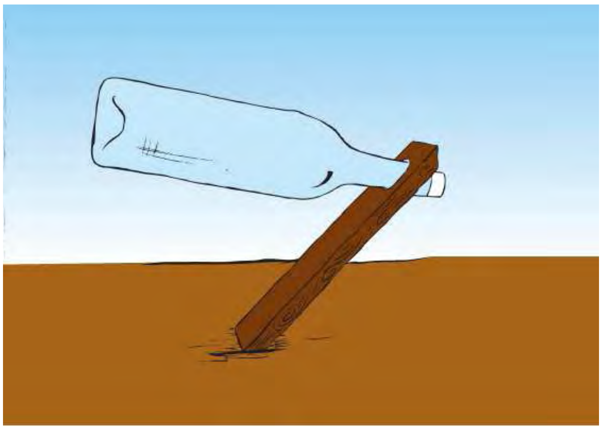
7.6 Important tips

While testing and experimenting, one factor is tested while other influences remain constant. If you vary more than one variable, you cannot determine which variable is responsible for the observations you make.

8. Activity 8: Teaching experiments as discrepant events

8.1 Introduction

Discrepant events are short teacher **demonstrations** or student performed activities. They have a counterintuitive and unexpected outcome. As a consequence they generate interest and **curiosity** with students. They also stimulate students **to ask questions**, formulate hypotheses and predict outcomes.



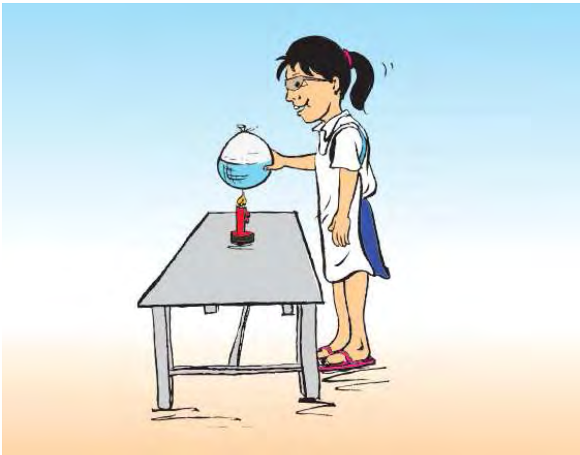
8.2 Objectives

- To challenge student teachers ' prior beliefs and knowledge
- To increase student teachers' motivation and generating a "willingness to know"
- To promote problem solving and critical thinking skills.
- To understand scientific concepts rather than just being able to recall them.
- To improve skills of observing, predicting, gathering data and experimenting.

8.3 Position in Lesson Plan

This activity can be done in step 3 of the lesson. It can serve different objectives:

- to introduce a new topic in a captivating way ("warming-up"):
- to test students ability to predict outcomes of an experiment
- to make observations and hypothesis



8.4 Procedure

Go through the demonstration before the class begins. Make sure that it is clearly visible for all students. Ask students to predict outcomes and challenge their answers after the demonstration. Allow at least three seconds for students to reply to your questions. Use open ended questions to let students pull upon their prior knowledge and experiences and guide them into finding a reason for the discrepant event. At the end relate the discrepant event to the topic of instruction.

You may wait to explain the demonstration and ask your students to do so at the end of the lesson after they received instruction.

8.5 Examples: see activity manuals

The experiment manuals contain many short and counterintuitive experiments that can serve as discrepant events. Keep in mind that also a drawing, a question or a story can be used as discrepant events. However, often a short experiment is the most powerful way to create a discrepant event.

Standing on Paper Rolls (physics experiment guide: pressure)

First let students predict how many paper rolls are needed to support one person. Usually they will overestimate the number. Then stand (or let a student stand) on the rolls while another student removes one paper roll at the time. Usually, one person can be supported by only three paper rolls. Next, challenge students to explain what they have seen, <u>but don't give them the correct answer yet</u>.

You may continue with instructing about the difference between pressure and force, using other demonstrations or experiments. <u>Near the end of the lesson, return to the discrepant event and let students try again to explain the observations</u>. By doing this, you can test whether they have understood the lesson and for the students it is stimulating to experience directly that they have learned something.

8.6 Important Tips

Discrepant events are often related to student misconceptions. Make sure their misconceptions are corrected at the end of the lesson.

References

Books

- Angelo, T.A. & Cross, K.P. (1993)Classroom Assessment Techniques, Jossey Bass, - Wiley & Sons, San Francisco, California, USA.
- Churchill, E.R. et al. (1997) 365 Simple Science Experiments with Everyday Materials, Black Dog & Leventhal Publishers, New York.
- Driver, R. et al. (1994) Making Sense of Secondary Science: Research into Children's Ideas, Routledge.
- Harrison, A.G. & Coll, R.K. (2008) Using Analogies in Middle and Secondary Science Classrooms, Corwin Press, Thousand Oaks, California, USA.
- Harrison, A.G. and Treagust, D.F. (1993) Teaching with Analogies: A Case Study in Grade-10 Optics, Journal Of Research In Science Teaching, Vol. 30, No. 10, pp. 1291-1307
- Herr, N. (2008) The Sourcebook for Teaching Science, Jossey Bass, - Wiley & Sons, San Francisco, California, USA.
- Keeley, P. (2008) Science Formative Assessment, NSTA Press – Corwin Press, Thousand Oaks, California, USA.
- Keeley, P. et al. (2005) Uncovering Student Ideas in Science: 25 Formative Assessment Probes, Vol. 1, NSTA Press.
- Keeley, P. et al. (2007) Uncovering Student Ideas in Science: 25 Formative Assessment Probes, Vol. 2, NSTA Press.
- Keeley, P. et al. (2009) Uncovering Student Ideas in Science: 25 Formative Assessment Probes, Vol. 4, NSTA Press.
- Mazur, E. (1997) Peer Instruction: A User's Manual, Prentice Hall.
- McDaniel, M.A. and Donnelly, C.M. (1996) Learning with Analogy and Elaborative Interrogation.
- Naylor S., Downing, B. and Keogh B. (2001) An empirical study of argumentation in primary science, using Concept Cartoons as the stimulus. Third International Conference of the European Science Education Research Association. Thessaloniki, Greece.
- Naylor, S. and Keogh, B. (2000) Concept Cartoons in Science Education, Millgate House Publishers.
- Tweed, A. (2009) Designing Effective Science Instruction, NSTA press, Arlington, Virginia, USA.

Websites

Physics:
- http://galileo.harvard.edu

Chemistry:
- http://www.chem.wisc.edu/~concept/
- http://www.chemcollective.org/find.php

Earth and environmental science:
- http://serc.carleton.edu/resources/1302.html: Assessment and Active Learning
- Strategies for Introductory Geology Courses
- http://serc.carleton.edu/resources/21699.html: Using ConcepTests to Assess and
- Improve Student Conceptual Understanding in Introductory Geoscience Courses
- http://serc.carleton.edu/introgeo/interactive/ctestexm.html: Concept Tests for many earth science topics.