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Student Centred Approaches for Science Education

Part 3

Chapter 5: Analogies and Models

Chapter 6: Educational Games

Teacher Training Department 2012

Part 3

Chapter 5: Analogies and Models

Chapter 6: Educational Games

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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 need 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 scientific 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 encourages all teacher trainers to use this manual to teach science in the teacher training centres, and thus contribute to improve 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 15, 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 is 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 strategic reading and writing skills with students in science lessons.

Chapter 2: Developing Science 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 encourage teacher trainers to 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

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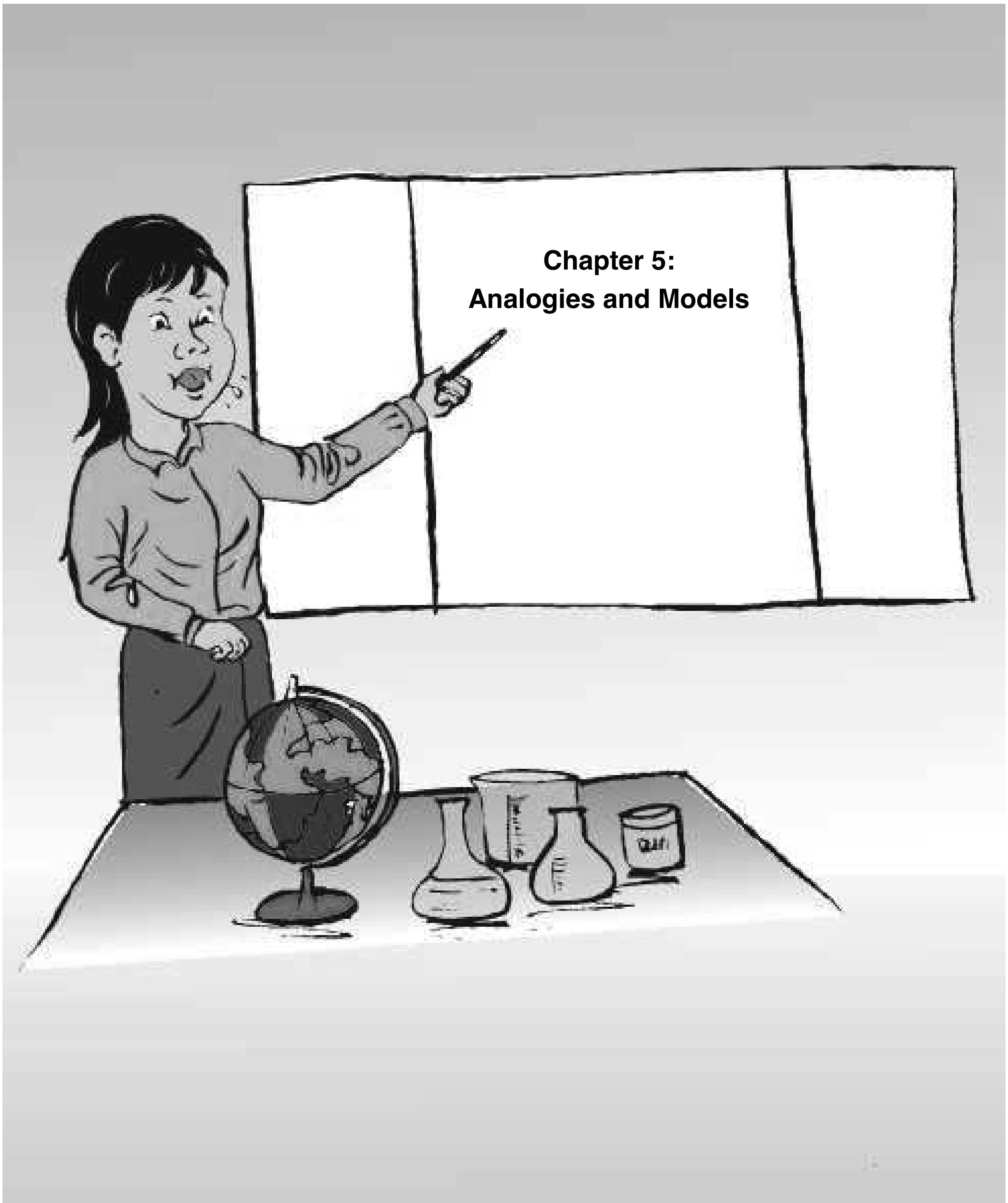

Chapter 5:
Analogies and Models

Chapter 5: Analogies and Models

Introduction

An analogy can be described as a linguistic link between one subject and another, seemingly unrelated item. In education analogies are often used to relate a new concept for the student to one that he/she is already familiar with. This is particularly relevant in science education, because **many concepts are outside the students' experiences**, such as genes, energy and atoms.

Apart from their power to explain difficult concepts in a clear way, analogies also stimulate higher order thinking skills, such as problem solving and lateral thinking ("out of the box" thinking). Moreover, analogies bring fun and variety into the classroom, improving student motivation.

Analogies have the highest effect on student learning when students are challenged to discuss or, even better, to create their own analogies. Analogies should not be regarded as superficial comparisons between two items, but as **opportunities to discuss concepts in-depth**.

Analogies are a two-edged sword. They offer **enormous potential for student-centred learning**, but on the other hand, when used without care, they can develop or enhance misconceptions. Every analogy breaks down at a certain point – the point where the analogy is not a correct explanation of the concept. This point should be clear for all students. For example, when a teacher compares solid matter with students sitting in the classroom at their desks and liquid matter with students doing a group activity in the class, students may wrongly derive that atomic particles are like little organisms and act purposefully.

This unit presents a set of analogies for wide range of science subjects. Besides, it offers effective and student centred ways to integrate them in your lessons. However, these analogies should be regarded as a starting point. Don't be afraid to change, adapt or improve them. Or, even better, let your students create their own analogies.

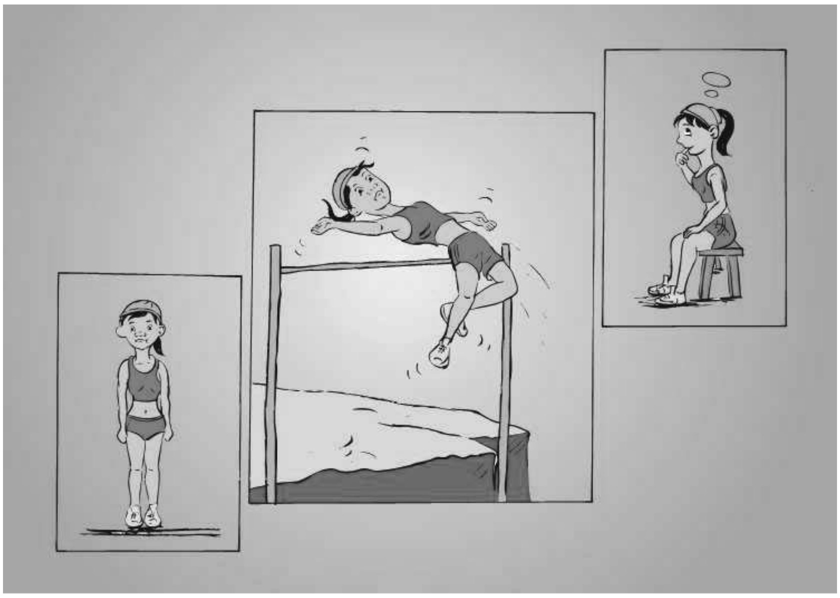
This chapter introduces 5 techniques to integrate analogies in your science lessons. They are ordered loosely in order of student involvement. We mentioned above that the more students are invited to think and develop the analogy, the stronger its effect will be.

Activities

1. Using the Focus – Action – Reflection (FAR) Guide

1. **Introduction**

The Focus-Action-Reflection (FAR) guide offers a carefully planned strategy in order to make the analogy relevant and useful for as many students as possible. It presents teachers with a guideline to successfully apply analogies in class. The technique comprises teacher and student activities before and during the lesson and reflection after the lesson.



2. **Objectives**

- To maximize the benefits and minimize the problems when using analogies in class.
- To increase students' understanding of difficult and abstract concepts.
- To capture students' interest and involve them in challenging concepts.

3. How to use this technique?

The FAR guide consists of three questions for the teacher before the lesson. Two questions for the students during the lesson and finally two questions for the teacher after the lesson.

The table below summarizes the main steps in the FAR guide.

1. Focus (part of the preparation of the lesson)	
Concept	What difficult concept do you want to teach the students?
Students	What prior knowledge do students already have about the concept?
Analog	Is the analog something students are familiar with?
2. Action (part of lesson activities)	
Likes	What are the similarities between the analog and the concept?
Unlikes	What are the differences between the analog and the concept?
3. Reflection (to do at the end or after the lesson)	
Conclusion	Was the analogy clear and effective or rather confusing?
Improvements	Are there any changes to be made next time you use this analogy?

Summary of the FAR guide technique for analogies

The **focus part** includes identifying the concept that you expect students to have difficulty with to understand. What is it that makes the concept difficult to understand? Is it the small or large scale of the concept (cell, atom, Avogadro's number)? Is it the function or structure that is difficult to understand (DNA, ATP)? Or is the concept counterintuitive to daily life (atomic structure, electric current)?

Next, you need to know what prior knowledge students already have about the concept. If it is correct, you can build on it. In case it is incorrect it needs to be changed by the teacher. There are tools that you can use to assess the students' prior knowledge (brainstorming, concept cartoons…).

Finally, evaluate whether your students are familiar with the analog that you want to use. For example, comparing a cell with a city doesn't make sense if students are not familiar with a big city. It is useful to check whether students are familiar with the solar system before using it as an analog for the atomic structure. You can illustrate the analog with pictures or a poster.

During the lesson students study the analog and its relation with the concept. Let them work in small groups to fill in a table like the one below. They map the similarities and dissimilarities between the concept and the analog while discussing the concept with their peers. After the group activity collect the similarities and dissimilarities from the students. Correct if necessary, synthesize the analogy and ask review questions. You may ask students whether they think the analogy is useful. Maybe they can come up with a better analogy?

Steps:

1. Divide the class in small groups of 3 to 5 students.
2. Students discuss how the analogy works and where it breaks using a table as the one below. You can draw the table structure on the whiteboard. Provide enough time for this activity.
3. Make one student per group responsible for completing the table during the discussion.
   Let students present their findings and organize a class discussion. Use students' ideas when synthesizing the analogy. Write the main similarities and dissimilarities on the whiteboard using the table structure.
   Tip: Students will feel more motivated when they feel that their ideas and views have been incorporated into the analogy construction.

	Concept	***Analog***
Likes		
Unlikes		

Table for group discussion on analogy during lesson

After the lesson analyse whether using the analogy was useful for enhancing the students' understanding. Do you need to make some adjustments? Maybe another analogy could prove more useful?

4. Material

You can use pictures or drawings to explain better the analogy to the students. Students can use model-making equipment (paper, glue, matches, colour pencils etc.) to illustrate the analogy.


Source: Harrison and Coll, 2008

5. When to use this technique?

- to strengthen your students' understanding of the topic (stage 3)
- to explain a difficult or abstract concept (stage 3).

6. Examples from curriculum

Biology: Structure of the cell
Grade 7, chapter 3, lesson 1 (2009)
Grade 11, chapter 1, lesson 2 (2009)

The organelles of a cell have similar functions to some parts of a city. Work with the students in your group to identify parts of a city that have similar functions to the organelles that you have learned about. You may use your textbook. Write down the organelle, the part of the city that your group thinks is similar and the function they have in common.

CELL	*FUNCTION*	*ANALOG = CITY*
How the cell is like a city		
Nucleus	*The nuclear controls and coordinates all the cell's structures and functions so that all the parts work together*	*The city council controls roads, buildings, shops and makes sure that everyone respects the law.*
…		
How the cell is NOT like a city		
Cell wall	*The cell has a wall that encloses the cell's content.*	*A city doesn't have a wall around it.*
…		

Other examples can be found in the **annex.**

7. Important tips

Make sure that students are sufficiently familiar with the analog before doing the activity.
Explicitly mapping the similarities and dissimilarities between the concept and the analog is important since it avoids creating new misconceptions with the students.

2. Synectics

1. Introduction

The word synectics is derived from the Greek language. It means fitting together items that appear to be completely unrelated. This technique uses analogies to connect students' ideas with a concept.

2. Objectives

- Students learn to examine abstractly what they know about a concept.
- Students link prior knowledge with new concepts.
- Students learn to think creatively and "outside the box".
- Students learn to make new connections.
- Teacher discovers difficulties students have in understanding science concepts

3. How to use this technique?

Provide students with a chart containing four to six boxes. In the box list items that could be used to describe the scientific concept you want to explain. You can write the table on the whiteboard or give students a copy.

A chart to explain cell structure could be like the one below:

A cell is like a ---------------------------------- because ---

Market	School
Brick wall	Company

Divide students in small groups. Let students discuss and try to fill in each square of the table. Stimulate them to find creative but correct relationships between the analog and the items in the square.

Afterwards let them present their results. Provide feedback on the correctness of the analogies used. Stimulate students to try and recognize when analogies are not correctly used. This helps them to develop critical thinking skills.

3. Material

No material is needed, unless pictures to illustrate the items in the table.

4. When to use this technique?

- You can apply synectics as a consolidation activity to strengthen your students' understanding of the topic (stage 3)
- You can use it to explain a difficult or abstract concept (stage 3).
- You can use it as a review activity at the end of a series of lessons (stage 4).

5. Examples from curriculum

A list of topics and suitable analogies is listed in **annex**. If you have multiple analogies for a concept, you can use synectics.

For *chemistry*, structure of the atom (Grade 8, chapter 1, lesson 1, 2010) is a possible topic.

For *physics*, electric circuits (Grade 7, chapter 3, lesson 6, 2009) are an excellent example.

For *earth and environmental science*, the solar system (its structure, origin) (Grade 7, chapter 1, lesson 1, 2009) could be described with multiple analogies.

3. Models

1. Introduction

Models can be seen as simplified constructions of reality and are thus a type of analogy. They have the advantage that they can be seen and touched by students, increasing their familiarity with the analog and improving the relation with the concept. Constructing models creates a concrete, immediate image to students and reduces the chance that they will misunderstand the analogy.

2. Objectives

- Students develop higher-order thinking skills.
- Students develop creative thinking skills
- Students learn to link prior knowledge with new concepts.
- Students learn to work together

3. How to use this technique?

Try to let students discover the relation between the model and the concept for themselves. Of course, this depends on their prior knowledge. If necessary, you need to help the students. The more they can find out themselves, the stronger they will make the relation between concept and model. However, be sure to point out where the model does not correspond with reality in order to avoid misconceptions.

4. Material

This depends on the type of model. Many models can be constructed with low-cost materials. Sometimes you can let students construct their own model. Building their own model increases the memorability and their motivation.

5. When to use this technique?

- You can apply model building as a consolidation activity to strengthen your students' understanding of the topic (stage 3)
- You can use a model to explain a difficult or abstract concept (stage 3).
- You can use it as a review activity at the end of a series of lessons or at the end of the semester (stage 4).

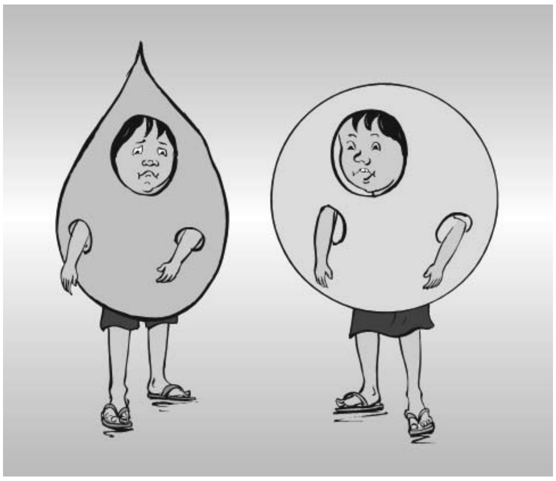
6. Examples from curriculum

Examples for all sciences can be found in the annex and the activity guides for each subject.

4. Role Plays

1. Introduction

Role plays are special analogies that can help students to imagine and understand difficult concepts. The more students are involved in the elaboration and acting out of analogies, the more likely they are to accept the ideas you have in mind. Also, the fun character of role plays enhances their memorability.



2. Objectives

- Students learn to examine abstractly what they know about a concept.
- Students learn to link prior knowledge with new concepts in a creative way.
- Students learn to work together
- Students' involvement and motivation are increased

3. How to use this technique?

The sequence of steps in this technique varies from topic to topic. The list of analogies at the end of this manual contains many ideas for role plays. In general you can follow these steps:

1. Divide the students in groups, depending on the scenario. Sometimes every group will prepare the same role play; sometimes every group will play a different part, for example in a cell division process.
2. Explain the general idea, but don't go into much detail.
3. Student groups work together to distribute roles and develop a scenario. They take notes of their scenario.
4. Groups of students present their role play to the others.

5. The teacher organizes a class discussion. Students discuss correct and incorrect elements during the play and how they can be improved. Sometimes extra elements can be added to the play to strengthen the relation between the concept and the analog.

This last step is important to avoid that students still have misconceptions or gaps in their understanding. Questions that can be used during the class discussion are:

- What are the likes and dislikes of this analogy? Where does the analogy break down?
- Stimulate students to expand the analogy. This means that they try to fit more elements of the concept into the analog. For example, students develop a role play on the greenhouse effect. You can ask them how they could integrate global warming in the role play.

4. Material

This depends on the role play. Often paper and pen is sufficient.

5. When to use this technique?

- as a consolidation activity to strengthen students' understanding of the topic (stage 3)
- as a review activity at the end of a series of lessons (stage 4).

6. Examples

Examples of analogies that are suitable for a role play activity are listed in the annex. Some examples that are not in the annex are:

Biology:

- Function and structure of a cell membrane

- Cell division: mitosis and meiosis
- Digestive system

Chemistry:

- Chemical reactions involved in electrolysis
- Radioactivity and half-life time

Earth and environmental science:

- Solar and lunar eclipse
- Tides
- Greenhouse effect. Why is Venus so much hotter than the Earth?
- The function of the ozone layer. The hole in the ozone layer.

Physics:

- Nuclear fission and nuclear fusion
- Electric circuits

5. Student-Generated analogies

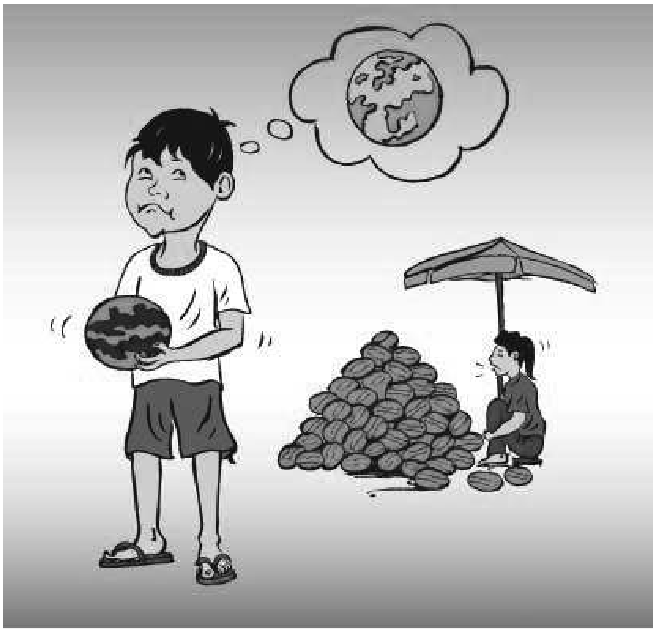
1. Introduction

Students sometimes spontaneously generate analogies that are close to their daily life. Letting students develop their own analogies provokes rich scientific discussion during the generation process and creates student enthusiasm. Also, student generated analogies are much more likely to be relevant and accessible to all of your students, since it comes from themselves. On the other hand, unlike teacher generated analogies, they are more difficult for the teacher. He cannot think through the analogy before the lesson, but has to react immediately. This requires a thorough understanding of the science concepts involved.

The distinction between teacher-generated and student-generated analogies is not always so clear. An analogy can be initiated by the teacher, but developed by the students.

2. Objectives

- to increase students' understanding of abstract and difficult concepts
- to increase student engagement and motivation
- to stimulate higher order understanding and lateral thinking skills with students



3. How to use this technique?

1. Divide students in groups of approx. 6 students. Assign one student per group to take notes.
2. Explain the topic on which students need to develop an analogy.
3. During the activity:

- Provide needed information to the groups, give tips and help students to develop their ideas.
- Provide sufficient time for students to find and develop analogies.
- Stimulate students to make drawings to illustrate the analogy.

4. Let groups present their analogy. Let them focus on:
   - Where is the analogy alike the analog?
   - Where is it breaking down?
5. Stimulate students to develop their analogy further by asking questions. This forces them to think about the concept and will increase their understanding.
6. Avoid saying “this is right” and “that is wrong”, but praise students for their creativity.
7. You may use student generated analogies afterwards in a synectics activity.

4. Material

If possible, provide students with a sheet of paper to record the analogy on.

5. When to use this technique?

Use this technique in stage 3 of the lesson as an activity to strengthen students’ understanding. You can combine the technique with other techniques, such as the FAR-guide. After explaining the analogy, you can let students brainstorm to develop their own analogy.

6. Examples from curriculum

The list of analogies in annex contains many ideas for student generated analogies.

7. Variation

Sometimes students may bring up new analogies spontaneously during class discussion or in response to an analogy used by the teacher. Stimulate the student to develop the analogy and let other students comment on it.

For example, the teacher explains the concept of dynamic equilibrium. A student asks if you can compare dynamic equilibrium to a pot of food on the fire with a lid on. At the same time some water is evaporating and some is condensing. The teacher takes the question from the student to analyse how a pot with food on the fire is similar and different to a dynamic equilibrium.

8. Important tips

The uncritical use of analogies may use to students developing misconceptions. The teacher needs to monitor the developed student analogies closely and point out where the analogy breaks down.

List of effective analogies per science

Each of the analogies listed below has been tried and tested. Study the analogy thoroughly before using it.

A. Effective analogies for physics

The abstract and difficult nature of physics concepts means that analogies and models are often useful in teaching them.

1. The Dominoes and Books analogy for Conduction of Heat

Link with curriculum: Grade 7, chapter 2, lesson 1 (2009)

Heat transfer by conduction can easily be introduced with **practical activities**. For example, hold the end of a wooden stick and a piece of wire in a candle flame. You quickly drop the wire, but you can hold the wooden stick. Another way is to let students feel at the tap, their desk and a wooden cupboard. Afterwards, they measure the temperature of the objects. Although, objects feel "warmer" or "colder" they have the same temperature.

Conduction of heat relies on particles. Students can visualize solids as close particles that jostle each other and transmit heat energy from one particle to another. Metals conduct heat quickly while wood and plastic are poor conductors because of the difference in structure. Metals are good conductors because they have **free electrons**. Wood and plastic are poor conductors because they don't have free electrons.

Adapted from: Harrison & Coll, 2008

To explain why some materials are good conductors and others not an analogy can be useful:

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Dominoes standing up that can fall over	Free electrons that can move around
Books standing up that can fall over	Atoms and molecules that can vibrate
Dominoes falling over, quickly one after another in a line	Free electrons speeding up when heat is absorbed and moving around bumping others.
Books falling over slowly, one after another, in a line.	Atoms vibrating faster when heat is absorbed and jostling atoms next to them.
Fast-falling dominoes compared to slow-falling books.	Good heat conductors compared to poor ones.
Slow-falling books	Non-conductors having only vibrating atoms or molecules.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
There are many more electrons and atoms than there are dominoes and books.	
Dominoes and books fall once, one way and in a straight line. Atoms and molecules vibrate continuously in all directions all the time.	
The difference in size between electrons and atoms is much greater than the difference in size between dominoes and books.	

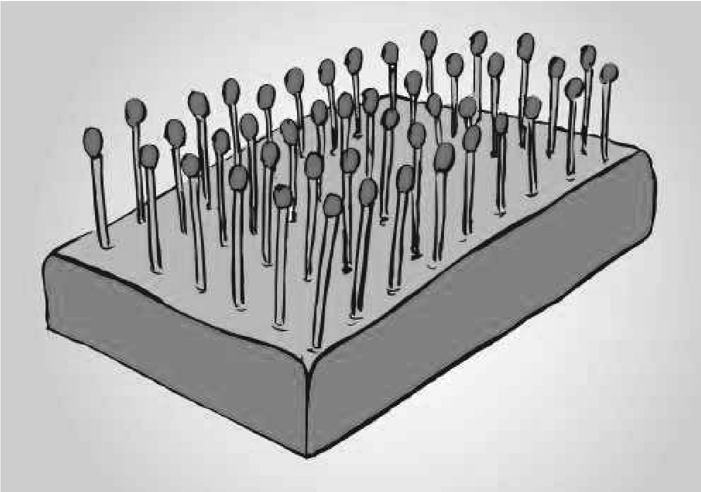
2. The Matches Analogy for Nuclear Fission

Link with curriculum: Grade 12, chapter 4, lesson 3 (2011)

Nuclear fission and chain reactions are non-observable concepts. Students are often surprised how fast an atomic reaction can spread. The reaction's speed and extent can explain the enormous amount of energy that is released. You can use this analogy to explain how nuclear reactors and atomic bombs work.

The speed with which matches ignite is like an exponential chain reaction.

To demonstrate the analogy, stick 100 matches in a block of clay. Keep the match heads approx. 5 mm apart. Ignite the match on the corner and watch the whole lot bursting into flames. Be careful for the students' safety. You can use the model to explain a sustained nuclear fission reaction, like in a nuclear reactor (each match ignites on average one other match) and to explain an exponential nuclear fission reaction, like in an atomic bomb (each match lights two other matches).



Adapted from: Harrison & Coll, 2008

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Matches can ignite rapidly	U-235 hit by a neutron splits into pieces immediately.
Matches must be close to ignite each other	U-235 atoms must capture a neutron.
Match ignition spreads exponentially.	U-235 fission spreads exponentially.
Energy is released	A huge amount of energy is released.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
There are many more U-235 atoms than matches.	
U-235 atoms release 3 neutrons each. Matches just affect one other match.	

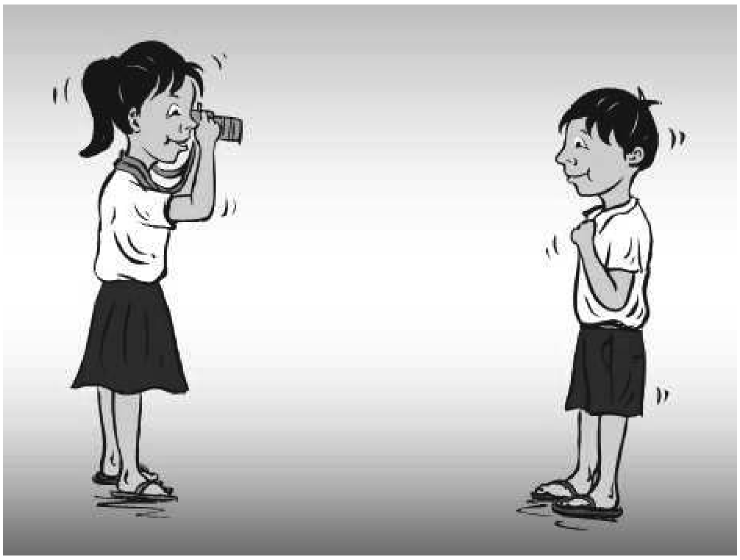
3. The eye is like a camera analogy

Link with curriculum:
Physics Grade 9, chapter 5, lesson 4 (2011)
Biology Grade 12, chapter 3, lesson 2 (2010)

This analogy is often used by science teachers to explain how an eye forms images. However, the analogy assumes that students know how a camera works and that they understand image formation with convex lenses and pinholes. If not, it's advised to include a practical activity where students make a pinhole camera or experience real image formation with convex lenses and candle flames.

The analogy can work in both directions. It can use prior knowledge about the eye (from biology lesson) to teach about the camera (and lenses) or it can use knowledge about convex lenses to teach about the eye.

Both the camera and the eye form images. Real images are formed when light rays from a source point focus on an image point.



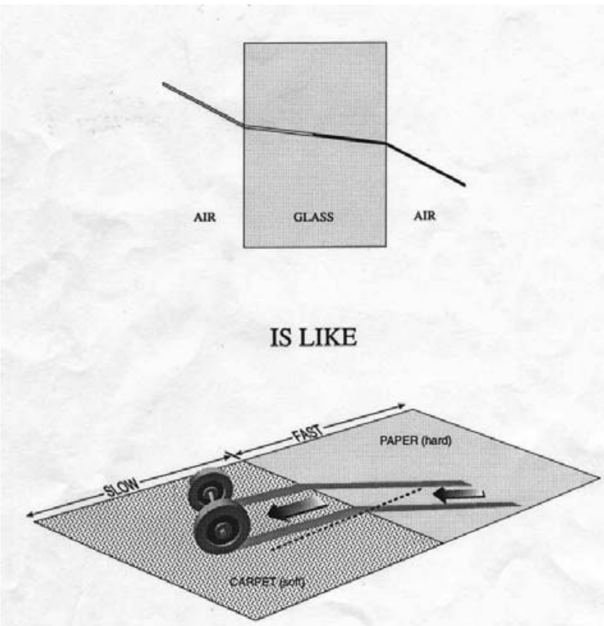
LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Convex lens focuses light on film	The cornea and lens focus light onto the retina
Lens changes position to focus on near and distant objects.	Lens changes shape to focus on near and distant objects.
Aperture size controls exposure brightness.	The pupil controls the brightness of light on the retina.
Black interior prevents multiple reflections.	Black interior prevents multiple reflections.
Lens cap protects the lens	Eyelids protect the cornea
An image is captured on film or chip	Image is captured on the retina.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
A camera has one lens at the front of the camera. The eye has two lenses: the cornea at the front (not adjustable) and an adjustable lens behind it.	
A camera captures single images, whereas the eye captures continuous images.	
A camera works in a limited range of brightness, whereas the eye can work in a vast range of brightness.	

4. The Pair of wheels analogy for light refraction

Link with curriculum: Grade 9, chapter 5, lessons 2 & 3 (2011)

Refraction can easily be demonstrated with the bending of light as it passes from air to water or from air to glass. The phenomenon itself however is more difficult to explain. Some students may confuse refraction with reflection of light.

Use a set of wheels and two surfaces of different smoothness. Let students experience the change in direction that happens when the wheels cross from one surface to the other. Let them find out that the change in direction happens because the wheel on the hard surface rolls easily while the one on the soft surface slows down. The wheels could be coated with paint to visualize the change in direction. Afterwards, let them investigate what happens when you roll in the opposite direction. Let them think through the reverse process using the analogy.



Source: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Wheel tracks	Rays of light
Perpendicular path shows no deviation	Vertical ray doesn't change direction
Oblique path bends towards the vertical	Oblique ray bends toward the normal
Tracks change direction as one wheel slows.	Ray bends because it slows.
Wheels slow because the carpet increases friction	Light slows because the glass is optically denser than the air.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	

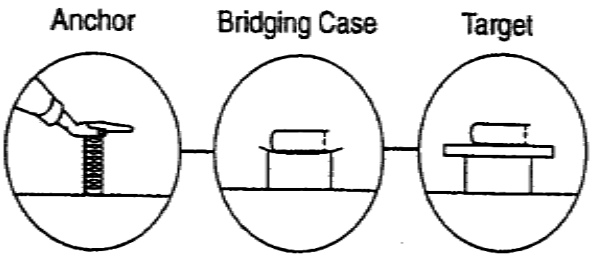
Light rays are very narrow, whereas wheels are quite wide.
Two wheels are needed to represent one ray of light.
Optical density of the glass slows the light, whereas friction slows the wheels.

5. Bridging analogies for the balanced forces of a book on a table

Link with curriculum: Grade 8, chapter 2, lesson 1-3 (2010)

Objects like tables exert an upward reaction force on objects placed on them (Newton's Third Law). Objects such as books do not move because the upward and downward forces are balanced.

A bridging analogy is a series of small analogies that is used to bridge the gap towards an understanding of a concept. Balanced forces in squeezing a spring act as an anchor for understanding similar situations such as a book on a flimsy table or the book on a normal table. This analogy helps understanding action and reaction forces.



Source: Clement, 2003.

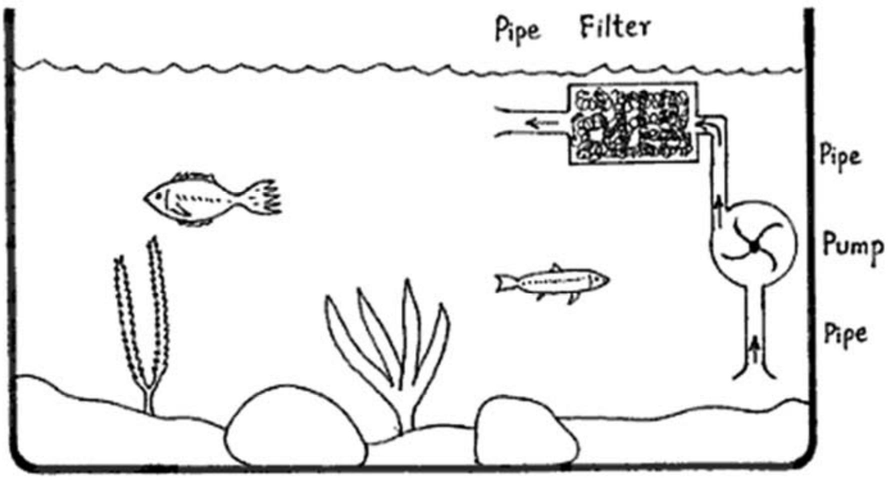
LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
A compressed spring exerts force back on a hand.	Book has a downward weight but no deformation can be seen or felt.
Flimsy table bends under the book sitting on it.	The table must push back on the book on top of it.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
The table exerts a reaction force but does not visibly bend under the book's weight. The analogies could be used examples.	

6. The Water circuit analogy for a simple series circuit

Link with curriculum: Grade 7, chapter 3, lesson 6 (2009)

This analogy addresses the common misconception that current is "used up" in electric circuits. In fact, energy can only be changed into another form, it's never used up.

Use a picture or drawing of an aquarium or swimming pool filter system in order to make sure that all students understand the analog. An aquarium filter draws water in through a pipe, a pump pushes it through another pipe into a filter that resists water flow, and then the water exits through another pipe into the aquarium.



Source: Harrison and Coll, 2008.

If possible, combine the use of this analogy with **practical activities**. Let students make simple series and parallel circuits using a battery, wires and a few light bulbs.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
water	Electricity
Flowing water	Electric current
Pipes carrying water	Wires carrying electricity
Pump pushing water (pressure)	Battery pushing electrons (voltage)
Pump pressure	Battery voltage
Filter (resists water flow)	Thin wire in light bulb - resistance
No water lost	Current is conserved
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Water is a liquid; electricity is a flow of charge in an electric field.	

Water can flow in an incomplete circuit, electricity needs a complete circuit to flow
Water flow depends on the pump output and pressure, electric current is determined by the entire circuit (the circuit must be looked at as a whole)

7. Voltage is like water pressure analogy

Link to curriculum: Grade 7, chapter 3, lesson 3 (2009)

Potential difference (or voltage) is measured in volts and is a difficult concept for students to visualize. It is a measure of the force with which the battery can push electrons around. Understanding potential difference is crucial when working with electric circuits.

The analogy with water pressure can help to understand this concept. Students are familiar with water pressure and depth and this relation can easily be demonstrated by the teacher.

Adapted from: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Water bottle	Battery or dynamo
Hole for water to escape	Battery in a circuit so current can flow
Deeper the water over the hole	Higher the potential difference
Deeper hole, more water flows	Higher potential difference, more current flows
Flow rate is proportional to depth	Current flow is proportional to potential difference.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	

Electricity is not a material substance.
Water flow rates decline as the bottle gets emptier; a battery may have reduced potential difference across its terminals but it is not empty.

8. The analogy of doors in a meeting hall for parallel circuits

Link with curriculum: Grade 7, chapter 3, lesson 6 (2009)

Parallel electric circuits function as independent circuits. Two light bulbs connected in parallel glow equally bright. Each light receives the battery's full voltage and they divide the current between them.

A useful analog is that of students leaving a big meeting room. The rate that students can leave the meeting room depends on the number of doors open. This is like a circuit with light bulbs connected in parallel.

Teaching this analogy can be combined with a **role play exercise**. You can lead the role play or let students organize it (depending on student age).

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Meeting room full of students	Fully charged battery
Students exiting through 1 door open	One bulb in the circuit
Students exiting through 2 doors open	Two bulbs connected in parallel
Students exiting through 2 consecutive doors (in one hallway)	Two bulbs connected in series
Speed of exit through each door is the same	Each bulb receives the same voltage and current.
2 doors open hall empties twice as fast	2 bulbs in parallel, battery runs flat twice as fast.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Two light bulbs often do not draw as much current as two separate circuits of 1 globe and 1 battery.	
Students stop and talk and bump against each other as they leave the meeting room. Electron flow is regular.	

9. The analogy of a bicycle chain for current conservation in a series circuit

Link with curriculum: Grade 7, chapter 3, lesson 6 (2009)

The idea that current is used up in an electric circuit is a common belief with many students. They think that current is consumed because batteries go flat or flashlights go dim. An analogy can be useful to teach students the difference between electric current and electric energy.

Adapted from: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Bicycle chain	Electric current in closed circuit
Energy going from pedals to back wheel	Electrical energy
Feet driving the pedals	Battery
Rotation of rear wheel	Light bulb
Bicycle chain parts	Charge carriers or electrons
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
The analogy only works for simple series circuits.	

10. The candy circle analogy for electric current

Link with curriculum: Grade 7, chapter 3, lesson 2 (2009)

Another way to help students differentiate between electrical energy and electric current is a **role play**. A role-play engages students at many levels: from telling them the scenario through to allowing them to discuss circuit concepts and design the analogy.

Put desks on the side or go outside. Mark a large circle on the floor using coloured rope. Place one student on one side of the circle and another student on the other side. Let the other students position themselves in a circle ready to move. One student holds the battery card and one person holds the light bulb card. The circle moves in a direction determined by the students. When a student passes the light bulb student he/she receives two candies. They eat one and the other they give to the battery student when they pass him/her. Two revolutions are enough for the students to understand the idea.

Organize a **discussion** (in small groups or with whole class) after the role play, using questions such as:

- What do the two students outside the circle represent?
- What do the two candies represent?
- What do the students represent?
- Why did we draw a circle?
- Can the role play continue forever?
- How can we improve the role play?

Source: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Students in a circle	Electrons in a wire
Students moving	Electrons moving around a simple circuit
Candies	Energy

Student outside circle, receiving candies	Light bulb
Student outside circle, giving out candies	Battery
Giving the candy to light bulb student	Electrical energy making the light bulb glow
Students eating one candy	Energy used to make electrons move
Light bulb student eating second candy (or putting it in a box)	Light bulb glows, converting electrical energy to heat and light.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Circuit wires rarely consume as much energy as a light bulb, but both representatives receive one candy.	
Candies are not really energy (although they release a lot of energy), but electricity is energy.	
Electricity is represented as moving objects, whereas electricity is not a substance.	

B. Effective analogies for biology

Analogies are a popular way to explain biology concepts like cells, DNA and classification.

1. The city analogy for a cell

Link with Curriculum: Structure of the Cell (Grade 7, chapter 3, lesson 1, 2009)

Comparing a cell to a city helps students understand that cells have activity sites that perform city functions. For this analogy there are many possible analogs. You can let students find their own relations between cell organelles and city structures.

You can also let students develop their own analogy (**student generated analogies**). A cell can be compared with a factory, with a school, with a market …

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
City council governs and controls the city	Nucleus controls all the cell's activities
A power station provides electricity	Mitochondria provide chemical energy (ATP)
Construction companies build houses	Ribosomes construct proteins
Roads, cars and trucks provide transportation	Endoplasmic reticulum is a transportation system
Shops store food, clothes and hardware	Plastids store substances like starch
Garment factories make things for export	Golgi bodies produce substances exported to other cells (e.g. hormones)
Bakeries make bread	Chloroplasts make the cell's sugars
Post office	Golgi bodies
Fence around the city council building	Nuclear membrane

Bricks to build houses	proteins
Waste disposal facility	lysosomes
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Chloroplasts use sunlight energy, but a bakery uses wheat and electricity.	

2. The (super) market analogy for a classification system

Link with Curriculum: Taxonomy, Classification of Living Matter (Grade 10, chapter 1, lesson 1, 2008)

Biologists have named 2 million species of plants and animals. The total number of species may be 10 times as much. Scientists bring order in this huge amount by using a classification system. There is the traditional classification system of 5 kingdoms. Molecular biology has resulted in an alternative domain system based on ribosomal RNA.

An analogy is useful to help students understand how a classification system works. Show some pictures of a supermarket shelves to introduce the analogy.

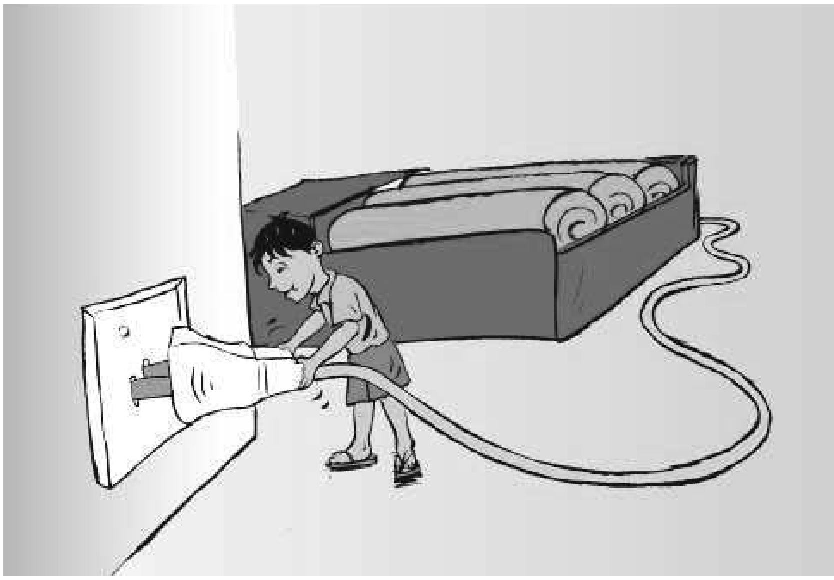
LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Products in a supermarket are organized into regions to help customers and staff find items.	Classification brings order to the study and identification of organisms.
A supermarket has many levels: fruit, vegetables, preserved foods, non-food items…	A classification system is hierarchical from large groups with high diversity to small groups with little diversity.
Each product has its own characteristics for	Each species has specific characteristics that

finding or placing it in the shop.	place it in levels of increasing specificity.
Some products are difficult to put into specific places.	Some organisms don't fit easily into groups. For example, some organisms can photosynthesize like a plant and ingest food like an animal.
Different shops arrange their products in different ways, but they always use a system.	Scientists use different classification systems, but they always use a system.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
There are more living species than there are items in the biggest supermarket.	
Classification systems include all known species, but shops don't sell every available item.	
Scientists use other criteria for classification than shop owners.	

3. The rechargeable battery analogy for ATP

Link with Curriculum: Grade 8, chapter 1, lesson 3 (2010)

The role of ATP in living cells is an important biochemical concept, but it is abstract and difficult for many students. All living cells make and use ATP in their energy-releasing and energy-using process. Most students will have experienced rechargeable batteries used in various devices. Bring one to class or show pictures if you're not sure.



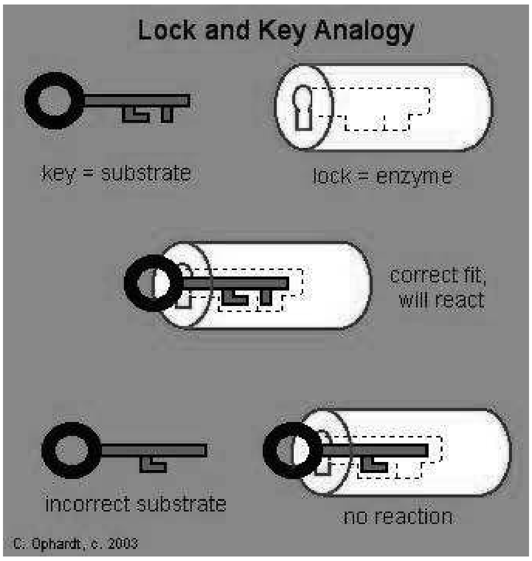
LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
A charged battery has the ability to provide energy.	ATP has the ability to provide energy.
Batteries move energy to where it's needed	ATP is moved to where energy is needed in

to power an electronic device.	the cell.
A charged battery turns into a flat battery as energy is used.	ATP converts to ADP as energy is used.
A rechargeable battery can be used over and over again.	ATP can be used over and over again. The chemical reaction is reversible.
A battery recharger is the site where energy is reintroduced into the battery	Mitochondria are the sites where energy is used to change ADP back into ATP.
Recharged batteries can be used in many devices.	ATP can be used at many sites in the cell (for example ribosomes, cell membrane) for different functions.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
A battery's energy is released gradually, whereas a single molecule of ATP will release all the energy in a single instant.	
A phosphate molecule breaks away from ATP, but nothing breaks away from the battery	
Usually only one or a few batteries are needed for an electronic device, whereas there are many ATP molecules in one cell.	

4. The lock and key analogy for enzyme action

Link with Curriculum: Grade 12, chapter 4, lesson 3 (2010)

Enzymes are very important chemicals that are used to speed up (catalysing) cellular reactions to rates that allow the cell to function properly. They are very specific, which means that they can only be used for the particular reaction to which they belong. It is an abstract concept, in particular the notion of active sites that react only with certain substrates.



Source: Ophardt, 2003

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Key	Enzyme molecule
Lock (padlock)	Substrate molecule
Notched part of key (has unique shape)	Active site (has unique chemical makeup)
Keys unlock only specific locks	Enzymes react only with specific substrates
Key unlocks a padlock	Enzyme action breaks apart substrate molecules.
The key comes out of the lock unchanged and can be reused.	The enzyme comes out of the reaction unchanged and can be reused.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Locks are usually bigger than keys, whereas substrate molecules are usually smaller than the enzymes they react with.	
The matching between key and lock is based on physical shape, whereas the matching between enzyme and substrate is based on chemical bonding patterns.	
Padlocks don't break apart to form different products as some substrate molecules do.	
A key can only lock or unlock a padlock, whereas an enzyme speeds up a chemical reaction.	

5. The geography analogy for the human genome

Link with Curriculum: Grade 2, chapter 5, lesson 2 (2010)

Chromosomes are made up of long strands of repetitive DNA which are not part of the direct code for proteins, but which are important in the regulation of the genes. Genes are part of the chromosomes that contain the code for producing a protein. They make up only 5% of the human genome. This analogy helps students understanding the relation between chromosomes, genes, DNA and proteins.

A map or atlas could be useful to help students imagining the geography analog.

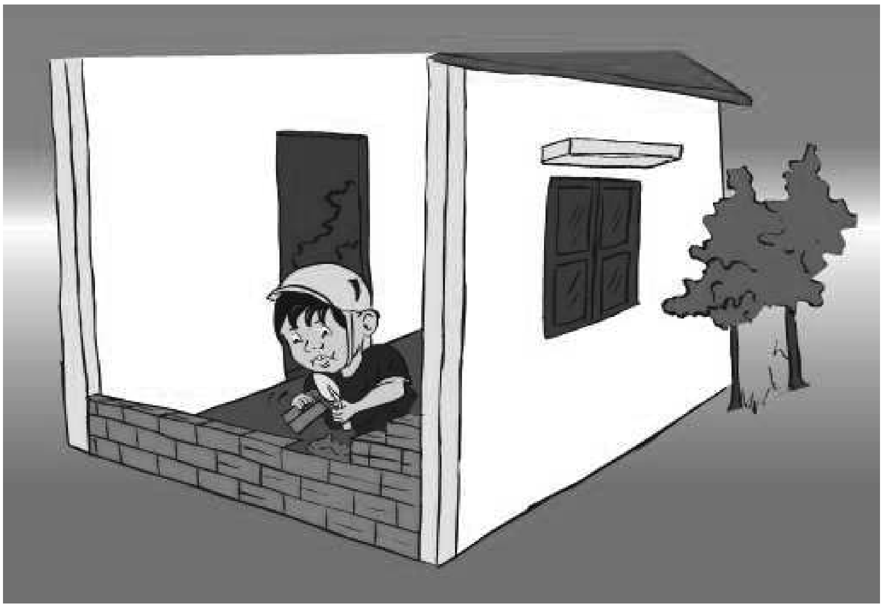
LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
1600 km road journey (3 x from Phnom Penh to Bangkok)	Length of the human genome
Provinces along the journey	Chromosomes
Monotonous sections of the journey, such as fields or forests	Repetitive DNA with regulation functions
Busy towns	Genes
Some cities are smaller than others	Genes vary in size with some being many DNA letters long and others relatively short.
Some cities are grouped together	Families of genes producing similar things

	are grouped together.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Monotonous sections along a road can be very productive, whereas strands of repetitive DNA do not code for proteins.	
Cities manufacture goods on site, whereas genes code for proteins that are manufactured in the ribosomes.	
There about 25.000 working genes in the human genome, much more than there are cities between Phnom Penh and Bangkok.	

6. The Building a House Analogy for Protein Synthesis

Link with Curriculum: Grade 12, chapter 4, lesson 2 (2010)

Protein synthesis is a complicated process involving many components and sites of activity. It is difficult for students to get a big picture of the process and, at the same time, understand the functions of each of the individual components. You can also use this analogy to explain the concept of phenotype.



LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Master plan of house	DNA
Architect's office	Nucleus
Copying of the master plan for use on construction site	Transcription

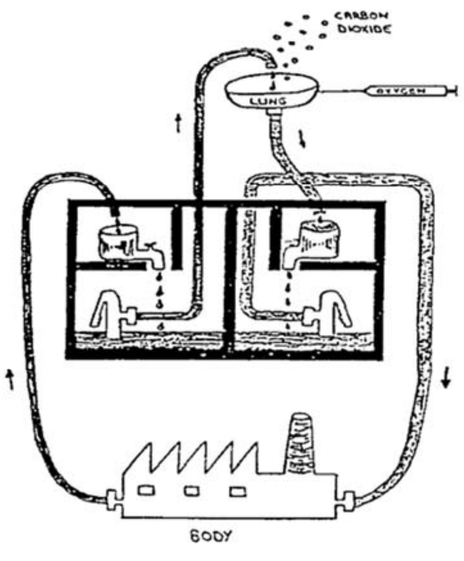
Copy of master plan	mRNA
Tradesmen bringing bricks and other materials	tRNA
Bricks	Amino acids
Mortar to bond bricks together	Energy, to bond amino acids to form a protein
Following the plan to organize bricks and build a house as planned.	Translation of DNA code into mRNA.
The same kinds of bricks arranged differently can build lots of different houses	The same kinds of amino acids can be arranged to build lots of different proteins.
Mistakes made by bricklayers	Mutations
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Protein synthesis is sub microscopic, whereas houses are not.	
Bricks can be cut up, whereas amino acids are always used in their entirety	
An architect can make changes to a design, whereas in protein synthesis, no intentional changes can be made.	

7. The buckets and pumps analogy for the heart

Link with curriculum: Structure of the Heart (Grade 8, chapter 4, lesson 4, 2010)

Students often find the dual system of pumps in the heart confusing and cannot distinguish between the pathways of the oxygenated and deoxygenated blood. An analogy can help them to understand the structure and role of the different parts of the heart.

This analogy can be used in combination with a model of the heart or the dissection of a pig heart.



Source: Wilkins, 1991

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Buckets collect water	The right and left atria collect blood as it returns from the body and lungs, respectively.
Pumps actively pump water to places where it is needed	The right and left ventricles actively pump blood from the heart to the lungs and body, respectively.
Taps can be closed to prevent the water from flowing backwards	Heart valves prevent blood from flowing in the wrong direction.
Needles can inject substances into places.	The lungs put oxygen into the blood coming from the right ventricle.
Factories use up raw materials	The body is like a factory that uses up the oxygen in the blood.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Buckets have an open top where water overflows, whereas the atria have valves that allow the movement of blood to the ventricles.	
The movement of gases into and out of the blood in the lungs happens by diffusion, bot by an active injection.	
The heart is made of organic substances, whereas buckets and pumps are made from inorganic substances.	
The atria actively pump blood to the ventricles. It is not a passive process like the dripping of water from a bucket.	

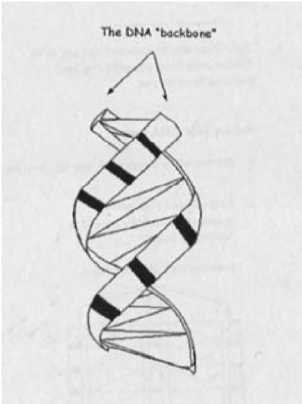
8. An Origami Paper Model for the Structure of DNA

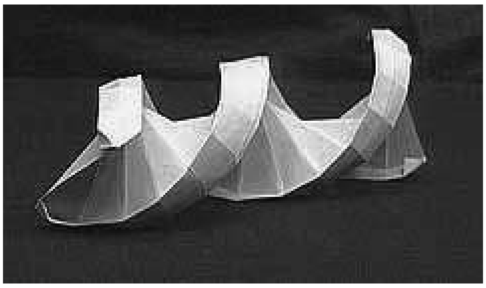
Link with Curriculum: Structure of DNA (Grade 12, chapter 5, lesson 1, 2010)

The double helix structure of DNA is made up of two molecular strands twisted into a helix. A clear understanding of the chemical structure of DNA and the relation with the production of amino-acids and genes is important in biology.

With a few simple materials students can create a concrete and easy-to-make **model** to help them understand the basic structure of DNA. Students only need a copy of the next page and preferably some colour pencils. Start with colouring each of the 4 nitrogen bases of the DNA. Each colour represents one of the 4 bases in DNA (adenine, thymine, cytosine and guanine). Further detailed instructions how to make a model with your students are included on the next page.

Challenge students to work out appropriate details of the model, using their knowledge of DNA. You can also stimulate them to develop an alternative analogy to explain the structure of DNA and processes such as transcription and replication.

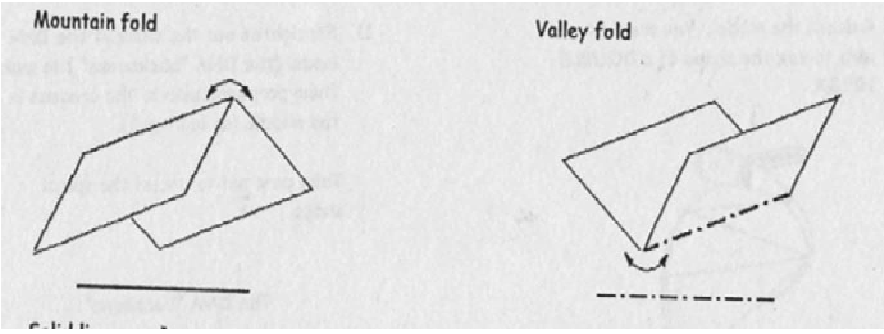




LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
4 colours on paper	Nitrogen bases (4 types)
Central structure	Desoxyribose and phosphate group
Paper parts connected with two or three lines	Weak hydrogen bonds between nitrogen bases (double and triple bonds)
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
DNA molecules are very long, consisting of thousands of base pairs, whereas this model is relatively short.	
The papers have physical bonds, whereas the bonds between the nitrogen bases are chemical bonds.	

How to make your own origami paper DNA model?

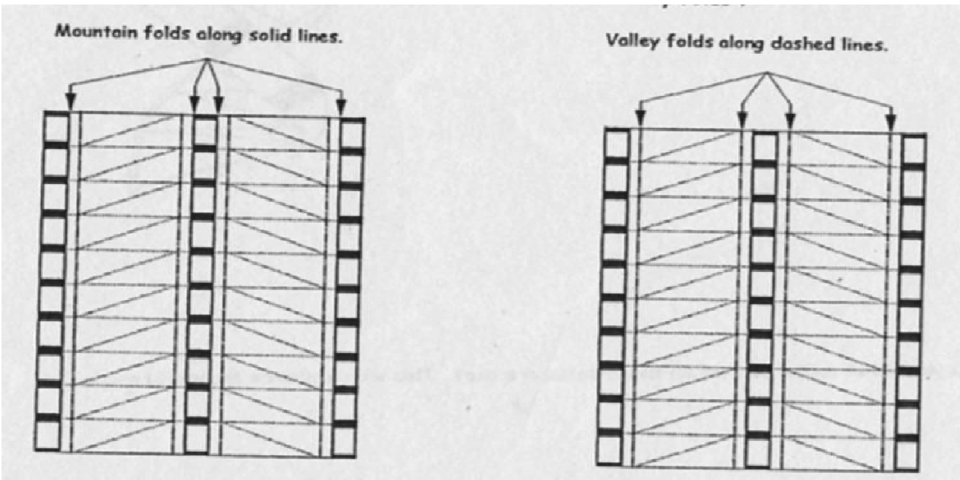
1. Fold your DNA model



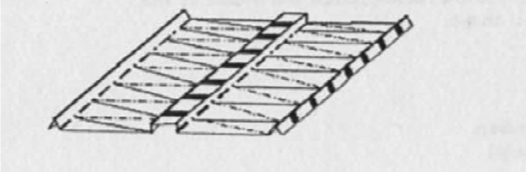
Solid lines are "mountains" and are to be folded away from you with the peak pointing towards you. Dashed lines are "valleys" and are to be folded towards you with the peak pointed away from you.

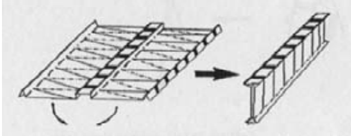
2. Making your DNA model

- *Cut the white border off the top, bottom and sides of the template*
- *Colour the 4 nitrogen bases, each with a different colour (optional, or can be done in advance at home)*
- *Fold all solid lines going lengthwise down the page into "mountain folds".*
- *Fold all dashed lines going lengthwise down into "valley folds".*



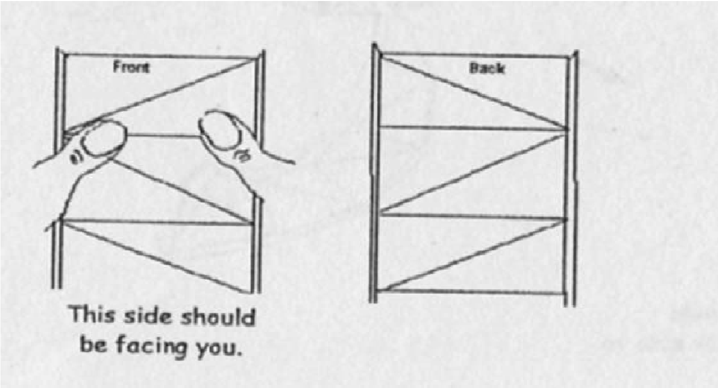
At this point, the paper should look like the picture below left.



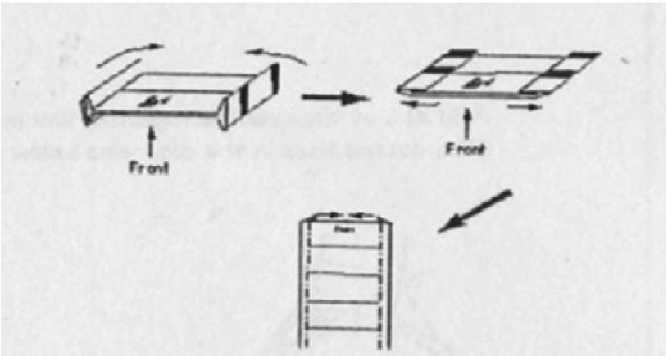


3. Bring the two sides of the model together, similar to an "I" beam (see picture above right)

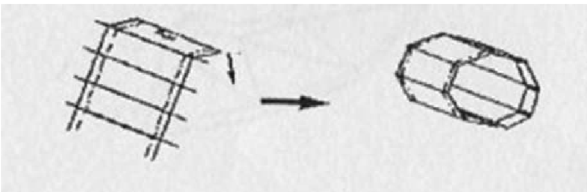
4. Look for the words "front" and "back" at the top of your model. Hold the model with the front side facing you.



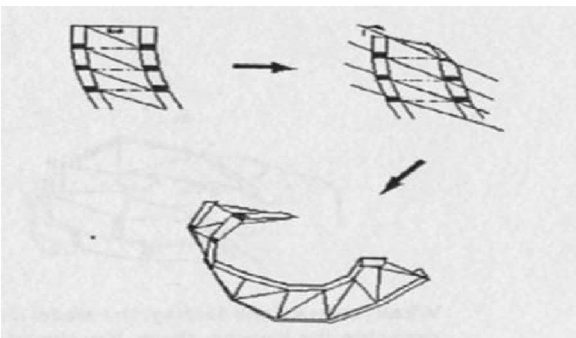
5. Fold the two sides of the DNA model so that the "front" side is flat.



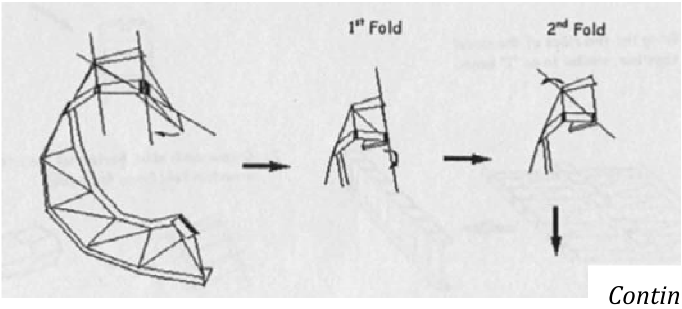
6. Crease each solid, horizontal line into a mountain fold (away from you)



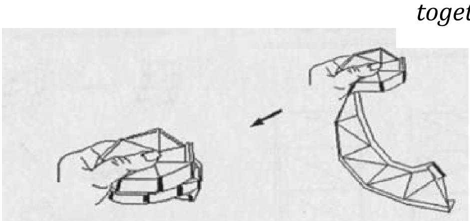
7. Flip the model to the "back" side. Crease each solid, diagonal line into a mountain fold (away from you). Your model should look like the picture below.



8. Fold ALL of the creases together in the directions of the folds made in steps 5 and 6. Your model will fold up like an accordion. While you are folding, pinch the middle of the model to keep it together to make a cylindrical shape.

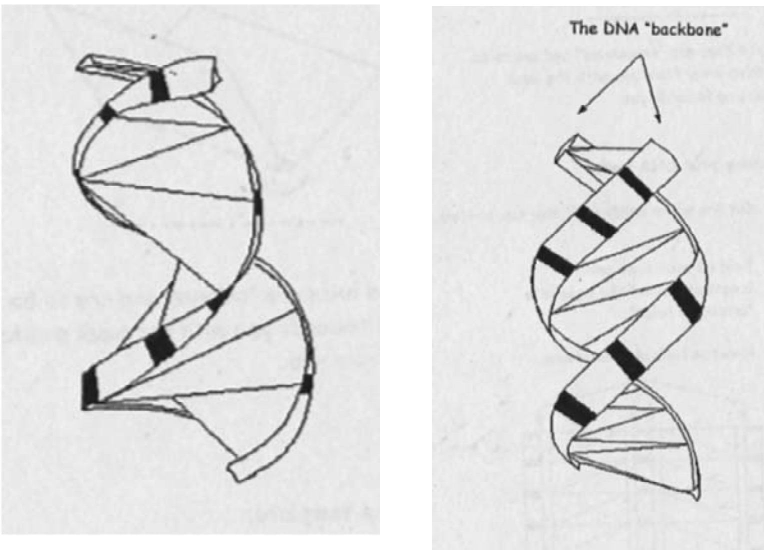


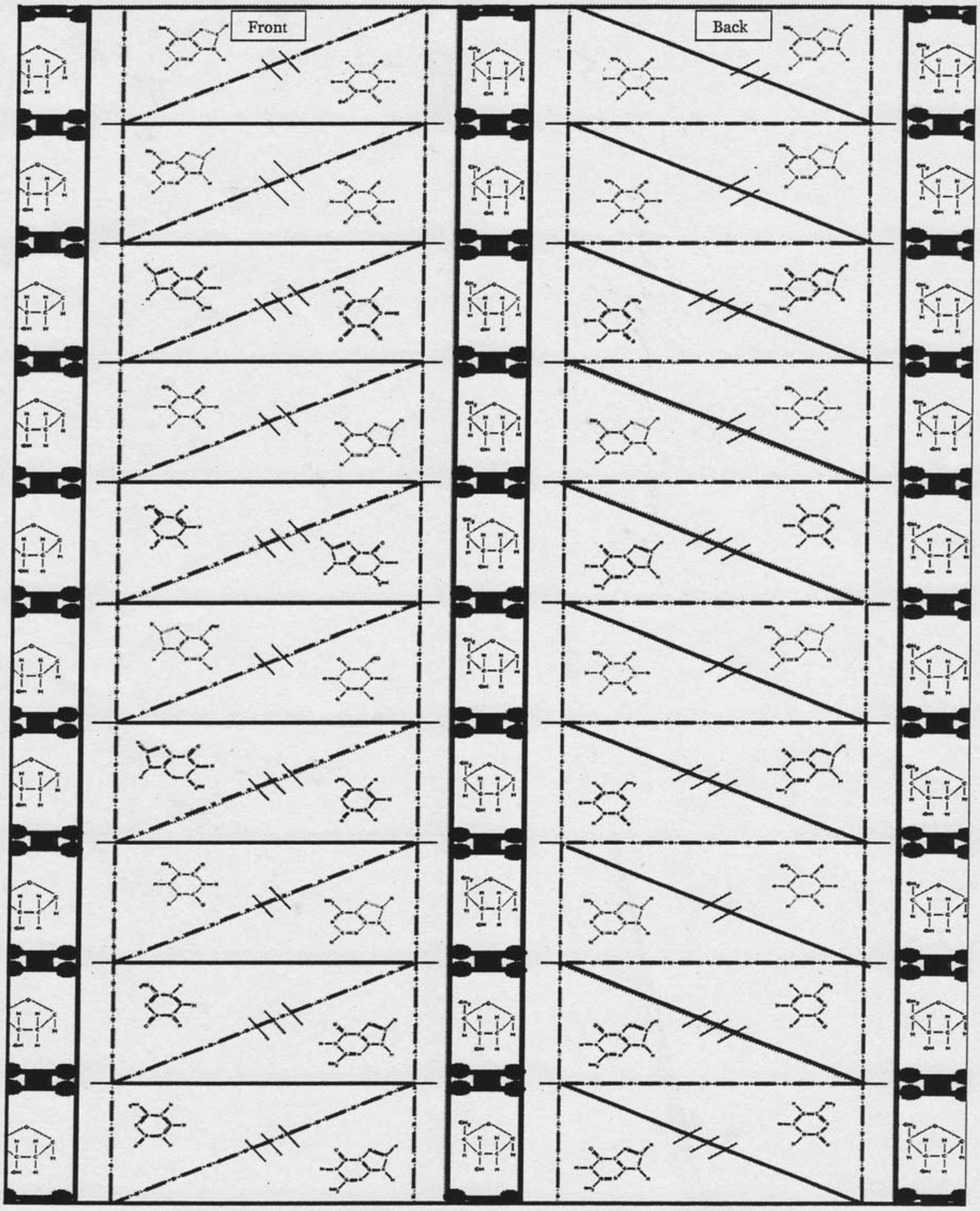
Continue to fold, pinching these folds together in the middle as you go.



When you are finished with folding your model should look like the picture above.

9. Release the model. You should be able to see the shape of a double helix (below left). Straighten out the sides of the DNA model (the DNA "backbone") to make them perpendicular to the creases in the middle (as in step 2) (see below right).





Adapted from Yen, T., 1995, Make your own DNA. *Trends in Biochemical Sciences*, **20**: 94.

9. An Earth analogy for Cell Components

Link with Curriculum: structure of the cell (Grade 7, chapter 3, lesson 1, 2009)

An analogy can help to give students an idea of the relative sizes of the cell components. The analogy compares a cell to the Earth. Students work together to extend the analogy to other cellular components (mitochondria, ER…)

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Earth	Cell
A continent	Cell nucleus
A country (e.g. Cambodia)	Chromosome
A city	DNA fragment on chromosome
A street address	Codon (3 base pairs)
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Only relative sizes are compared and not structure and function.	

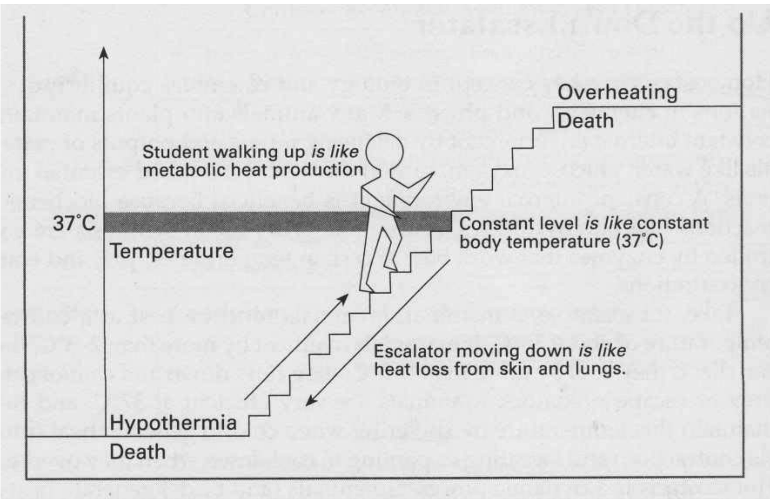
10. The analogy of Homeostasis Being like a Student Walking up the down Escalator

Link with Curriculum: Homeostasis (Grade 11, chapter 6, lesson 2, 2009)

Homeostasis is a key biology concept, that explains how many animals and plants maintain a constant internal environment by regulating input and output of heat, water, CO_2, nutrients and minerals. However, many students misunderstand homeostasis as organisms sealing off their interior to the environment. Seeing homeostasis as a dynamic process helps them understand how organisms respond to changing conditions in their environment.

Homeostasis can be compared with a student walking up and down an escalator. However, make sure that students are familiar with escalators before using this analogy!

The analogy can be used to explain the dynamic balance of heat production and heat loss. Afterwards, students can work in groups on an explanation.



Source: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
The escalator is constantly descending	Heat is constantly lost through lungs and skin
Student is walking upward	Human body generates heat by exercise
A student walks upward as fast as escalator goes downward.	Heat loss and heat production are balanced, so the body temperature remains constant.
The escalator descends faster	Heat loss is higher than heat production: the person gets cold
The student walks up faster	Heat generation is faster than heat loss: the person gets hot.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	

The escalator moves at a constant rate, but the heat loss rate depends on the environmental temperature.	
Heat loss and production can only be balanced at 37˚C. This would correspond to one position on the escalator.	

C. Effective analogies for earth science

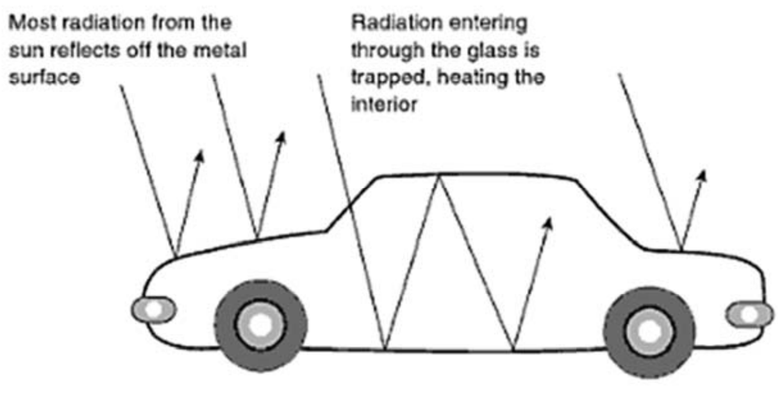
The vast scale of events in the Earth and space requires models and analogies to bring events down to a size that students can see and understand.

1. The heating of a car analogy for the greenhouse effect

Link with Curriculum: Greenhouse effect (Grade 12, chapter 4, lesson 4)

The increasing concentration of certain gases in the atmosphere is helping to trap heat and this is gradually raising the Earth's temperature. The greenhouse effect is often confused with the hole in the ozone layer.

You can link this analogy with **practical activities**. Let students determine the greenhouse effect using bottles and thermometers (see experiment guide). You can use **science reasoning techniques** to discuss the political and sociological implications of the greenhouse effect. The analogy can be introduced as a **group challenge**. If students know why the interior of a car in the sun heats up, they can try to work out why increased concentrations of greenhouse gases result in higher atmospheric temperatures.



Source: Ernst, 2010.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Heat entering the car through the windows	Heat entering the Earth's atmosphere
The glass windows and windscreen	Layer of gases in the atmosphere

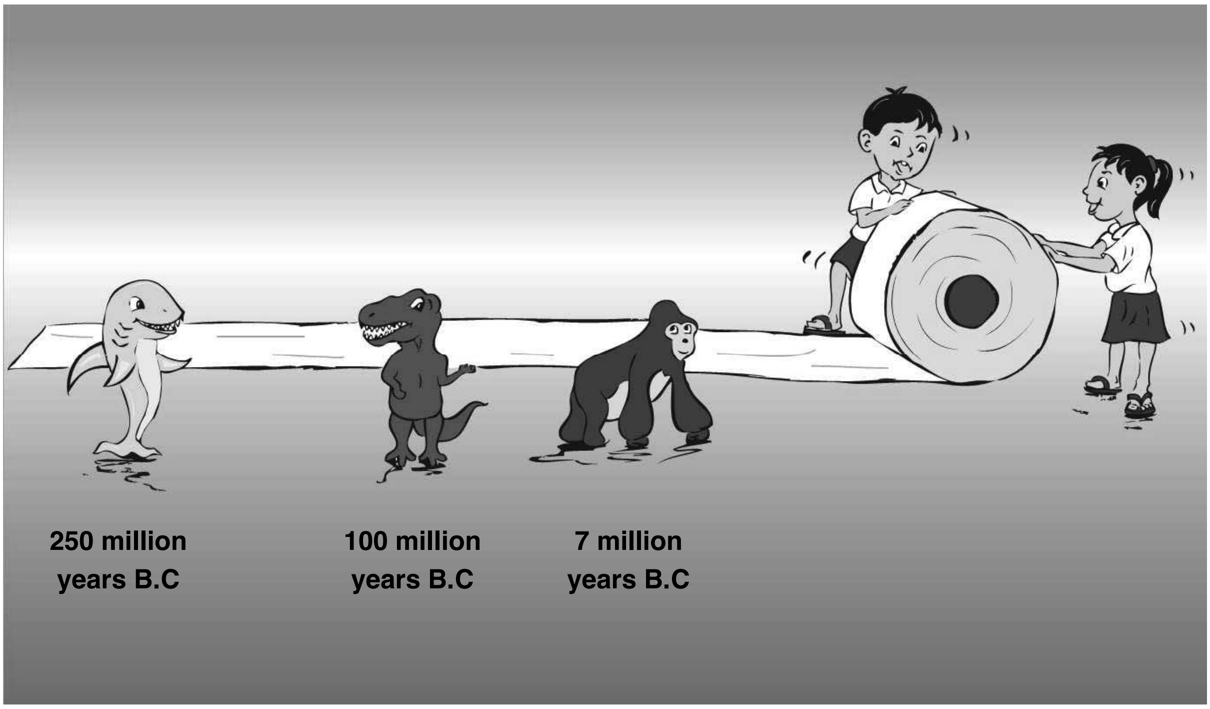
Heat cannot escape easily from the car	Excess heat is trapped in the atmosphere
Air within the car warming up	Atmosphere warming up
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
The interior of a car heats up much faster than the Earth's atmosphere. (However, it should also be pointed out to students that, in terms of geological time, the atmosphere heats up very rapidly.)	
In a car, the solid exterior acts as the insulator. In the atmosphere, gases play this role.	
Re-radiation and the resulting lengthening of wavelength of the electromagnetic rays is a much more significant factor in the warming up of the atmosphere than in the interior of a car.	
It's easy to cool down the interior of a car (by opening the windows or switching on the air-conditioning). However, cooling the atmosphere is a very complex scientific and political problem.	

2. The Time Line Analogy for Deep Time (Geological Time)

Link with Curriculum: Grade 10, chapter 1, lesson 4 (2010)

Scientists believe that the history of the earth covers about 4.6 billion years. Humans and other mammals have been present in only very recent geological times. However, many students have difficulty visualizing the magnitude of time intervals involved in geological history relative to their own experiences.

An analogy between the history of the earth and a roll of paper can be developed as a **group activity**. Students determine the position of key geological events on the paper strip. The teacher can decide on the scale of the time line. For example, a scale in which one A4 sheet takes up 100 million years would require 46 sheets. The model can be created and displayed in various ways (made outside and photographed or filmed, hung around in the classroom just below the ceiling etc.)



Adapted from: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
A long strip of paper (toilet roll, connected A4 sheets etc.)	The earth's 4600 million year history
Markers on the time-line	Key geological events
Long empty intervals and short crowded sections	Long periods of little biological development, contrasting with a great variety of living things in a short time period.

UNLIKES (WHERE THE ANALOGY BREAKS DOWN)
Markers give the impression of clear start and end dates. However, boundaries between geological periods are approximate and geographical changes are often very gradual.
Life forms don't appear or disappear at certain times, but are the result of continuous evolution.

Some practical tips:
- Make groups responsible for indicating certain events.
- Tell each group to divide tasks: one student counts, another writes, another makes a drawing etc.

Examples of key-events
- First atmosphere
- First unicellular organisms
- First multicellular organisms
- Origin of Himalaya
- Last Pangaea situation
- First mammals
- Appearance and Extinction dinosaurs
- Appearance Homo Erectus, Homo Sapiens etc.

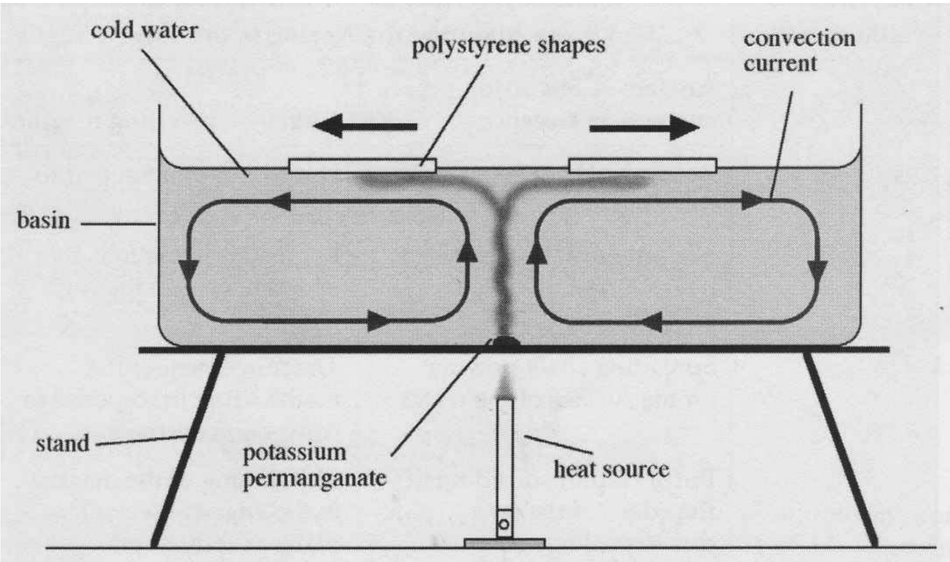
3. Convection currents and movement of tectonic plates

Link with Curriculum:
Grade 9, chapter 2, lesson 1 (2011)
Grade 11, chapter 1, lesson 4 (2011)

Students are often unaware of the mechanism that drives plate tectonics. The model shows how convection currents in the earth's mantle cause the crust to move apart.

The model consists of a transparent tank with water with potassium permanganate crystals at the bottom and chalk powder on the surface of the water. Place a candle directly below the crystals, resulting in convection currents that students can observe as the crystals dissolve.

The model is not a perfect analogy to plate tectonics. However, even flawed analogies can act as strong learning activities, as long as the flaws are clearly discussed with the students.



Source: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Purple liquid moving up from the area of heating	Upwelling of magma into the earth's crust
Candle	Radioactive reactions in the earth's core generate heat
Spreading chalk powder	The movement of the earth's crust in response of the convection currents
Purple liquid subsiding at the edges of the container	Sinking of the magma at the edges of tectonic plates (subduction).
Polystyrene shapes on top of the chalk	Continents floating on the tectonic plates

powder	
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Subduction happens at the edges of continents, not at a fixed location on the earth's crust.	
Continent-continent collisions and resulting mountain formation is not represented in the analogy.	
The speed of the model is much higher than the actual speed of plate tectonics.	
New crust is created at the mid-oceanic ridges, but the purple liquid doesn't turn into chalk.	

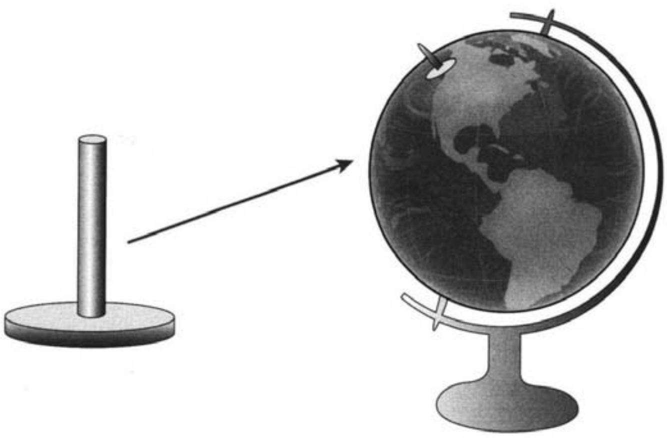
4. The Mini Sundial Analogy for Day and Night

Link with Curriculum: Grade 8, chapter 3, lesson 1 (2010)

Many students fail to explain the origin of day and night in a scientifically correct way. Using a model provides a strong visual representation for the students of how the rotation of the earth in combination with the Sun causes day and night.

Let students illuminate a globe of the earth on one side and then rotating it slowly to model how different places enter day and night. The model can then be further developed by adding a mini sundial (like a match) to the globe and demonstrating that the length and orientation of shadows is a result of the earth's rotation. This seems to change the elevation of the sun during the day.

You can combine the use of this model with a **concept cartoon**. The model can also be replaced by a **role play activity** in which students play the role of Earth, Sun and Moon and use a low intensity flashlight.



Source: Harrison and Coll, 2008

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
A stationary light source	Sun
A matchstick stuck to the globe	Sundial

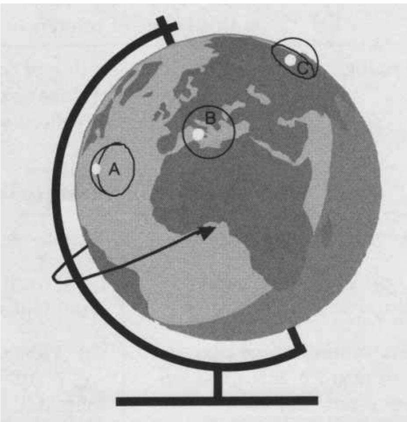
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)
The matchstick is much taller relative to the globe than a sundial on Earth.
Students rotate the globe much faster than the Earth's real rotation rate.

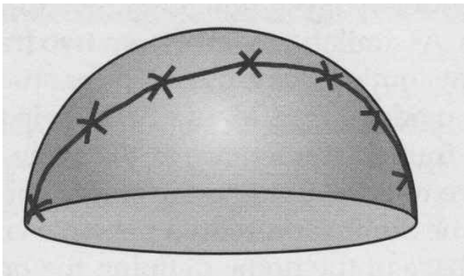
5. The Mini Dome Analogy for the Arc of the Sun

Link with Curriculum: Grade 7, chapter 2, lesson 1&2 (2009)

This model helps to explain the relative motions of the Earth and the sun. It is intuitive to think that we are stationary, while the moon, sun and other planets move across the sky. This model shows how the Sun describes an arc across the sky from east to west. The arc varies with the seasons due to the tilt of the Earth's axis.

This model requires a small plastic dome that you can put on a globe.





Source: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Light source, such as a flashlight	Sun
Transparent dome place on the globe above a town	Our view of the sky from any point of Earth is shaped like a dome and has a circular horizon.
As the globe rotates from W -> E, the dome emerges from the dark side and a bright dot is seen at the base of the dome.	As the Earth rotates from W -> E, we move from the darkened hemisphere into the light. We see the Sun rise in the East
As the globe rotates further the bright dot appears to move across the dome in an arc. The curve of this arc depends on the position of the dome on the globe and the tilt of the globe.	As the Earth rotates, the Sun appears to move in an arc across the sky. The shape of this arc depends upon the location of the observer on Earth and on the season.

UNLIKES (WHERE THE ANALOGY BREAKS DOWN)
The domelike shape of the sky is only apparent, there is no real dome.
Because of various landforms we seldom see the horizon as a circle.

6. The Motion of the Planets in the solar system

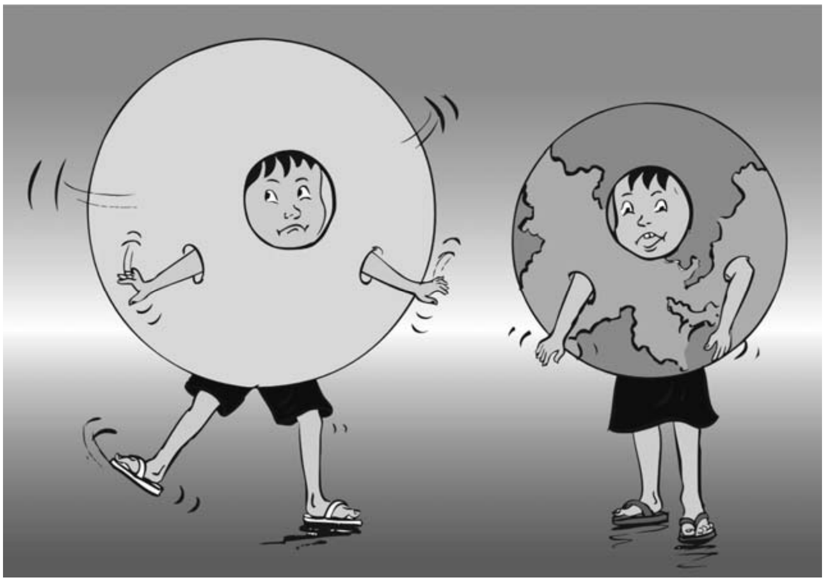
Link with Curriculum: Grade 7, chapter 1, chapter 3 (2009)

Many students have a wrong or incomplete understanding of motions and scales in the solar system. It is important to spend enough time developing conceptual understanding with the students. Using **models** and **role plays** as analogies is an excellent way to achieve this.

A mechanical model of a part of the solar system (called an orrery) can show relative motions of Earth, Moon and Sun. Otherwise in a role play students can play the different planets, moons and the Sun. This can vary from a simple model with only a few planets to a full scale role play with many planets, moons and even comets or asteroids.

Prepare cards with the names (and a picture) of planets, moons, the sun etc. Every student picks a card. They discuss with each other where they have to stand, how they need to move, how fast etc. You can make a set of cards for each group of students. You may repeat the activity a few times until everyone has a firm grasp of the structure of the solar system.

Discussion questions after the role play may include:
- Why do the Moon and Venus have phases and Jupiter not?
- On which planet takes a year the longest?
- What are the limitations of the role play?



LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Students	Planets, moons, Sun
Sequence of students from the Sun	Sequence of planets from the Sun
Relative speeds at which the students orbit the Sun	Relative orbiting speed of the planets around the Sun.
Students use a stick to simulate the orbit axis of the planet	Planets orbit around their axis much more slowly.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Sizes of the planets are very different.	
Students orbit the sun more rapidly than the planets orbit the sun.	
Relative distances of the planets are difficult to reproduce by the students	
In reality planetary orbits are not circular but elliptical.	

7. The Scale of the solar system

Link with curriculum: Grade 7, chapter 1, lesson 4 (2009)

Two-dimensional pictures or models often introduce a wrong understanding of distances in the solar system. A **role play** activity which includes objects on real scale and correct relative distances between the planets will help students to create a correct conceptual understanding of the scale of the solar system. They will appreciate the large distances and realize that most of the solar system is empty space.

Prior to the role play you can organize a **group work activity** in which students discuss which objects to use and calculate the distances. An example is included in the table below. You may limit the role play to the inner solar system, but let students calculate the sizes and distances for all the planets.

PLANET	SCALED PLANET DIAMETER	SUGGESTED MODEL	DISTANCE FROM THE SUN
Sun	30 cm	Yellow plastic ball	
Mercury	1 mm	Seed	12m
Venus	3 mm	Dried pea	23m
Earth	3 mm	Dried pea	32m
Mars	2 mm	Pepper corn	49m
Jupiter	30 mm	Tennis ball	167m
Saturn	26 mm	Tennis ball	300m
If you have a lot of space around the school			
Uranus	10 mm	Marble	Approx. 600m
Neptune	10 mm	Marble	Approx. 900m

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Spheres of different sizes	Planets of the solar system
Relative distances between spheres	Relative distances between planets
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
There is air between the spheres, but in reality there is a vacuum between the planets.	
The planets are positioned on a straight line. In reality they are positioned on various points of their orbit.	

8. The Supernova Water analogy for Exploding Stars

Link with Curriculum: Grade 12, chapter 3, lesson 2 (2011)

Shockwaves are very powerful. They occur when bombs go off or when stars explode as supernovas. Students are generally not familiar with shock waves. This **model** can be used to show how a shock wave works and relate it to the process of a supernova explosion.

Fill a water bottle full with water and keep the lid off the bottle. Hold the bottle in your hand about 30 – 40 cm above a solid object such as a table or the floor and bang it bottom down with a sudden move on the table or floor. The water suddenly decelerates, creates a shock wave that continues on, hits the bottom, rebounds and blows much of the water up and out of the bottle. Take care, use a strong plastic bottle and do the experiment outside.

Adapted from: Harrison and Coll, 2008

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Plastic bottle (with lid off)	Star bigger than our sun
Water in the bottle	Star's gases (mostly the outer half)
Rapid downward motion	Star's gases collapsing under intense gravity
Shock wave generated when the bottle stops moving.	Shock wave generated when gases cannot collapse any further.
Shock wave reflected off the bottle's bottom	Shock wave reflected off maximum density layer
Water blown out from the top	Gases blasted off the star's outer half.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Water is a cool liquid. Stars are made of very hot gases (plasma)	
Stars are much bigger than a water bottle	
Water just sprays out into the air, whereas the gases become a nebula and later can form planets.	

9. Role play on Tides

Link with Curriculum: Grade 8, chapter 3, lesson 4 (2010)

Tides are a complex phenomenon that is difficult to understand for many students. A role play can be useful to explain the interplay between Sun and Moon in creating tides on Earth.

When performing the role play students need to review other elements they have learned about Sun and Moon, such as:

- The Moon orbits the Earth every 28 days.
- The Earth orbits around the Sun in one year.
- The time for one orbit is equal to the time for one rotation, so we always see the same side of the Moon.
- The Moon is much closer to the Earth than the Sun.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
3 persons	Sun, Earth and Moon
Persons rotating and moving around each other	Moon, Sun and Earth orbiting and rotating
Persons holding each other	Gravity between objects
“Earth person” stretching arms outward in two directions	High tide in that part of the Earth
“Earth person” stretching arms more in two directions	Spring tide in that part of the Earth
Other directions (where arms are not stretched)	Low tide in that part of the Earth.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
The Moon is 400x closer to the Earth than the Sun	
The Sun is also approx. 400x bigger than the Moon.	

D. Effective analogies for chemistry

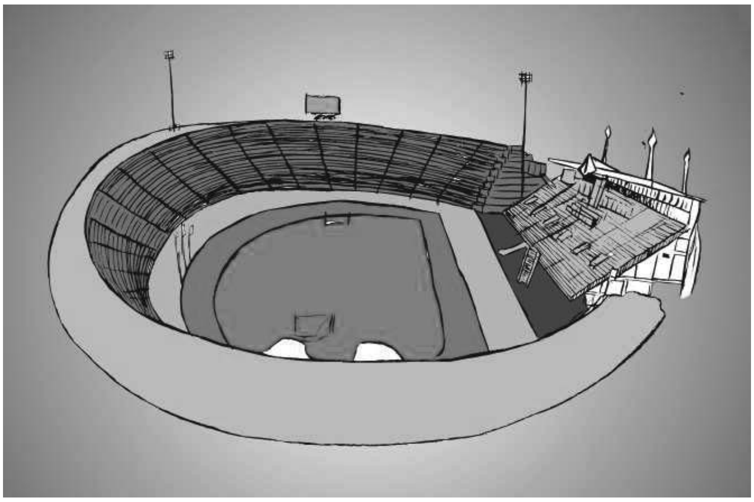
Many chemistry concepts lie outside the world experience of students. They are invisible to the naked eye (like atoms and molecules), are counterintuitive (like atom models) or are too fast or slow to observe (like some chemical reactions). Analogies therefore possess considerable potential to aid students' understanding. They are sometimes called the special language of chemistry.

1. The sports stadium analogy for the hydrogen atom

Link with Curriculum: Structure of the atom (Grade 10, chapter 1, lesson 2, 2008)

An atom is mostly space. The ratio the nucleus diameter: atomic diameter is approx. 1:100,000. However, students often visualize the atom as a solid sphere and have great difficulty visualizing that atoms are mostly empty space and that the nucleus is so tiny and dense.

Show a picture of a large sports stadium such as the Olympic Stadium, if your students are not familiar with the image. Let students think of another analogy (for example a tennis ball as the nucleus and the distance home – school as the size of the electron cloud.)



LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Grain of rice	Nucleus of a hydrogen atom (one proton)
Playing area and seats out to the last row of Olympic Stadium.	Region where the electron might be found.
Ratio of grain of rice: whole stadium	Ratio of hydrogen nucleus: electron cloud.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
The analog is two-dimensional, whereas the atom is three-dimensional.	
The ratio is slightly different for larger atoms, but the concept is identical.	
The atom is filled with empty space, whereas the stadium is filled with air (another common misconception).	

2. The Solar System Analogy for Atomic Structure

Link with Curriculum: Grade 8, chapter 3, lesson 4 (2010)

Students have difficulty visualizing tiny, microscopic particles like electrons and protons. They are familiar with planets and the solar system, as a result of having seen pictures and videos about it. Our solar system provides a simple analogy to understand the Bohr atomic model. Illustrate the model with pictures from the solar system or by using a model. This will make the model more impressive and it will more likely be remembered.

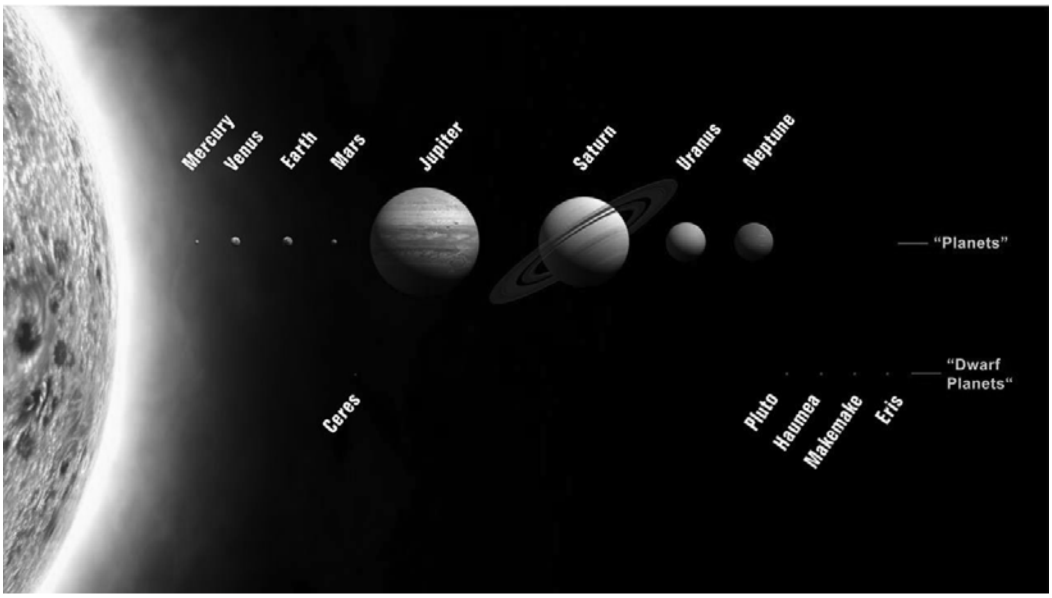


Image courtesy http://danieldendy.blogspot.com

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Sun	Nucleus
Planets	Electrons
Orbits of planets around the sun	Orbits of electrons around nucleus
Rotation of planets	Spin of electrons
Spherical shape of sun and planets	Spherical shape of nucleus and electrons
Planets at fixed distances from sun	Electrons at fixed distances from nucleus
Sun composed of hydrogen and helium	Nucleus consists of two elementary particles
Gravitational attraction in solar system	Electrical attraction between electrons and nucleus.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Sun is hot, whereas nucleus is not	
Orbits of planets are elliptical, whereas orbits of electrons are circular	

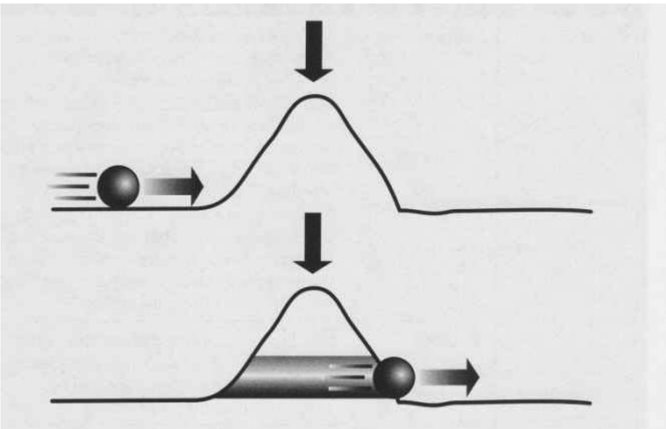
Electrons can change their orbits if they gain or lose energy. Planets cannot change their orbits.
Real electrons occupy clouds of space around the nucleus rather than a strict orbital path
Protons and electrons have electrical charges, unlike the sun and the planets
Some planets have moons, whereas electrons are alone in their orbits.
Electrons are all the same size, unlike planets.

3. The tunnel analogy for catalysis

Link with Curriculum: Catalysers

This model helps students to understand activated complexes, activation barriers and the role of catalysers in chemical reactions. Catalysts speed up chemical reactions by providing an alternative pathway with a much lower energy barrier. Because the reactants do not require so much energy input to reach an activated complex, the reaction happens more rapidly.

The analogy consists of the idea of a car trying to drive over a steep mountain. The steep hill is replaced by a tunnel, which is the analog of the catalyst's alternative reaction pathway.



Adapted from: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Height of the hill	Height of energy barrier
Car	Reactants
Driving over hill	Reactions overcoming energy barrier, the reaction takes place.
Tunnel	Alternative pathway provided by catalyst
Ease of travelling through tunnel	Reaction speed
tunnel can be reused	Reactants can overcome energy barrier

	again and again.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
There is only one car, whereas there are many reactants	
The car and hill are large, but atoms are very small	
Cars move very slowly compared to atoms	

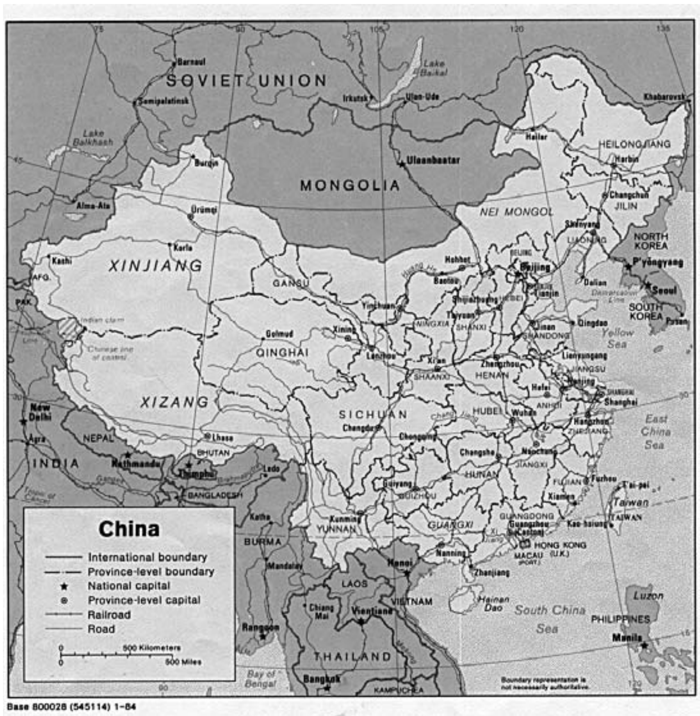
4. The rice grains analogy for Avogadro's number

Link with Curriculum: Mole (Grade 10, chapter 1, lesson 2, 2008)

Avogadro's number is an important and useful construct used by chemists to deal with large quantities of matter and to perform calculations on chemical reactions. Students may be able to recite the value of Avogadro's number, but often it lacks them appreciation on how big the number really is or what its meaning is.

The analogy uses the visualization of rice grains covering a large land area such as China. It will help students to imagine the size of the number. You can also show a mole of substance of a common material such as water (18 grams of water is 1 mole). Some key data to do the exercise are listed below:

9.63E+12	area china (m^2)
6.02E+23	avogadro's number
1.50E-05	rice grain (m^2)
1.00E+01	height rice grain (mm)



LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Rice grain	Atom or ion
Large country such as China covered with rice grains to depth of approx. 5 km	Avogadro's number of rice grains

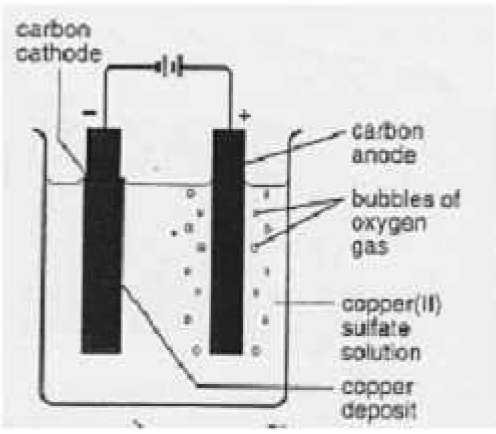
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)
Rice grains are much larger than atoms.

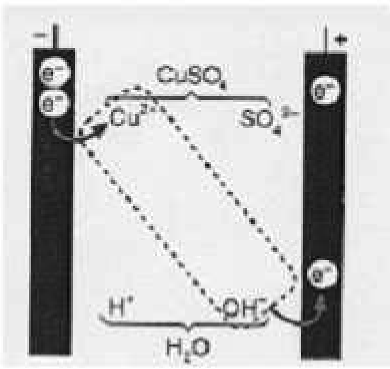
5. The role-play for chemical reactions

Link with Curriculum: chemical reactions, electrolysis (Grade 11, chapter 3, lesson 5, 2009)

Chemical reactions can be visualized in a fun way using **role plays**. An example is the extraction of copper metal from copper carbonate, involving the electrolysis of copper sulphate. There are three steps in this reaction process:

- The dissolution of copper carbonate
- Formation of copper sulphate
- Electrolysis of copper sulphate





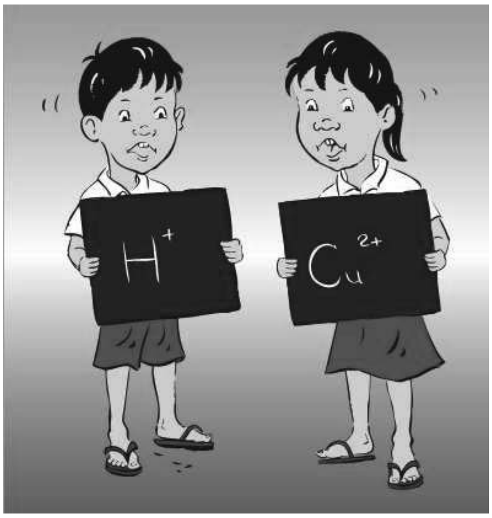
Source: Harrison and Coll, 2008

Reaction equation:
At cathode: Cu^{2+} (aq) + $2e^-$ ➔ Cu (s)
At Anode: $2H_2O$ (l) ➔ $4H^+$ + O_2 (g) + $4e^-$

Students are assigned roles as atoms or ions and make labels. Five students make up copper carbonate ($CuCO_3$). Linking of arms represents covalent bonds within the complex ion and an ionic bond between copper ions and the electrons are represented by two books held in the hand which rests on the shoulder. Thus before dissolution in water, we have a group of four students linked together by their arms, two of whom are holding books (the CO_2 ion) and the books are on the shoulder of a 5th student (the Cu ion). When dissolution occurs, the group of four separates from the fifth and retains the books (the electrons showing that the CO_2 ion is charged).

In the second phase, the formation of copper sulphate ($CuSO_4$) is simulated. Six students are needed, five representing the sulphate ion and one representing the copper ion, and two books representing electrons. In the reaction dilute sulphuric acid (H_2SO_4) reacts with the copper carbonate to form copper sulphate, carbonic dioxide and water.

Finally, for the electrolysis, three more students are needed to represent water and two chairs represent the electrodes. The copper ion students go to one chair and accept the two books (electrons) and go and sit on the chair, showing that they are attached to one electrode (metallic copper). The other electrode is made of (carbon) graphite. The water students go to the other chair and give the chair two books. Two students then link both arms to represent a double-bonded oxygen molecule and wander off (gas disappearing from the system). The sulphate students walk around freely, being spectator ions.



This kind of role play can also be done for other chemical reactions. The teacher can present different chemical reactions and students can then work out their own role play in small groups and do the role play in front of the class, whereas one students acts as "presenter".

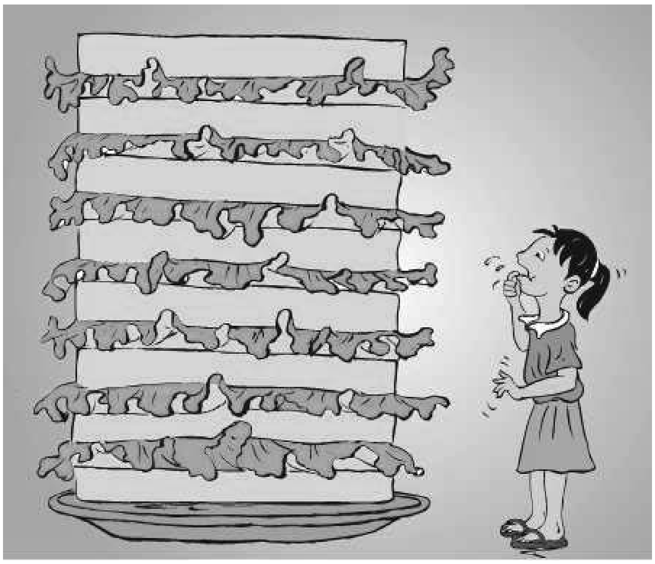
LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Individual Students	Atoms
Four students linking arms	Complex ions
Book resting on shoulder (person)	Electron (ion)
Students separating	dissolution
Air	Water
Linking with one arm	Single bond
Linking with two arms	Double bond
Chair	Positive electrode
Chair with books on it	Negative electrode
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Students and books are much larger than atoms or electrons.	
Forces bonding atoms together are much stronger than the linked arms	
There are many more atoms and electrons present than students in the classroom.	
The shape of ions is different from the student arrangements.	

6. The bread analogy for stoichiometry

Link with Curriculum: stoichiometry (Grade 10, chapter 1, lesson 1, 2008)

Stoichiometry is a difficult concept for many students. The basic principles of stoichiometry can be explained with a simple analogy.

Making a sandwich and representing the recipe using symbols can be used to model the stoichiometry of a chemical reaction, the ratios involved, as well as the limiting reagent concept. For example, a sandwich made from two slices of bread and one slice of ham has a ratio of 1:2. By using the masses of ham and bread per slice, it is possible to model mass-mass and mass-mole/ mole-mass calculations. Let students **develop their own analogies** and have them write down their stoichiometry problems using their analogy.



LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Symbols H and B for ham and bread and HB2 for sandwich	Symbols for reactants and products in a chemical reaction.
Sandwich equation: H + 2B → HB2	Chemical equation
Ham and bread make a sandwich in a ratio of 1:2	H2 and O2 react in a ratio of 2:1
Slices	moles
Mass per slice of bread or ham	Molar mass of compounds
Slice – slice calculations	Mole-mole calculations
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Ham and bread don't react.	
Making a sandwich is easily reversible, whereas chemical reactions are not always reversible.	
In a chemical equation often molecules consisting of more than one atom, are involved.	

7. The soccer analogy for weak and strong acids and bases

Link with Curriculum: Properties of acids and bases (Grade 12, chapter 3, lesson 1, 2010)

Strong acids are often confused with concentrated acids and the link with ionization rate is not always made.

Depending on the class, you may use another ball game such as volleyball.

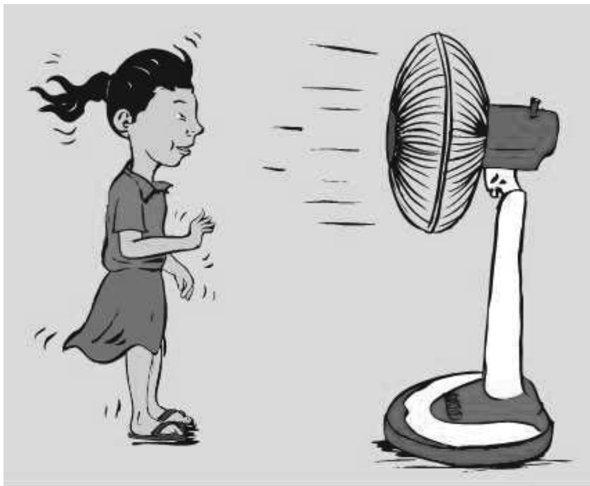
Source: Globalteer.org

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Soccer ball	Proton
Good soccer player (accurate passer)	Strong acid
Poor soccer player (bad passer)	Weak acid
Good receiver of ball	Strong base
Poor receiver of ball	Weak base
Receiving the ball	Accepting a proton
passing the ball	Donating a proton
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Soccer players are very large, whereas acid or base particles are very small.	
A soccer player after passing the ball is not charged, whereas an acid after donating a proton is negatively charged.	
Even fast soccer players move much slower than the acid or base particles	
There are many more acid and base particles than there are soccer players on a field.	

8. The fan analogy for electron clouds

Link with Curriculum: atomic models, electron density (Grade 10, chapter 1, lesson 2, 2008)

Advanced atomic models that use electron density clouds to describe the orbit of electrons around the nucleus are difficult concepts for students. The notion that electrons seem to be at different places at the same time is a counterintuitive concept. The concept can be clarified using an analogy of a fan.



LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Centre of fan	Nucleus
Fan blades	Electrons
Fan rotation	Electrons orbiting the nucleus
Fan blurring	Electron cloud
Tip of fan	Outermost part of electron cloud
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Electrons move faster than blades can rotate	
Electrons are much faster than blades	
Fan can be switched off, but electrons cannot be stopped.	
Blades are fixed to the fan centre, but electrons are not fixed to the nucleus	
In most atoms there are multiple electrons at various distances from the nucleus	
The fan is two-dimensional, whereas the electron clouds are three dimensional	

9. The bookshelf analogy for atomic energy levels in the atom

Link with Curriculum: Atomic energy levels in the atom (Grade 10, chapter 1, lesson 2, 2008)

The concept that electrons can only reside at certain energy levels is difficult to grasp, as well as the fact that electrons need or emit a fixed energy amount when moving between energy levels.
These concepts can be clarified using the analogy of a bookshelf filled with books. Let students make a drawing of the analog, in which they explain the analogy.

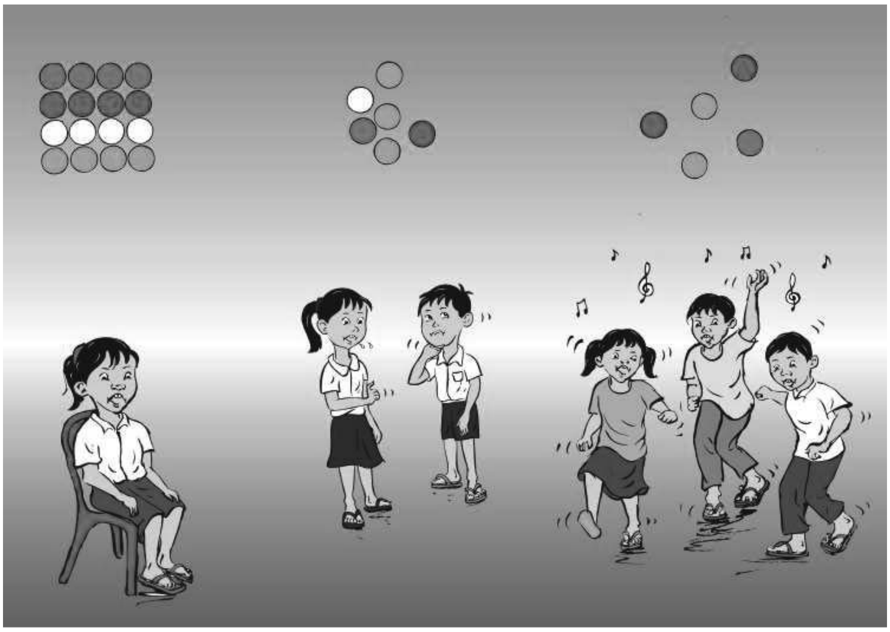
LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Bookshelf	energy levels in an atom
Shelves	Specific energy levels
Books	Electrons
Capacity of shelves	Capacity of electrons in energy level
Lifting the book to higher shelf (requires energy from your body)	Raising electron to higher energy level (requires electromagnetic energy)
Shifting the book from higher to lower level	Electron going from higher to lower energy level.
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
An electron going from a higher to a lower level emits energy, but shifting a book to a lower shelf also costs energy.	
A bookshelf is much larger than an atom and books are much larger than electrons.	
All shelves usually look the same, but not all energy levels have the same shape	
Electrons are moving rapidly, whereas books are stationary	
Books can come in different sizes, whereas all electrons have an identical shape.	

10. The students in school analogy for the kinetic theory

Link with Curriculum: States of Matter (Grade 8, chapter 2, lesson 5, 2009)

An analogy is useful to focus on some aspects of kinetic theory that are susceptible to misconceptions. For example, many students think that there is more empty space between liquid matter particles than between solid matter particles. Also, the low energy of matter in the solid state, compared to matter in the gaseous state is not always clear.

An analogy between energy and student activities is familiar to all students. Each state of matter is related to a classroom practice. First, students are sitting at their desks (solid state), then students during a practical activity in the classroom (liquid state) and finally students running around on the schoolyard during a break (gaseous state). The energy level of each state can be compared to the enthusiasm of the students.



Adapted from: Harrison and Coll, 2008.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Students	Particles of matter
Students sitting at their desk	Matter in solid state (fixed positions)
Students breathing, moving while sitting at desk	Vibrating of atoms around fixed position
Students walking around class during class activity.	Movement of particles in liquid state (similar spacing, higher energy)
Classroom walls	Boundaries of vessel containing liquid
Students running around school during break	Movement of particles in gaseous state (more energy)

School boundaries	Walls of vessel containing gas
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
Particles, especially in the gaseous state, move very rapidly, compared to students.	
All particles look the same, unlike students	
Particles in solids and liquids are much more closely packed than students in a class.	
Particles do not move purposely, whereas students may do.	
In the gaseous state particles move around independently, whereas students may play together in groups.	

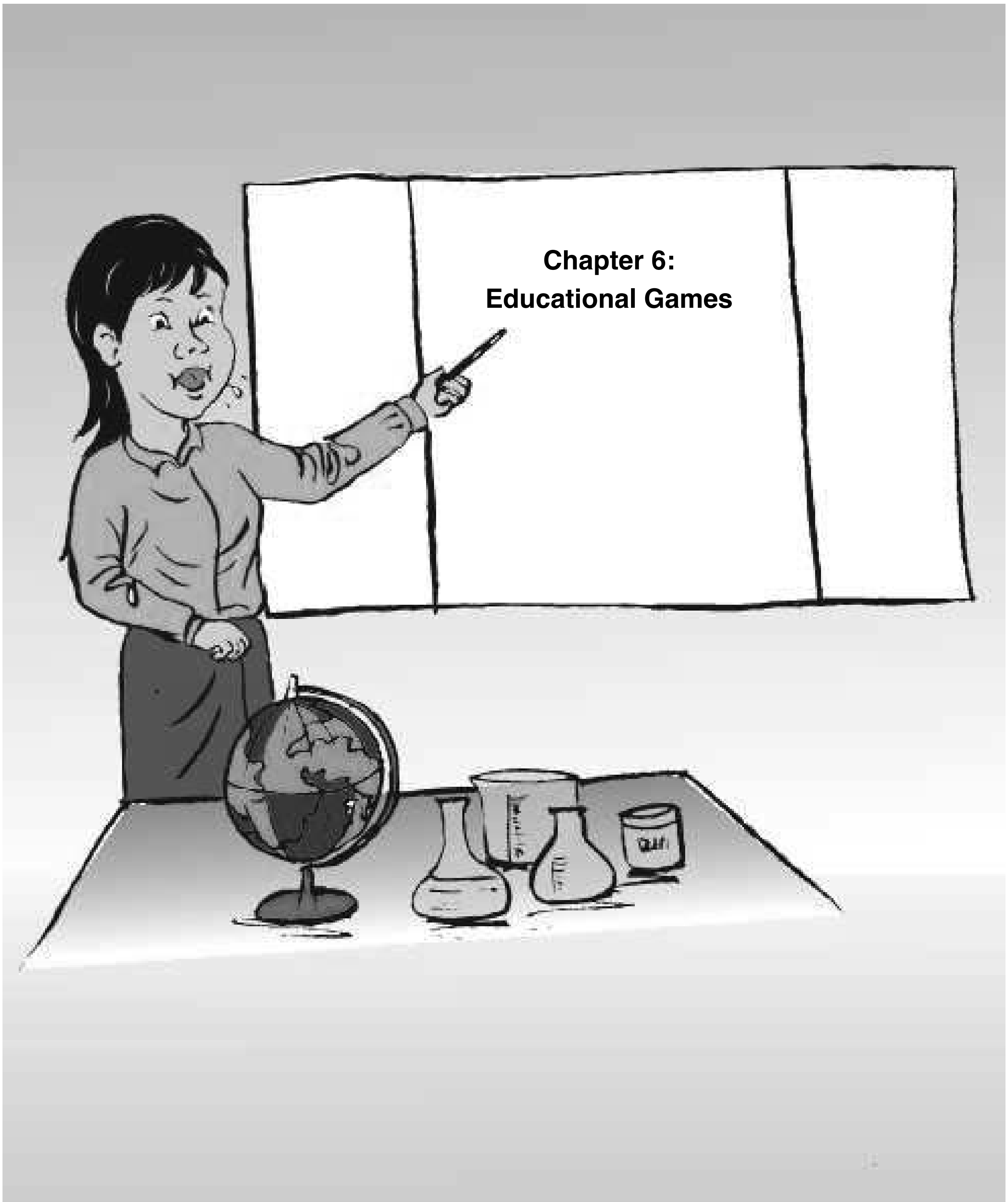
11. The dance party for chemical equilibrium

Link to curriculum: chemical reactions, equilibrium (Grade 12, chapter 4, lesson 1, 2010)

Almost all chemical reactions ultimately reach a state of equilibrium. This means that the rate of forward and reverse reactions is the same and that there are no further changes in the concentration of reactants or products. However, many students find it difficult to visualize the dynamic nature of equilibrium. They assume that reactions stop when equilibrium is reached.

The analog is a dance party for example at a marriage. There is a maximum number of people that can dance simultaneously on the dance floor but people are entering and leaving the dance floor continuously.

LIKES (WHERE THE ANALOG MATCHES THE CONCEPT)	
Dancing people in the hall	Moving and colliding particles
People starting to dance	Formation of a chemical bond (and products)
Number of people in the hall	Effect of concentration on reaction rate
Changing size of the hall	Effect of concentration on reaction rate
Speed of dancing people	Temperature effect on reaction rate
Couples starting and stopping to dance	Simultaneous forward and reverse reactions
Dance hall doors closed	Reaction system closed
UNLIKES (WHERE THE ANALOGY BREAKS DOWN)	
There are much more particles involved in chemical reactions than there are dancers	
The particles move much faster than the dancers	
Particles are much smaller than the dancers	
There are big gaps between gaseous particles compared with the space between dancers	


Chapter 6:
Educational Games

Chapter 6: Educational Games

Introduction

Educational games are a powerful teaching and learning method. Games can be used in the classroom to stimulate inquiry, make students familiar with abstract concepts and expose students to higher-level thinking. Teaching with games enhances motivation by involving students in the lesson.

Games in the classroom can serve several **objectives**:

(a) to review a topic
(b) to develop new relationships among concepts and principles, creating deeper understanding.
(c) to identify gaps or weaknesses in knowledge, skills or attitudes.

Educational games have important **advantages**. They provide opportunities for students to apply what they have learned in a new context. They are interactive and increase student interest and motivation.

Successful educational games have following **characteristics**:

(1) Winning should be based only on the demonstration of knowledge and skills. Games that are based solely on luck or strategy are not suitable.
(2) The game should address important concepts or content.
(3) The rules of the game should fit the age and developmental level of the players.
(4) Students should not lose points for wrong answers.
(5) All players should be able to "win" from time to time.

When introducing games in the classroom, following **tips** are worthwhile:

- Make teams of equal strength;
- When preparing the game, think about how the game design provides you with feedback on student learning.
- Grievances should be dealt with after the game and outside class so as not to distract from the lesson.
- Evaluate the game after the lesson. Did you reach the game's objectives? Were students engaged? Think about how you can improve the game design. You can let students give or write down their comments and suggestions on the game.

There is a **wide range of games**. Some games are adapted versions from popular TV games, while others have their origin in traditional culture. Some types of games are:

- Board games
- Card games
- Quizzes
- Role plays
- Puzzles

In this manual we present some examples of different types of games for science lessons. Each example illustrates a game type that can also be applied in other topics.

A very powerful learning activity is to let students **design their own game**, as a project, for example for a science fair. This requires them not only to understand the topic in-depth, but also to think about how to transfer the knowledge to others and work together in a team.

Role plays are discussed in the module "Analogies & Models".

Activities

1. Memory Game

1. Introduction

Memory is an easy-to-construct game that is ideal for letting students practice their knowledge of scientific vocabulary, formulas, units or concepts. It is best played in small groups.

The game consists of a set of cards, where two cards are identical or related to each other.

2. Objectives

- Students practice their knowledge of key concepts, definitions and formulas
- Students are engaged with the lesson content;
- Students can make and apply a memory game with their students.

3. Link with curriculum

This game can be applied with many topics from all sciences.

4. When to play the game

As a review activity at the end of a lesson or unit of instruction (stage 3, stage 4)

5. Material needed

- You need a set of approx. 20 cards. The more cards, the more difficult the game gets. Two cards always belong together. For example, a keyword and its explanation. Or a concept and its opposite, a symbol and its meaning etc.
- Make sure the back sides are identical, so matching cards cannot be easily recognized.
- You need one set of cards per 4 or 5 people. If you have different sets of cards, groups of students can pass them on when they have finished.
- You may laminate the cards to make them more durable.

6. Procedure

- Give one set of cards to each group of students. The game is best played in groups of 4 or 5 students. The smaller the groups, the more active their involvement, but the more sets you need to make.
- Students mix the cards and place them in front of them, with back sides up. They're not allowed to see which card is where.
- Student take turns in flipping two cards. If the two cards match, the student can take them from the table and put them on a personal stack. If they don't match, he puts the cards back at the same position.
- Students try to collect as many cards as possible.

7. Examples

Chemistry: organic chemistry, structural formulas

This memory game helps students to learn about structural formulas and their names. A set of cards is included in annex.

For **earth and environmental science** you can make a memory game with pictures of the planets and their games. For **biology** the different organelles of the cell are a good topic. For **physics** you can make a set with terms and their units (voltage, current, resistance…)

8. **Variation**

You can let students develop their own memory game. Next, groups exchange their set of cards and play the game.

2. Science quizzes: science jeopardy

1. Introduction

Jeopardy provides an active way to revise a chapter or unit before a test or an exam. In jeopardy, students play in teams to answer gradually more difficult questions on a series of topics.

2. Objectives

- To review a chapter in an active way
- To assess students' understanding of the topic
- To stimulate team work.

3. Link with curriculum

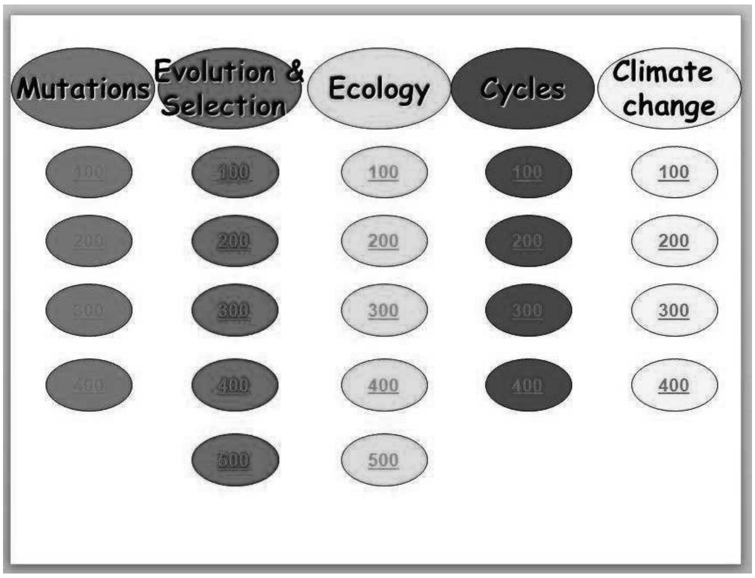
This game can be applied with many topics from all sciences.

4. When to play the game

As a review activity at the end of a lesson or unit of instruction (stage 3, stage 4)

5. Material needed

- Prepare the jeopardy board on a flipchart, with colours as in the figure below.
- You can make a reusable game template on which you stick cards with the names of the topics. Next time you play the game, you only need to change these cards.
- Prepare a list of questions per category on a sheet of paper, so you can quickly read the selected question aloud.



6. Procedure

1. Divide the class in three of four teams and assign a team captain for each team.
2. The first team starts by selecting a category.
3. Read the question aloud. If none of the team members knows the correct answer (or if the majority votes for the wrong answer) the next group can answer. The team that answers correctly gets a point. The team captain of this team selects a next topic.
4. The first question of a topic is worth 100 points. The next question 200, and so on. The first question has to be answered correctly before a team can choose the second question.
5. The jeopardy ends when all answers have been answered. The team with the most points is the winner.

7. Examples

- Jeopardy biology (biological cycles, ecology, population growth)
- Jeopardy earth science (Earth's atmosphere, Moon, planets, stars)
- Jeopardy chemistry (acids & bases, salts, oxygen, hydrogen)

3. Science quizzes: Last Man Standing

1. Introduction

Last Man Standing (from which the successful "Who Wants to be a Millionaire" is derived) is an interactive quiz that you can easily use to review a topic. All students participate in the game, but those who answer a question wrong, drop out the game. The student(s) still standing after the last question wins the game.

2. Objectives

- To review an instruction unit in an active way
- To increase understanding about an instruction unit
- Students learn how to use 'Last Man Standing' in their lessons

3. Link with curriculum

This game can be applied with many topics from all sciences.

4. When to play the game

As a review activity at the end of a lesson or unit of instruction (stage 3, stage 4)

5. Material needed

- A list of around 10 multiple-choice questions, in order of increasing difficulty.
- Voting cards (see Concept Tests) or Traffic Light Cards (See Teaching the Scientific Method) for the students
- A projector to project the questions (optional)
- A “price” for the winner

6. Procedure

- Have all students stand up.
- Read the first question and, after a short amount of thinking time, let students vote their answer.
- Tell the correct answer. Students with the wrong answer have to sit down.
- Continue with the second question, repeat the process.
- Remember which questions result in a lot of wrong answers in order to explain in more detail after the quiz.
- The quiz ends after the last question or when only one student is left standing.
- You may create a price or “award” for the winning student
- During the game, take a note of the questions that many students answer wrong. After the game you can explain these questions in more detail.

7. Examples

Example biology: the respiratory system.

Example physics/ chemistry: energy

Example earth science: the universe

Example chemistry: the periodic table of elements

4. Earth Science: Rock Cycle Game (earth and environmental science)

1. Introduction

The rock cycle game is an interactive game that teaches students about the different stages in the rock cycle, how rocks “travel” between stages and about the relation between the rock type and the physical environment. In the rock cycle game, students play the role of a stone and simulate its journey between places and through geological processes.

2. Objectives

- To teach students that rocks cycle indefinitely through the Earth system
- To teach students that the cycle is complex and nonlinear.
- To improve students’ insight in the relation between rock type and the physical environment.
- To generate student interest in rock types and geological processes.

3. Link with curriculum

Grade 8, chapter 2, lessons 3 and 4

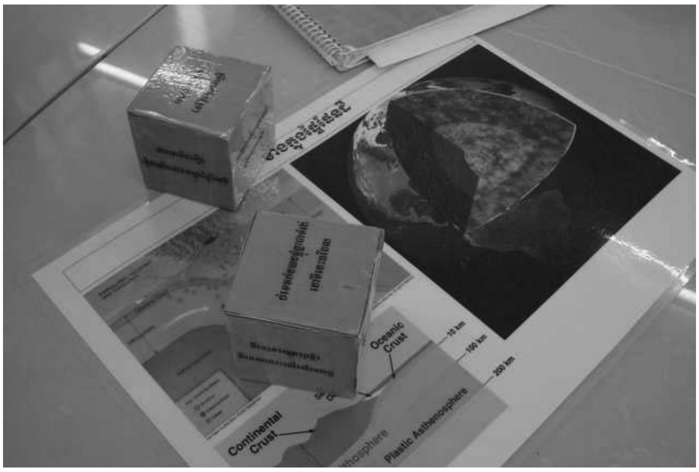
4. When to use this technique?

During step 3 of the lesson.

5. Material needed

- ***Station cards***: print the cards in annex. Laminate them to make them more durable.
- ***Worksheet***: make a copy of the worksheet in annex for every student or let them copy the worksheet in their notebooks.
- ***Dice***: Cut out the dice for the stations and fold them into dice. You may also stick them on wooden cubes.

- An alternative for dice is to use ordinary dice and provide dice codes on a sheet of paper for each station that explain what each number means. See the nitrogen cycle game material for an example.



6. Procedure

Part I: Preparing the game

Set up your classroom with 7 areas or **stations**. These represent places where a change in the rock cycle occurs. Place a station card and two dice at each area. Divide the students over the stations.

Part II: Playing the game

Each student starts at one area in the rock cycle. Every student takes turns to throw the die at the station card to determine the geological process that occurs to them. Depending on the outcome they go to another station or stay at the same station. A student may remain at the same station for several turns. For every throw of the die, they record what happens on their worksheet.

During the activity the teacher walks around to guide students in their journey through the rock cycle.

Part III: Making the rock cycle scheme

When they have completed all lines in their worksheet, their journey is finished.

Afterwards, students process their journey by creating a scheme of the rock cycle on which they indicate how their journey fitted into the rock cycle scheme. For each station they also write down what type of rock they are. Students could even be given a particular starting type of rock, such as clay, sandstone or limestone. With arrows they indicate their journey through the rock cycle. This can be done in small groups as students can help each other.

Part IV: Class Discussion

The teacher discusses the activity with following questions:

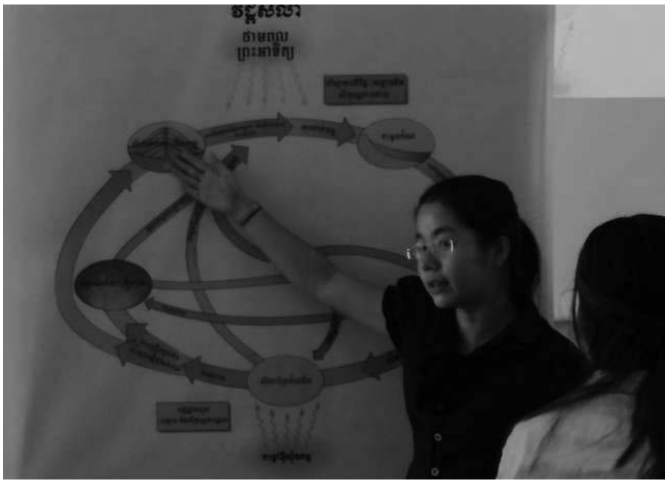
- Did you go through the whole rock cycle or only part of it?
- As what type of rock did you spend the most stages?
- Do you think your journey also occurs in reality?
- How much time do you think the complete journey would take in reality?

7. Variation

Usually the activity is done individually, but you can let students play in pairs as well. Then, one student throws the dice and the other records the results.

8. Important Tips

Students should be familiar with the rock cycle before the activity. If necessary, organize a short lecture before the game.



5. Water Cycle Game (Biology and Earth and Environmental Science)

1. Introduction

Water is constantly in motion. Sometimes quickly, as in a fast-moving river, and sometimes slowly, like in underground aquifers. Understanding the water cycle is important for understanding ecosystems and how contaminants and pesticides are transported. Introduce the topic by asking where they think the water they drank today came from.

2. Objectives

- Students learn about the complex movement of water through the water cycle.
- Students can identify the state of water and changes in state as it moves though the water cycle.
- Students understand the central role of water in our environment.

3. Link with curriculum

Grade 8, chapter 6, Lesson 14

4. When to use this technique?

You can play this game during instruction on the water cycle (stage 3) or as a review activity.

5. Material needed

- Station cards: print the cards in annex. Laminate them to make them more durable.
- Worksheet: make a copy of the worksheet in annex for every student or let them copy the worksheet in their notebooks. You may develop your own worksheet.
- 9 dice (one per station card)
- A card that explains what each number means for that station. See the nitrogen cycle material for an example.

6. Procedure

Part I: Before the game: class discussion

- Explain the students that they will play the role of <u>tiny water molecules</u> in the water cycle.
- Introduce the game with a few discussion questions:
  - Where can water be found on Earth? Compare the result of their brainstorming with the 9 stations of the game.
  - Select a few places (stations) and let students write down where they think water can go from there. Compare their notes with the instructions from the dice code card.
- Assign approx. an equal number of students to each station. Explain that this station is their starting position.

Part II: Playing the game

- Students roll the die and perform the action that corresponds with the number. They write down in their worksheet where they are going and what happens to them.
- After about 10 turns, end the game and put students in groups of 4.
- Let the members compare their journey. Do they find differences? Where in their journey do phase changes occur?

Part III: Group and class discussion after the game

- Have students identify the various stages of the water cycle and the states in which water may be found.
- You can let students write an essay about their journey. How and why is it different from other students' journeys?

7. Variant: include the concept of 'contamination'

With a few extra elements you can teach students about contaminants and how they spread through the water cycle. What you need are approx. 50 small blocks or units (small stones, paperclips, tooth picks) and 9 small containers or boxes. The blocks represent amounts of pollution.

Place a container at every station. Put an equal number of units in each container except for Animals and Plants (where you put no units). Play the game, but at every station the players collect or remove units according to the table below.

Student moves		***Action***
From	***to***	
Clouds	All	Collect 1 as airborne contaminants are absorbed
Animal	Soil	Collect 2 for wastes
Animal	Clouds	Remove all as water is purified as it is respired
Soil	plants	Remove 1 as some plants absorb pollutants
Soil	River	Collect 2 as run-off collects pollutants
Soil	Groundwater	Remove 1 as soil filters some pollutants
Soil	Clouds	Remove all as water is purified as it evaporates
Plants	Animals	Collect 1 as contaminants are ingested
Plants	Clouds	Remove all as water is purified as it transpires
Ocean	Clouds	Remove all as water is purified as it transpires
Lake	Clouds	Remove all as water is purified as it transpires
Lake	Groundwater	Remove 1 as soil filters some pollutants
Lake	Animal	Collect 1 as pollutants are ingested
Lake	River	Remove 1 as water moves downstream
Glacier	Groundwater	Remove 1 as soil filters some pollutants
Glacier	River	Collect 1 as runoff collects pollutants
Glacier	Clouds	Remove 1 as water is purified as it sublimates
Groundwater	Lake/ river	Remove 1 as soil filters some pollutants
River	Groundwater	Remove 1 as soil filters some pollutants
River	Lake/ ocean	Collect 1 as water moves downstream
River	Clouds	Remove all as water is purified as it evaporates
River	Animal	Collect 1 as contaminants are ingested

Compare for each station the amount of pollution units before and after the game. Discuss how pollutants are transported through the water cycle.

8. Explanation

In the textbooks the water cycle is often shown as a simple, circular diagram. This depiction oversimplifies the actual movement of the water. The actual path of a water molecule within the cycle can be quite complex and varied. The cycle doesn't say anything about how long water molecules stay at a place in the water cycle. For example, it may take hundreds of years for a water molecule at the bottom of the ocean to resurface and evaporate.

Water also changes states along its path. Water in its liquid form is the most visible, but an important part of the water cycle the water is in gas or solid state. Fog and clouds give some indication of the water present in the atmosphere. 90% of the water supply is in the oceans. Ice caps and glaciers take up only 1.7% of the total water supply, but they contain 70% of the total amount of fresh water.

Living organisms also move water about. Water, either directly consumed as liquid or extracted from food, is carried within bodies. Plants are important in the water cycle. Roots collect water, of which most travels to the leaves and evaporates back into the atmosphere.

9. Important Tips

Discuss the game afterwards with your students. Did they increase their understanding about the water cycle? Would they change the game when playing with their students?

6. Loop games

1. Introduction

A loop game is an interactive review game that can be played in various ways.

2. Objectives

- To increase students' understanding on a topic or unit of instruction by presenting it in a different context.
- To make students familiar with the idea of 'loop games'.

3. Link with curriculum

A loop game can be played with many topics in all science subjects.

4. When to use this technique?

- As a review activity during stage 4 of the lesson

5. Material needed

- Prepare as many cards as there are students. Laminate cards to make them more durable.

6. Procedure

- Each student receives one card. Each card contains a question and an answer (on a different question).
- One student starts reading his question aloud. The student who thinks the answer on this question is on his card stands up and reads the answer. If it's correct, the student goes on to read the question on his card. The student who has the correct answer stands up to read the answer and so until all questions and answers have been read.
- If there is time left, you can play the game a second time. Encourage students to beat the time from the first round.

7. Examples

See annex for a set of cards for **chemistry** (atoms). The questions are a starting point. You can change the questions according to the level of the students and the content of the lesson.

For **biology** you may develop a game on the respiratory system. For **earth science**, the solar system is a good topic for a loop game.

8. Important tips

The game can also be played in small groups. The annex contains a set of cards in the correct order. Mix the cards and distribute them to the students. They have to group questions with their correct answers and create a frame. In the meantime you can walk around and quickly see if the puzzle is correct.

7. Domino games

1. Introduction

A domino game challenges students to place a set of domino cards in the right order, based on questions and answers or corresponding words. Played in small groups, it generates discussion and forms an active review activity. Groups can compete with each other.

2. Objectives

- To review keywords and concepts from an unit of instruction
- To challenge students to think and discuss about the content
- To provide feedback to the teacher whether the unit is well understood

3. Link to curriculum

This game can be played with many topics in all science subjects.

4. When to use this technique?

- During or at the end of instruction on a topic (stage 3 or stage 4)

5. Material needed

- ***Domino cards*** can be made from a white sheet of paper or a piece of thin cardboard. Laminated cards can be reused many times. You need one set of domino cards per group of students.

6. Procedure

- Give each group of students (4 to 5 students) a set of domino cards.
- Instruct students to work together to match domino cards together.
- You can organize a competition in which students try to complete the domino as soon as possible. For every mistake they lose a number of seconds.

7. Examples

In the annex we have included an example for each topic:

- Biology: genetics
- Earth science: space
- Chemistry: symbols
- Physics: general

You can make and play domino games for many other topics.

8. Important Tips

The more domino cards the more difficult to solve the game and the longer it will take the students. An average set contains around 20 cards.

You may let students try to develop their own domino game in groups. Then, groups play each other's game.

8. Chemistry: Element Bingo

1. Introduction

Elements Bingo is a game for learning about the Periodic Table of Elements. Students play just like a normal Bingo Game, except all items and cards have a chemistry element topic. This kind of game is expected to stimulate students enjoy and enthusiasm while they actively participate.

2. Objectives

This game is designed to help students learn how to become acquainted with the elements in the periodic table and determine element symbols and names.

3. Link with curriculum

Grade 8, chapter 1, lesson 2

4. When to use this technique?

As a learning and review activity (step 3 and step 4)

5. Material needed

- Create as many bingo cards as there are students (The annex contains 30 cards, but you can easily make more)

- Prepare a list of elements in the order that you will call them out. You can use the list to check whether a student's bingo is correct. You need as many lists as you plan to play the game.

6. Procedure

- Give each student a game card (see annex). This will be their "answer key.
- Students place the bingo cards in front of them. Then teacher calls out elements, students place a coloured marker on the appropriate square. The first person to get five in a row vertical, horizontal or diagonal is the winner.

7. Examples

The game is designed for the topic on the periodic system of elements (chemistry), but you may use the bingo format in other topics as well. For example, for **biology** you could develop a bingo game on parts of the human body.

8. Important Tips

This game can be played by individual students, pairs or teams. The best option is to play individually as to promote each student's in-depth understanding of element and self-regulated study of element symbols and names.

Instead of calling out the elements yourself, you can ask a student to call out the elements one by one from the list.

9. Taboo Game

1. Introduction

This game helps students to remember and understand key terms of a lesson. They learn to formulate the meaning of a term in their own words. Other students listen and try to guess the key term. It encourages students' **critical thinking skills**. Students are supposed to guess the words at the top of the card without saying any of the words that are below the line because those words are **"taboo"**.

2. Objectives

- to review and improve understanding of key terms
- to stimulate thinking skills

3. Link with curriculum

Taboo game can be applied with many topics in all science subjects.

4. When to use this technique

In stage 4 of the lesson, as a review activity.

5. Material needed

- Small index cards
- Colourful markers, crayons and/or coloured pencils (optional)

6. Procedure

- Divide the class into a few teams and explain the rules.
- Assign one student to watch over the student in front of the class. His/ her task is to check if a student uses one of the "taboo" words.
- Assign a student to play the first taboo game. He or she picks a card with a key term written on it.
- The student will try to get the class to guess the key term as soon as possible. If the student says one of the taboo words he/she needs to return to the seat and another student takes his/ her place.
- For each word that is guessed correctly you can give 1 point to the team that guessed the world.

Game rules:

- No form or part of any word printed on the card may be given as a clue.
- No gestures can be made.
- Descriptions like "sounds like" or "rhymes with" are not allowed.
- No initials or abbreviations can be given if the words they represent are included on the card.

7. Examples

Biology: Inheritance

Explain the term…	***Without using the words…***
Genes	- Nucleus - Chromosomes
Chromosomes	- Cell - Nucleus - Genes
Selective breeding	- Choosing - characteristics
Cloning	- Identical - Asexual - Parent

Biology: Structure of the Cell

Explain the term…	***Without using the words…***
Cell wall	• Plants • Structure • shape
Cell membrane	• Plants • Animal • control
Cell nucleus	• Control • Chromosomes • DNA

Earth and environmental science

Telescope	• Stars • Observatory • Astronomer • Planet

Physics

Convection	• Heat • Rise • Cold • Dense • Sink

- Stars
- Observatory
- Astronomer
- Planet

8. Important tips

You can also play the game in small groups. For groups of 2 – 4 students, they can take turns giving clues. The person with the correct answer keeps the card. Then the next player tries to describe the term.

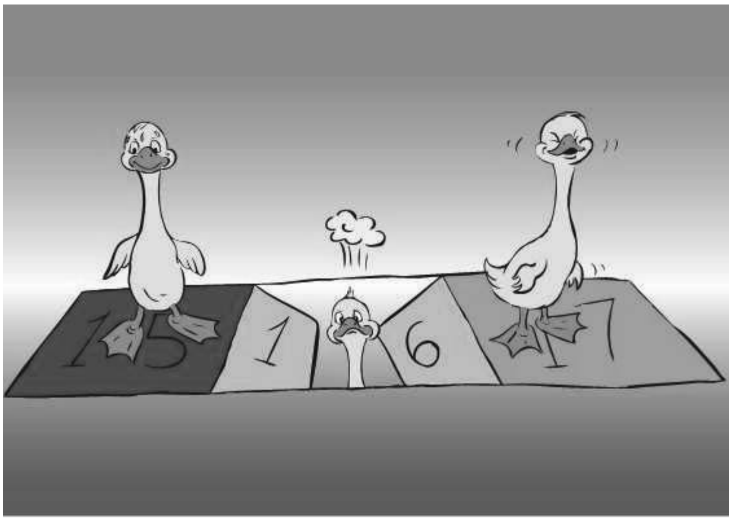
The game is easily scalable, depending on the available time. If you have only 5 minutes left, you play two rounds, whereas more time available enables to play more rounds.

Let students make their own taboo cards. Give them empty cards like the one below. Using pencil and (if available) colours they make their cards.

10. Game of the Goose

1. Introduction

Game of the Goose is a board game, where teams of players try to cross the board as quickly as possible. They do this by throwing the dice and answering questions. Some of the spots require special actions of the players, such as solving a calculating question or moving an opponent's pawn. The game takes at least one hour, depending on the number of teams and the difficulty level of the questions. However, it's an excellent revision activity.



2. Objectives

- Students increase their understanding of science topics
- Students recognize the use of educational games in science lessons
- Students can integrate an educational game in their science lessons

3. Link with curriculum

The game can be used for all kinds of topics. Since it takes up a lot of time, it's mostly suitable as a revision activity. The game can cover multiple topics, such as all the content of the semester or year.

4. When to use this technique

The game usually takes a full hour to play. It is best used as a review activity at the end of a unit of instruction.

5. Material needed

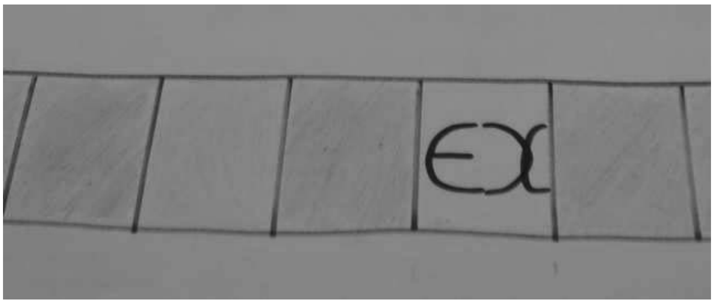
- Game board
- Dice
- Questions (on sheet of paper)
- Whiteboard
- Markers

If available, it is useful to attach the game board to a magnetic plate. The pawns of each group are magnets that can move but stick on the board.

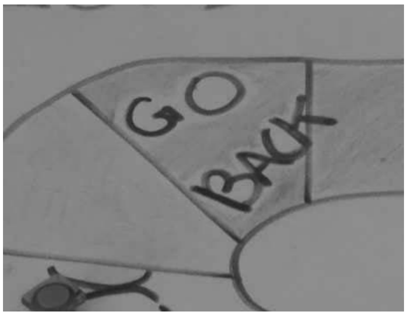
6. Procedure

Description of the game board

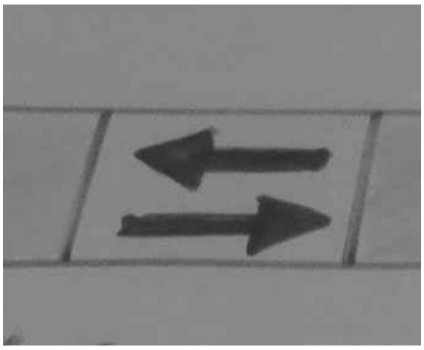
- There are 5 colours of numbers. Each colour corresponds with a topic. In the prototype, green means a question on mechanics, yellow a question on light, red a question on heat, brown on electricity and magnetism and orange on pressure.



- The game board counts some 'special' fields. When players reach these fields they need to do 1 exercise. When they have completed the exercise, they ask for a teacher to verify the answer. This numbers counts as a 'skip one turn' number, but if the students are fast they can prevent having to skip one turn. It could also result in having to skip 2 turns, this is the maximum.
- You may include other 'special' fields, allowing for example players to move 5 spaces ahead or making them go back 5 spaces.

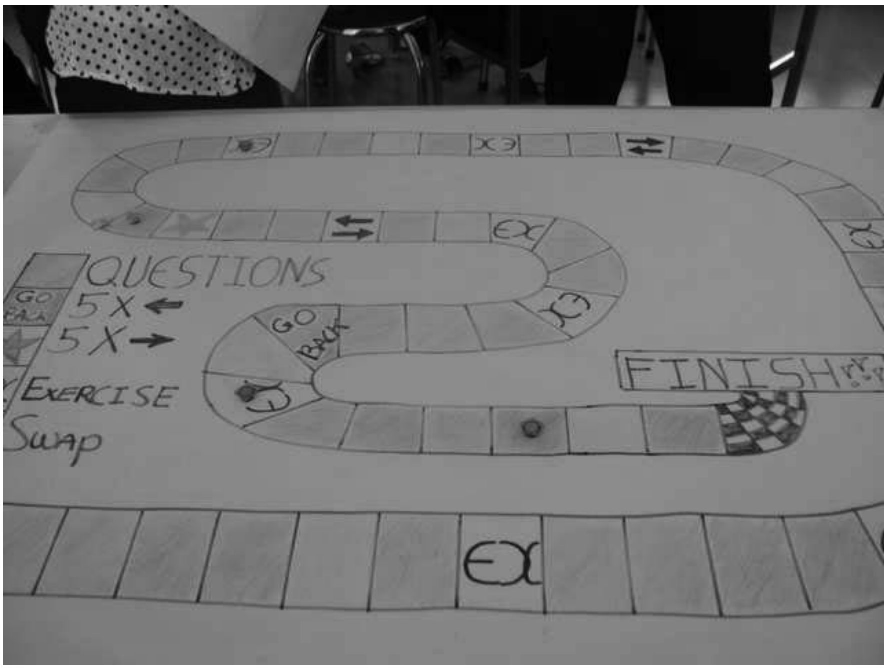


- In the prototype, we included a 'Swap' field (shown below). If a team stops on this field, it can swap position with another team (usually the team at first position). This introduces an element of luck in the game.



Game rules

- Divide the class in teams of maximum 4 students. You can choose the amount of groups, but it is recommended to have no more than 5 of 6 groups. Each group has one dice to roll.
- You may appoint one 'assistant' during the game, who helps moving the game pieces.
- The game board hangs in front of the classroom so all the players can view it clearly. Each group rolls the dice, who throws the highest amount starts the game with the number of eyes played.
- Read the question about the topic that corresponds with the question that the team hit. Allow a short amount of time for discussion and giving the answer. Only members of the team whose turn it is are allowed to answer. You may assign one person per team as the spokesperson.
- A right answer lets the team stay on the number, a wrong answer results in the team moving back 2 numbers.
- The first team that reaches the finish wins the game.



Questions

You can use different kinds of questions. You can let students make a drawing on the board, use true/false-questions, multiple choice questions or short exercises.

7. Examples

The annex includes examples of questions for a **physics** game. For **biology** you can play a game, where the colours represent the different parts of the human body.

For **earth and environmental science** you can play the game to revise what students have learned about astronomy, for example:

Red = question about planets of solar system
Yellow = question about Sun
Blue = question about Earth
Grey = question about Moon
Green = question about Universe

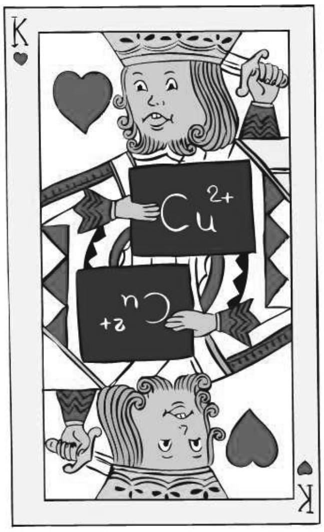
8. Important tips

Evaluate the game with the students after playing it. What would they change in order to improve the game? Did they find it a good revision activity? And did they learn something? Organize a short class discussion.

11. Chemistry Poker

1. Introduction

This game, based on the popular card game, helps students to construct chemical formulas.



2. Objectives

- to review and improve understanding of chemical formulas
- to stimulate collaborative learning
- to increase students' interest in chemical formulas

3. Link with curriculum

Grade 8, chapter 2, lesson 2

4. When to use this technique

You can play the game in stage 3 of the lesson to deepen students' understanding, or in stage 4 of the lesson, as a review activity.

5. Material needed

You need to make:

- As many sets of cards as you have groups in the class. Laminate cards to make them more durable.
- One scorecard per group. You can also draw the scorecard on the whiteboard and ask each group to copy it.

- Make playing cards with the following information:

    - At least one card with the ions, listed below (47 cards)
    - One blank or free card
    - 15 cards, five with each of the following subscripts (1, 2, 3)

Ba^{+2}	Be^{+2}	Cu^{+2}	Sr^{+2}
Na^{+1}	Mg^{+2}	Cu^{+3}	Sc^{+3}
Ca^{+2}	Ag^{+1}	Fe^{+2}	Al^{+3}
Li^{+1}	K^{+1}	H^{+1}	Hg^{+2}
Pb^{+2}	V^{+3}	Fe^{+3}	Sn^{+1}
Zn^{+2}	Ni^{+3}		Rb^{+1}

$NO3^{-1}$	$HCO3^{-1}$	$CrO4^{-1}$	S^{-2}
$NO2^{-1}$	$PO4^{-3}$	Cl^{-1}	O^{-2}
$SO4^{-2}$	$HPO4^{-2}$	$AsO4^{-2}$	F^{-1}
$SO3^{-2}$	$NH4^{+1}$	$C2H3O2^{-1}$	N^{-3}
$HSO4^{-1}$	OH^{-1}	$H2PO4^{-1}$	Br^{-1}
$CO3^{-2}$	$ClO4^{-1}$	I^{-1}	P^{-3}

6. Procedure

- This game is played as a 5-card draw. The dealer will pass out 5 cards to each player from the shuffled deck, placing all remaining cards in a central stack.
- Each player may discard as many as 3 cards in one rotation—taking as many cards from the central stack as s/he discards. Play begins with the player to the right of the dealer.
- Players try to make a chemical formula that uses as many of their cards as possible. If they cannot play, they must pass. It is possible to make two chemical formulas in one play.
- Once a player uses a number of cards to make a formula, that player should draw, from the central stack, as many cards as s/he used. Play then passes to the player on the right.
- Total the score by the number of cards that a player can use to make a chemical formula. It is possible for a player to score as many as 5 points per hand. Each player has her/his own score sheet or you can assign one player to keep the scores.
- Play continues until no more formulas can be made.

(SAMPLE) Score Card						TOTAL
1	Mg^{2+}	NO_3^{-1}	2	-----	-----	3
2	Sc^{3+}	ClO_4^{-1}	3	-----	-----	3
3	NH_4^{+1}	3	N^{-3}	1	-----	4
4	V^{+3}	2	S^{-2}	3	-----	4
5	Na^{+1}	Cl^{-1}	Ca^{+2}	NO_3^{-1}	2	5
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
Total						19

Example of a score card

7. Examples

The game is designed to help students use chemical formulas. It is not directly applicable for other topics.

8. Important Tips

You may change the ions on the playing cards, according with the chemical formulas you want students to learn.

After playing the game, you may discuss the game with your students. Let them think about how to improve the game.

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