Continuous Professional Development Certificate in Educational Mentoring and Coaching for STEM Teachers (CPD-CEMCMT)

Student Manual

Module 2

5th Edition

TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE AND GENDER IN STEM EDUCATION

March 2022

Module code: PDM1142

UNIVERSITY of RWANDA

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MODULE 2

TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE AND GENDER IN STEM EDUCATION (PDM1142)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AAAS	American Association for the Advancement of Science
BSCS	Biological Sciences Curriculum Study
CBC	Competence Based Curriculum
CPD	Continuous Professional Development
CoP	Community of Practice
DDE	District Director of Education
DHT	Deputy Head Teacher
HoD	Head of Department
HT	Head Teacher
IBL	Inquiry-based Learning
ICT	Information and communications technology
LCP	Learner-centred Pedagogy
NSF	National Science Foundation
NQT	Newly Qualified Teacher
NT	New Teacher
OER	Open Educational Resources
PCK	Pedagogical Content Knowledge
PP	Policy Priority
REB	Rwanda Education Board
SBI	School Based In-service
SBM	School Based Mentor
SEI	Sector Education Inspector
SSL	School Subject Leader
STEM	Science, Technology, Engineering, Mathematics
TDMP	Teacher Development and Management Policy
TPACK	Technological, Pedagogical and Content Knowledge
TTC	Teacher Training College
UR-CE	University of Rwanda – College of Education

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INTRODUCTION

This CPD Certificate Programme on Educational Mentoring and Coaching is designed for STEM SSLs and consists of two modules.

The first module focuses on coaching, mentoring and communities of practice (CoPs). In a context of shared leadership within a school, School Subject Leaders (SSLs) have an important role to play to coach and mentor their peers, particularly new teachers. They need to take up leadership roles in their schools, like organizing continuous professional development (CPD), facilitating induction and conducting lesson observations. To take up this role successfully, the first module of the programme equips participants with the skills to successfully coach, mentor and lead CoPs in their schools.

However, being a leader in STEM requires also that SSLs have a sound understanding of what makes a good STEM lesson. They need to be able to apply a variety of learner-centred methods in a suitable way that promotes learning, use creativity to identify teaching resources, integrate technology and conduct assessment. Moreover, they need to support their colleagues in improving the quality of their science and mathematics lessons. In the second module, we introduce a variety of techniques and methods that STEM teachers can use to make their lessons more learner-centred, inquiry-based and competence-based.

Although there are many examples from mathematics, physics, biology and chemistry in this programme, it is important to stress that this is not a programme in science content knowledge. A strong understanding of the curriculum content is a basic and crucial condition for a teacher. We refer to the many textbooks and online resources that can be used to improve content knowledge.

MODULE LEARNING OUTCOMES

By the end of the module participants should be able to:

1. Explain the principles of the Competence Based Curriculum for STEM subjects;
2. Understand the concepts of Technological, Pedagogical and Content Knowledge (TPACK), inquiry-based learning, scientific literacy and learner-centred pedagogy;
3. Demonstrate understanding of the 5 E's instructional model for STEM teaching;
4. Understand how students learn STEM subjects;
5. Apply a variety of techniques and approaches to develop learners' competences in STEM;
6. Use a variety of experiments, practical work and simulations to improve the quality of teaching and learning;
7. Organize effective professional development activities for STEM teachers, including providing effective feedback to peers;
8. Recognize gender stereotypes associated to the teaching of STEM subjects;
9. Select and develop appropriate and inclusive teaching and learning materials and methods for teaching and learning STEM subjects;
10. Integrating daily life in the teaching and learning of STEM subjects;
11. Use appropriate strategies to make STEM subjects enjoyable and interesting for girls and boys;
12. Develop an action plan for improving teaching and learning STEM subjects in their school;
13. Reflect on one's professional practice for continuous improvement;
14. Believe that all learners can achieve reasonable levels of mathematical and scientific proficiency;
15. Deepen your appreciation for science and mathematics;
16. Appreciate collaboration, teamwork and distributive leadership within the school;

UNIT 1: ANALYSIS OF SCIENCE AND MATHS COMPETENCE-BASED CURRICULUM

Introduction

In 2016, REB started the implementation of a competence based curriculum (CBC) in pre/primary and secondary education (REB, 2015). The CBC ensures that there is consistency and coherence in the delivery of education across all levels of general education in Rwandan schools. A competence is the ability to use an appropriate combination of knowledge, skills, attitudes and values to accomplish a task successfully. In other words, it is the ability to apply learning with confidence in a wide range of situations (REB, 2015). Within the CBC framework, teaching and learning are based on competences rather than focusing only on knowledge.

Within the CBC framework, teaching and learning are based on competences rather than focusing only on knowledge.

Learners work on one competence at a time in the form of concrete units with specific learning outcomes. The student is evaluated against these standards. Learning activities should be learner-centred, balancing individual and social learning. Therefore, mathematics and science teachers need to have the resources and skills that enable them to respond to curriculum requirements in the classroom. REB (2015) states that mathematics and science equip learners with the competences to enable them to succeed in an era of rapid technological change and socio-economic development. Mastery of basic mathematical and scientific ideas and operations (scientific literacy, numeracy) should make learners confident in problem-solving in life situations. A high-quality mathematics and science education therefore provides a foundation for understanding the world, the ability to reason mathematically and scientifically, an appreciation of the beauty and power of mathematics and science, and a sense of enjoyment and curiosity about the world.

Learning Outcomes

By the end of this unit, you should be able to:

- Explain the structure of the competence-based curriculum of secondary mathematics and science education;
- Explain the use of different components of the competence-based curriculum of secondary mathematics and science education;
- Continuously reflect on teaching approaches in line with the competence-based syllabus for STEM subjects;
- Plan learning activities that enhance learners' competences and move beyond transferring knowledge;
- Enjoy lifelong learning;
- Value the importance of collaboration, teamwork and joined leadership in the school;

Section 1: Competences in the Curriculum

> ***Activity 1***
> Reflect on your lesson planning and answer the following questions in your notebook:
> When planning your science/ mathematics lessons, what competences do you focus much on? Why do you choose them?

The CBC distinguishes between two categories of competences: basic competences and generic competences. Basic competences are key competences that were identified basing on expectations reflected in national policy documents. These competences are built into the learner's profile in each level of education and for all subjects and learning areas. Basic competences have been identified with specific relevance to Rwanda. These are literacy, numeracy, ICT, citizenship and national identity, entrepreneurship and business development, science and technology, and communication in the official languages.

Generic competences are competences which are transferable and applicable to a range of subjects and situations (REB, 2015). They promote the development of higher order thinking skills. In doing so they strengthen subject learning, but they are also valuable in themselves. They are generic competences because they apply across subjects. Generic competences in the CBC include:

- critical thinking
- creativity and innovation
- research and problem solving
- communication
- cooperation, interpersonal relations and life skills
- lifelong learning

The CBC also identifies a set of basic values, curriculum values (Figure 1) and crosscutting issues (Figure 2).

Basic Values (National)	Curriculum Values
• Dignity and integrity • Self-reliance • National and cultural identity • Peace and tolerance • Justice • Respect for others and for human rights • Solidarity and democracy • Patriotism • Hard work, commitment and resilience	• Excellence, aspiration and optimism • Equity and inclusiveness • Learner-centredness • Openness and transparency • The importance of family • Rwandan culture and heritage

Figure 1: Basic values and curriculum values in the CBC (REB, 2016)

Cross-Cutting Issue	Subjects
Comprehensive Sexuality Education	SET, Social Studies, History and Citizenship, Biology, General Studies, English, French, Kinyarwanda, Kiswahili, RE, ICT, Music, PE.
Environment and Sustainability	SET, Social Studies, Geography, Biology, General Studies, Agriculture, Home Science, English, French, Kinyarwanda, Kiswahili, Entrepreneurship, Art and Craft, Economics, ICT, Music, PE, Physics, Chemistry.
Financial Education	Mathematics, Economics, Entrepreneurship, General Studies, Social studies, ICT, Pre- primary.
Genocide Studies	Social Studies, History and Citizenship, General Studies, RE, ICT, Music.
Gender	Social Studies, History and Citizenship, General Studies, English, French, Kinyarwanda, Kiswahili, Entrepreneurship, Economics, Literature in English, ICT, Music, PE, Physics.
Inclusive Education	All subjects
Peace and Values Education	All subjects
Standardisation Culture	All subjects

Figure 2: Crosscutting issues in the CBC (REB, 2016)

To guide teachers in sequencing teaching and learning activities, competences have been elaborated at every level of the curriculum from the learner profile down to the Key Unit Competences. The **learner profiles** describe the general learning outcomes expected at the end of each phase of education. Teachers are responsible to design lesson plans with instructional objectives linked to the **Key Unit Competences** and leading to all competences above.

The key unit competence is the most important element to pay attention to while designing a lesson plan as it determines the instructional objective(s) of each lesson within the unit.

Figure 3 shows the links between the various competences in the CBC.

- **Broad Competences** are formulated for the end of each learning cycle (at the end of Pre-Primary, Primary 6, Secondary 3, and Secondary 6). National Exams assess the achievement of these broad competences according to National Assessment Standards.

- **Key competences** are formulated for the end of each grade. Districts and schools design assessment strategies to ensure learners have achieved the necessary competences and qualify for advancement or need further remediation to meet National Assessment Standards.

- **Key unit competences** are formulated throughout each subject syllabus. Syllabi are divided into units of study to organize learning and encourage teachers to focus on specific content related to learners' daily life and cross cutting issues. Each unit aims to develop some competences which are evaluated through end unit assessment according to National Assessment Standards.
- **Learning objectives** are specific knowledge, skills, attitudes and values learners should gain within lessons to build progressively the key unit competences. Teachers are responsible to prepare lesson plans based on given subject syllabi.

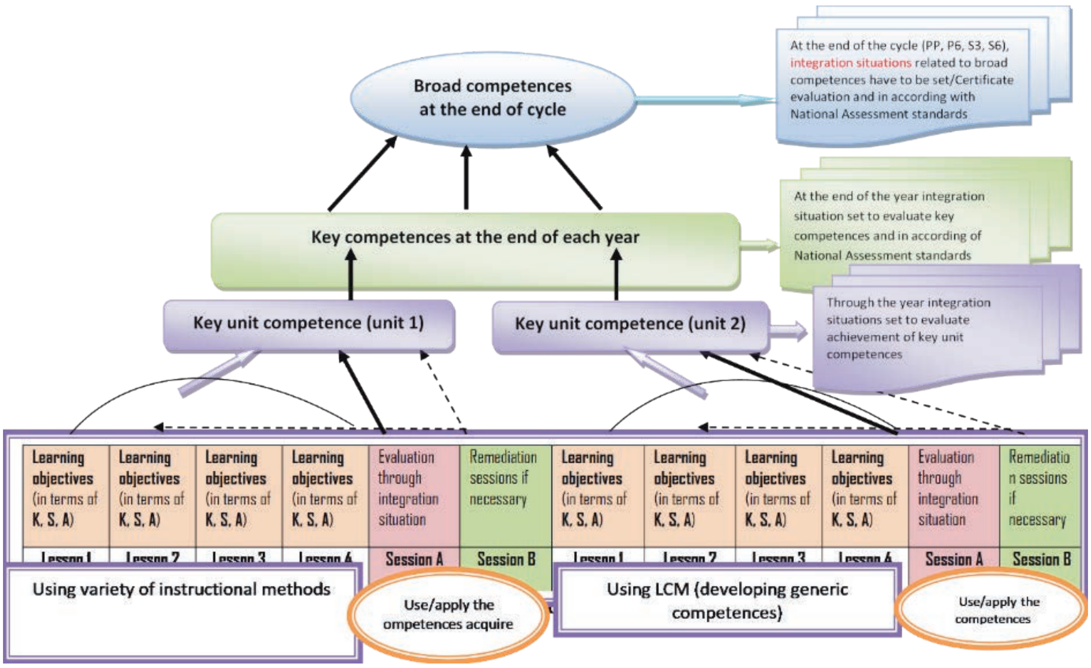


Figure 3: Links between competences in the CBC (REB, 2015)

The key unit competence is the most important element to pay attention to while designing a lesson plan as it determines the instructional objective(s) of each lesson within the unit.

While setting lesson instructional objectives, teachers are advised to balance Lower Order Thinking Skills and Higher Order Thinking Skills. Higher Order Thinking Skills are a central element in a competence-based curriculum because they develop the understanding that enables the effective application of knowledge.

Section 2: Mathematics and Science Syllabus

The secondary science and mathematics curriculum is structured into topic areas, sub- topic areas (where applicable) and in units. Table 1 shows the structure of each unit.

Table 1: Structure of a Unit in the CBC (MINEDUC, 2015)

<table>
<tr><th colspan="5">Topic area:</th></tr>
<tr><td>Year:</td><td>Unit:</td><td>No of period.</td><td></td><td></td></tr>
<tr><td colspan="5">Key unit competence</td></tr>
<tr><td colspan="3">Leaning objectives</td><td rowspan="2">Content</td><td rowspan="2">Learning activities</td></tr>
<tr><td>Knowledge and understanding</td><td>Skills</td><td>Attitudes and values</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Link to other subjects</td></tr>
<tr><td colspan="5">Assessment Criteria</td></tr>
<tr><td colspan="5">Materials</td></tr>
</table>

Section 3: Lesson Planning

> ***Activity 2:***
> What do you think is the benefit of lesson planning for both the teacher and the students?

Planning a lesson is an important responsibility for a teacher. A lesson plan is a teacher's description of the 'learning trajectory' for a lesson. A daily lesson plan is developed for a topic to guide class learning. A lesson plan is the teacher's guide for running a lesson: It includes the goal (what the students need to learn), how the goal will be reached (methods, procedures) and a way of measuring if the goal was reached (test, activity, homework etc. (REB, 2015). Below we discuss the key elements in developing a lesson (Figure 4).

a. Check your scheme of work

At the start of every academic year, teachers develop a Scheme of Work based on the subject syllabus, the school calendar and the time allocated to the subject per week. For lesson plan preparation, consider the following questions:

- What lesson have you planned to teach in a period, such as a term, a month and a week?
- What key competences do you hope to develop by the end of unit?

b. Identify relevant generic competences and crosscutting issues

Each lesson must address generic competences and crosscutting issues. In the lesson plan template, there is a section titled 'Competence and cross cutting issues to be addressed'. In this section, you can describe what learners should be able to demonstrate and how the teaching and learning approaches will address these cross-cutting issues.

c. Set instructional objectives

An instructional objective should have six components. The following steps can guide you to formulate an instructional objective:

1. Reflect on the conditions under which learners will accomplish the assessment task (teaching aids, techniques, outdoors or indoors);
2. Determine who you are talking about (learners);
3. Identify at least one measurable behaviour (knowledge, skills, attitude or values) that you are looking for – evidence of learners' activity. Use a verb which describes the result of learning activities. (e.g. read, write, explain, and discuss). Aim for Higher Order Thinking Skills.
4. Include the content of the activity. You can take this from the subject syllabus.
5. Set standards of performance. Write down the criteria for minimum acceptable performance. (e.g.; time, number of correct answers, presence of expected/ shared values).

6. Identify the types and number of learners with learning disabilities in the section 'Type of Special Educational Needs and the number of learners in each category, insert the type of disability that you have identified in your class and the number of learners with that disability. In addition, note how these learners will be supported in the learning activities.

Education policy targets learners with disabilities (Special Educational Needs or SEN), who qualify (through standardized SEN assessment) for adjusted educational provisions, or/and who meet barriers within the ordinary education system (REB, 2015). The group includes:

1. Learners with functional difficulties, including physical and motoric challenges, intellectual challenges, visual impairments, hearing impairments, speech impairments.
2. Learners with learning disabilities, including specific and general learning difficulties (dyslexia, dyscalculia…)
3. Learners with social, emotional and behavioural difficulties (Attention Deficit Hyperactivity Disorder, Asperger's Syndrome…)
4. Learners with curricula-related challenges and difficulties to comprehend or use the teaching languages (including linguistic minorities)
5. Learners with health challenges.

d. Identify organizational issues

This part of the lesson plan is about creating positive learning environments, specifically related to physical safety and inclusion. In the section titled "Plan for this class (location: in / outside)", you can write down where you will hold the lesson, seating arrangements etc.

e. Decide on teaching and learning activities

In this part, the teacher summarizes the learning and teaching process including main techniques and resources required. In the column "teacher's activities", you describe the activities using action verbs. Questions and instructions from the teacher are also written in this column. In the column "learner activities", the teacher describes the learner activities, findings and answers. Activities or answers which don't fit in the column, can be added in an appendix. The teacher will precise if the activities will be carried individually, in small groups, or whole class.

In the column of steps and timing in the lesson plan format, there are three main steps: introduction, development of the lesson and conclusion.

- **Introduction** is where the teacher makes the connection between the current and previous lesson. There are several ways to introduce a lesson. For example, the teacher organizes a short discussion to encourage learners to think about the previous learning experience and connect it with the current instructional objective.
- **Development** of the lesson. Depending on the lesson, the development of the content will go through the following steps: discovering activities, practical work, presentation of learners' findings, exploitation and synthesis/summary etc. In discovery activities, teachers give a task to learners to identify the prior knowledge in relation with the

new topic. The teacher and learners analyse their findings towards understanding and construction of the new concept. Thereafter the teacher deducts the learning facts which are the summary of the lesson.

- In **conclusion**, the teacher assesses the achievement of instructional objectives and guides learners to make the connection to real life situations. You may end with homework.
- After the lesson, the teacher should make a **self-evaluation**. This self-evaluation should be concrete and useful to guide the teacher in improving the lesson the next time.

f. Decide on the timing for each step

You need to allocate time for each step of the lesson. It is advised to reserve time for learners to write down key words or a summary of the content in their notebooks.

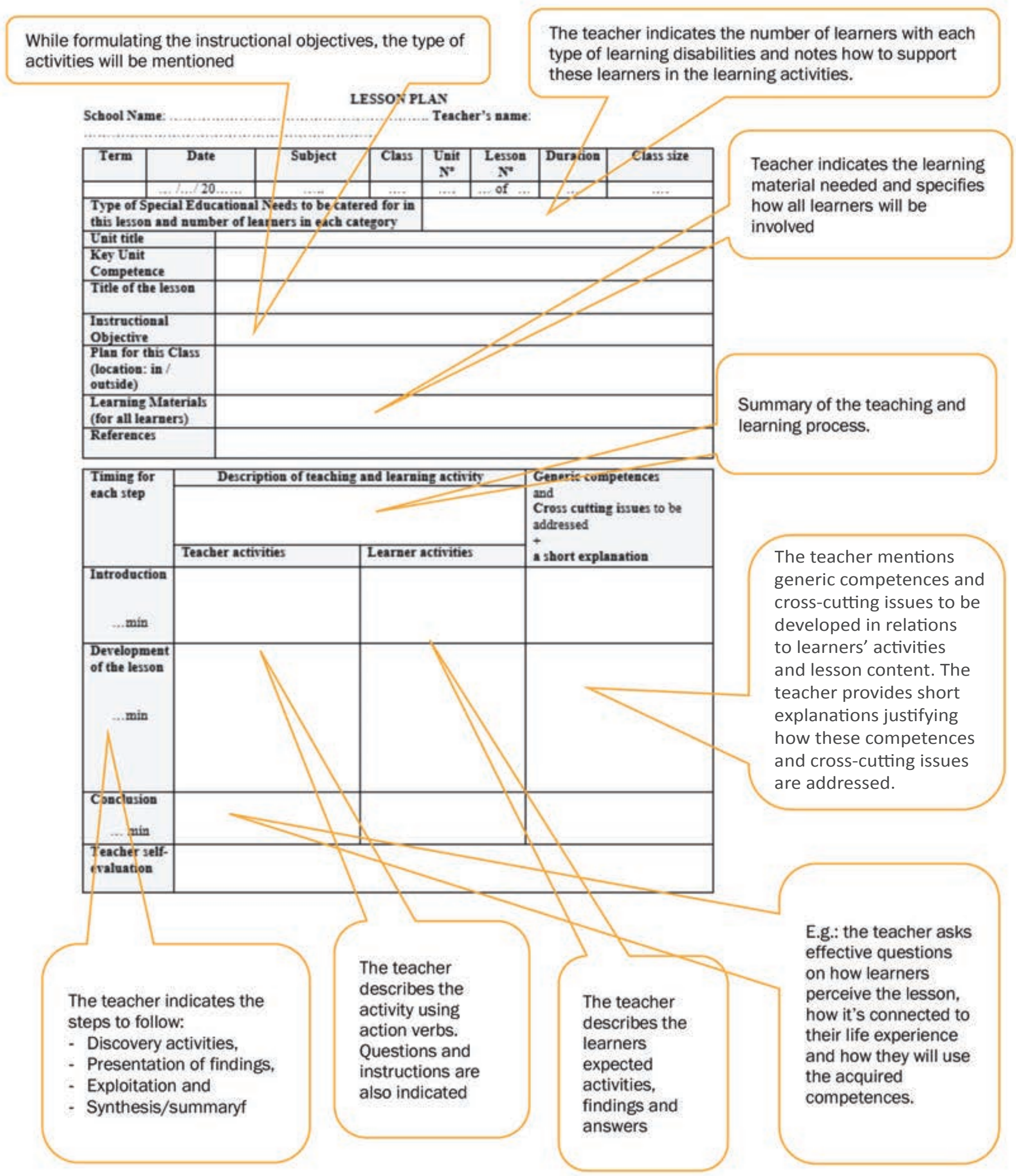


Figure 4: Key Elements of a Lesson Plan (REB, 2015)

UNIT 2: KEY CONCEPTS IN STEM EDUCATION

Introduction

In this unit we will explore some key concepts of STEM education that form the basis of this module. After a short introduction to STEM, the educational model TPACK (Technological, Pedagogical and Content Knowledge) is described. This is a framework that can be applied in several subjects in education, not only in STEM subjects.

We explore TPACK in more detail in sections 3 to 5, specifically on content knowledge (scientific literacy, section 3) and pedagogical knowledge (learner-centred pedagogy, section 4 & inquiry-based learning (IBL), section 5).

We end this unit with the instructional model of 5E's. This model fits well with the CBC lesson plan structure and supports teachers to implement IBL and learner centred pedagogy. It gives teachers concrete tools to prepare good science and mathematics lesson plans.

Familiarity with these concepts will make it easier to understand the purpose of the techniques that we discuss in Unit 3. Each of these techniques focuses on one or several stages in the 5 E's instructional model.

Learning Outcomes

By the end of this unit, you will be able to:

- Demonstrate understanding of the key concepts of STEM education;
- Demonstrate understanding that a good STEM teacher needs TPACK;
- Recognize the importance of connecting STEM teaching with students' daily life;
- Apply some simple strategies to increase the scientific and mathematical literacy of their learners;
- Understand the relevance of a learner-centred approach and inquiry-based learning, recognize and apply these concepts in STEM lessons;
- Recognize the relevance of STEM education for Rwandan society.

Section 1: STEM

Activity 3

- What do you understand under the acronym STEM?
- Why is it important in Rwandan education to focus on STEM?

The acronym STEM was first used in 2001 by representatives of the National Science Foundation in the US as an acronym for “Science, Technology, Engineering & Mathematics” (Fay, Grove, Towns, & Bretz, 2007). In recent years, STEM education has received much attention. In general, STEM is used to refer to school curricula and courses in the areas of S, T, E & M, from kindergarten to Senior 6, but also in universities and higher education institutions.

STEM can also refer to jobs which require an education in STEM, from scientists and engineers to technicians and construction workers (Van den Berghe & De Martelaere, 2012). The National Science Foundation defines STEM broadly, including not only the common categories of mathematics, natural sciences, engineering, and computer and information sciences, but also social and behavioural sciences such as psychology, economics, sociology, and political science (Green, 2007; Moon & Singer, 2012).

Why the enormous attention for STEM in education?

In order to achieve or maintain global competitiveness, governments and policy makers around the world have made STEM a priority for their education systems (Breiner et al., 2012)('STEM-Actieplan 2012-2020', n.d.). Nowadays, an understanding of scientific and mathematical principles, a working knowledge of computer hardware and software and the problem-solving skills developed by courses in STEM are necessary for many jobs. Therefore, there is a big need for STEM education (Tsupros et al., 2009).

The challenges such as how to produce enough food for more than 9 billion people by the year 2050, while using less land, water and energy, or how to develop innovation-centric models of advanced manufacturing in order to remain competitive in a globalized world, are real world challenges that need to be solved. Creating innovative solutions for these challenges will require an innovative, STEM literate workforce. STEM initiatives that emphasize collaboration, innovation, diversity, and inclusion are necessary now in order to develop the STEM talent that would be able to tackle the problems of tomorrow.

STEM education is not only for future scientists and engineers. Initiatives like Project 2016 in the US (AAAS, 2014) aim at helping all Americans to become literate in science and mathematics. All citizens, even non-STEM professionals, should have the skills and competences to deal with the challenges of our information-based and highly technological society. Many of our current challenges (global warming, pandemics, biodiversity, planetary exploration, genetic modification, brain science, renewable energy, population growth…) require a basic understanding of science and mathematics.

- Despite the many opportunities to study STEM and the need for STEM profiles in the labour market, few students are choosing for STEM fields in higher education. In many countries, girls are underrepresented, mostly so in richer countries (OECD, 2019; Stoet & Geary, 2018)many researchers around the world analyse them with the aim of shedding light on all sorts of questions. One question in search of an answer: why are women under-represented in science, technology, engineering and mathematics (STEM. The ROSE project (Sjøberg et al., n.d.) investigated the relevance of science education worldwide (40 participating countries including some African countries). In most European countries, students at the age of 15 rather disagree with the statement "School science has shown me the importance of science in our way of living". This is not a problem yet in African countries like Uganda, Ghana …. (Sjøberg et al., n.d.).

In Europe, STEM is seen as a fresh approach to science and mathematics education to increase its relevance. So, STEM does not only foster scientific and mathematical literacy but has also the objective to create more positive attitudes towards science and maths. Recent studies (Plasman & Gottfried, 2018) have shown additional benefits of applying STEM in education. Students with learning disabilities who took STEM courses have better educational outcomes: lower chances of dropout, higher test scores and increased enrolment in higher education. All of this has led that STEM education is nowadays a top priority all over the world.

Though STEM is a buzz word in education, there is no common conceptualization of STEM. *"What is STEM?".* Educators find the term confusing. Based on different international reports (Breiner et al., 2012) (De Meester et al., 2015) and our own experience, we notice some recurring characteristics of what STEM can and should be.

- STEM is not a curriculum, like there is the curriculum for chemistry or biology. STEM is an **approach**, different from the traditional lecture-based teaching strategies. STEM is an example of a learner-centred pedagogy.
- **Integrating** science, technology, engineering, and mathematics curricula is an objective. For some it is mandatory, for others not. An interesting question from a survey in the US is: "*In joining science, technology, engineering, and mathematics are we saying that each component of STEM education necessarily involves all STEM disciplines?* "
- The approach is often **project**- and/or **inquiry** based (see Unit 2, section 5). Students are not studying traditional science or mathematics courses but are often working on a project. This project can be initiated through a problem, a research question or a challenge. Projects combine aspects of several fields in science, mathematics and sometimes others (arts, architecture, economics…).
- Students are **active learners** in STEM courses: they raise questions, formulate problems, plan, investigate, perform experiments, test and construct, search and suggest solutions …
- Content should be drawn from **real-life experiences**, problems must have links with the real world, STEM must be 'conducted' in the real world, curricula must have realistic parallels with the work of a scientist or engineer. The **context** is important, and **relevance** is the keyword while teaching and learning STEM.
- What are your objectives in a STEM approach or project? The goals must not only be expressed through students' understanding of scientific and mathematical **concepts**. In STEM there is an important shift towards STEM **skills**[1] or and **attitudes**[2].

1 Some examples: raising questions, conducting investigations, collecting and process data, using maths, designing, prob lem solving, handle tools and equipment, …

2 Curiosity (willing to know), enterprising (willing to take action to find things out), creativity, …

Activity 4: Case study: Groupe Scolaire Muko II

Mr Justin is a Chemistry teacher at GS Muko. After realizing how much his students do not like science because they struggled to capture its application and relevance in real life, he launched a science club at his school. In this club, students get opportunities to apply the knowledge they learned in Chemistry to make cosmetic products such as hair shampoo, liquid soaps, etc. This does not only motivate students to learn science, but also creating innovative thoughts.

Watch this video of the case study: https://youtu.be/HyIz5DRzjAI . After watching the video, discuss the following questions in small groups:

- How does this initiative build resilience among STEM students?
- How does this initiative apply the concept of STEM as discussed above?
- Could you start a similar initiative in your school? Why or why not?

Activity 5

Below you can read 3 short descriptions of STEM-projects. Discuss in small groups the examples and answer following questions:

- How do these examples differ from the lessons you teach?
- Look at the characteristics above, are they good examples of STEM? Why (not)?
- Rank these examples from very good, good to less good, and argue your choice.

Example 1:The Cooler and Delivery Truck Evidence (*The Cooler and Delivery Truck Evidence*, n.d.)

Based on your students' knowledge of chemistry, local police have asked for their help in solving a local missing-persons case. The victim in this case is Kirsten K. How did Kirsten K.'s body wind up at the bottom of a lake—and what do wedding cake ingredients, soil samples, radioactive decay, bone age, blood stains, bullet matching, and drug lab evidence reveal about who did it? Your students will try to determine which suspect is most likely responsible for her disappearance based on the evidence provided by the police and analysed by the students.

Example 2: The Student Climate Research Campaign Community Group

The GLOBE Student Climate Research Campaign aims to engage students around the world in measuring, investigating, and understanding the climate in their local communities and the world. GLOBE provides grade level-appropriate, interdisciplinary activities and investigations about the atmosphere, biosphere, hydrosphere, and soil/pedosphere, which have been developed by the scientific community and validated by teachers. GLOBE connects students, teachers and scientists from around the world to conduct real, hands-on science about their local environment and to put this in a global perspective.

Drawing on GLOBE protocols and data - and other important datasets - students make climate-related measurements (such as temperature, air pressure, rain fall, …) and investigate the following research question: *'What is my climate and how has it changed over time?'*

Example 3: Project-Based Learning: Design and Build a Rain Garden (Conservancy, 2017)
Storm water runoff and the resulting erosion is one of the great challenges of our time. Erosion removes agricultural land and causes landslides. In areas with steep hills or that are covered with impervious surfaces—roofs, streets, and parking lots—storm water flows rapidly, picking up pollutants and delivering them into our water sources.

In a natural environment, storm water gets absorbed into the ground where soil, rocks, and plant roots filter the water. A rain garden is designed to simulate this process by slowing the flow and absorbing storm water before it reaches our waterways or can cause much harm through erosion.

The Design and Build a Rain Garden lesson series leads students through identification of a suitable site, the design and installation of a rain garden. The activities provide the basis for a rich, interdisciplinary, hands-on learning experience. There are four important parts:

- Part 1: Includes background content for students to understand how rain gardens address and fit into larger storm water management issues and approaches. The lesson lays the foundation for the class to locate, design, and install a rain garden.
- Part 2: Students work to identify the best site, size, and shape for the garden.
- Part 3: Students engage in a creative design process to come up with a class design for the rain garden.
- Part 4: Focuses on the installation of the rain garden and includes the final evaluation.

Section 2: Technological, Pedagogical and Content Knowledge (TPACK)

Activity 6

Reflect individually about the following question:

Think about a good STEM teacher that you had. What made that teacher so good?

Write down your ideas and discuss them with your neighbour.

A person who is expert in a subject is not necessarily a great teacher because he/she may be lacking the pedagogical knowledge to make the subject accessible and understandable for learners (Ball, Thames, & Phelps, 2008; D.L. Ball, Lubienski, & Mewborn, 2001). To be a great teacher, you need to combine the knowledge of the subject with the ability to teach. Especially in STEM education, you also need to be able to combine technology with content and appropriate pedagogy to create an effective learning environment.

The concept of TPACK was proposed by Mishra and Koehler (2006) to describe an integrated connection among content knowledge, pedagogical knowledge and technological knowledge. This concept was suggested to aid the potential of integration of ICT tools in classroom setting and school practice. TPACK is the overlap between the three domains of knowledge that teachers need to have to be a good teacher (Figure 5). It is the blending of interaction between the teachers' subject matter knowledge, what they know about teaching and the supportive tools.

In this module we will focus on pedagogical knowledge but, importantly, apply this every time to the content knowledge. However, it is important to be aware of the increasing role of ICT in the educational system. We will introduce technology-based learning tools in the different sessions and illustrate how they can be used in the classroom. However, simply knowing about the latest technology devices is not enough. Teachers must be able to engage with diverse learning technologies efficiently and effectively in the learning process (Srisawasdi, 2012). These learning technologies may be ICT based information tools, such as presentation software or tools for online voting tools, but also specific ICT based science tools like computer simulations, computer-based laboratories, calculation tools, sensors… We will introduce some specialized ICT tools for science like online simulations (unit 3, section 7) and computer-based measurements (unit 3, section 5). Note that the technology component in TPACK does not necessarily refer to expensive technologies. Teaching aids such as low-cost experiment materials and posters are also examples of technologies.

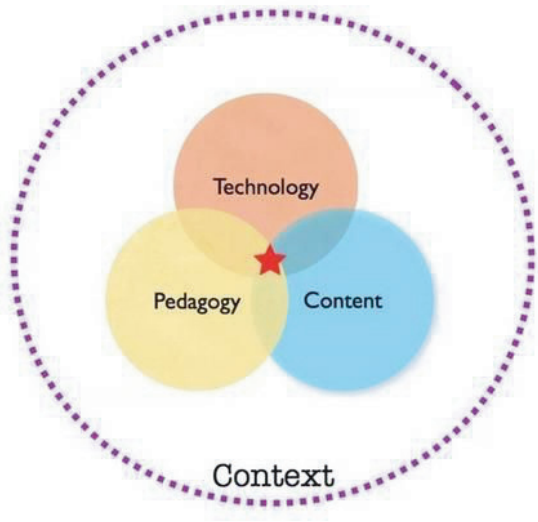


Figure 5: Visualisation of TPACK at the overlap between content, pedagogy and technology

Finally, we draw the attention to the context circle in Figure 5. TPACK is always related to the context. A low availability of technology, didactical materials and even handbooks are a daily reality in Rwanda. Some examples will only be applicable in the future and we will provide low-cost alternatives for the more expensive approaches.

In short, we focus on the different components of TPACK in this module as follows:

- The **content knowledge** refers to the subject matter knowledge of a teacher. Teachers participating in this Programme are expected to be an expert in one or more STEM subjects. However, we believe that keeping up to date and being prepared to learn more is an important attitude of a teacher. This manual will not focus on this component.
- The **technological knowledge** is about knowing which materials and tools to use during your lessons. This includes not only digital tools but also traditional tools as a blackboard, posters, voting cards and low-cost materials for experiments.
- The **pedagogical knowledge** is the focus of this Programme. It means knowing how to teach the subject matter. Again, and this is very important, pedagogical knowledge will be applied to content knowledge.

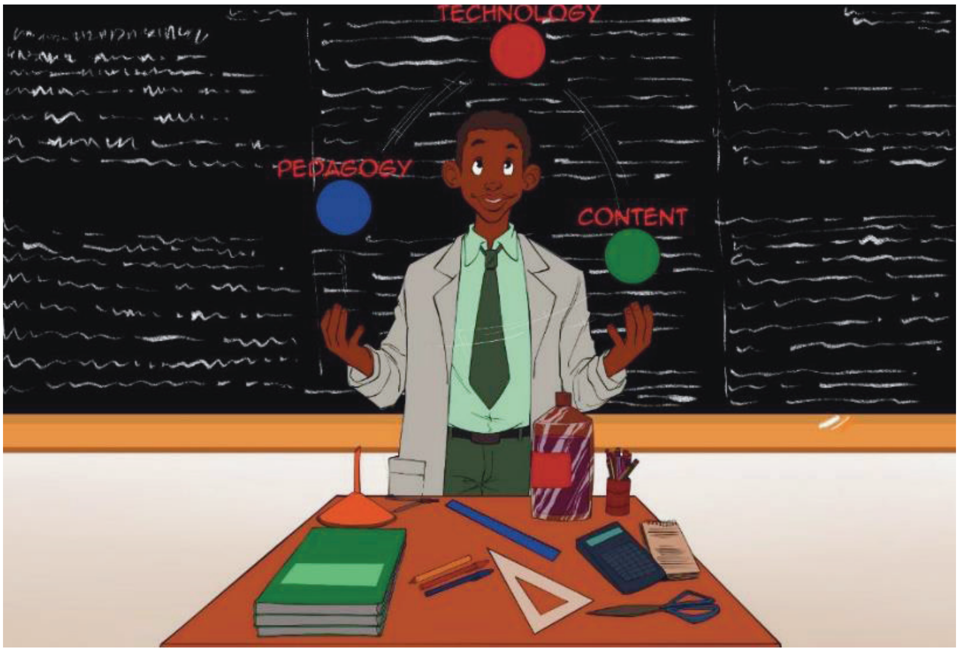


Figure 6: A good STEM teacher can balance content, pedagogical and technological knowledge

Activity 7

In groups, you will read, discuss and prepare a poster (one A4 page) for one of the following sections that summarizes what you think is important in that section for your colleagues to know. You will use your poster to explain the key ideas of each section to your peers. The questions can help you to identify those key ideas.

7.1 Scientific Literacy (section 3)

1. What is scientific literacy?
2. How has COVID-19 impacted the society's perceptions of science and maths?
3. How do you develop scientific literacy with your learners? Can you give examples?
4. Education systems should be part of the response to prevent or slow the spread of the corona virus and curtail its impact. As STEM SSL, how do you help learners to understand the transmission and prevention towards the entry or spread of COVID-19 virus at your school?

7.2 Learner-Centred Pedagogy (LCP) (section 4)

1. What is LCP?
2. Is LCP the same as group work?
3. How do you apply LCP in your teaching?

7.3 Inquiry-Based Learning (section 5)

1. What is inquiry-based learning?
2. Should every STEM lesson be inquiry-based?
3. Are there different levels of inquiry-based learning? Can you give examples?

Section 3: Scientific Literacy

An important objective for STEM teachers is to make sure that all students become scientifically literate. In this section, we explore what it means to be scientifically literate.
There is still discussion about the best definition for scientific literacy and how we can achieve it in education (Holbrook & Rannikmae, n.d.). For this programme we will use the definition of the National Science Education Standards (1996):

- Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about **everyday experiences**. It means that a person can **describe, explain, and predict natural phenomena**.
- Scientific literacy entails being able to read with understanding **articles about science in the popular press** and to **participate in conversations** about the validity of the conclusions.
- Scientific literacy implies that a person can **identify scientific issues** underlying national and local decisions and **express positions** that are scientifically and technologically informed.
- A scientifically literate citizen can **evaluate the quality of scientific information** based on its source and the methods used to generate it. Scientific literacy also includes the capacity to formulate and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.

These definitions not only include the understanding of the basic scientific concepts but also refer to learners' skills and attitudes. This means learning at the competence level. Scientifically literate persons can think and act like scientists. This implies that is not only a task for teacher to make sure students have basic knowledge about concepts, but are also able to formulate research questions, investigate, collect data, measure, plan experiments, be critical, interpret data etc.

Section 4: Learner-Centred Pedagogy

Learner-centred pedagogy (LCP) is a pedagogical approach with its origins in constructivist theories of learning. These theories start from learners' individual needs, interests, abilities and backgrounds, and aim at creating an environment where learning activities encourage learners to construct the knowledge, skills and attitudes either individually or in groups in an active way (Nsengimana et al., 2017). In learner-centred classrooms, learners **influence the teaching and learning process**, in contrast to a teacher-led classroom whereby the teacher is fully in charge of the content, the teaching and learning process. In a teacher-centred (or teacher-led) classroom, it is only the teacher who has the authority to deliver knowledge, skills and attitudes as if the learners are empty vessels to be filled. Students are passive receivers of knowledge. In STEM education, learner-centred pedagogy is characterized by features such as discovery approach, active participation of students and engagement in experimentation and other science processes (Nsengimana et al., 2014).

Examples of learner-centred pedagogy in STEM education are present in inquiry-based learning and projects, further described under sections 4 and 5. LCP is a common theme running through the key aspects of STEM instruction (Unit 3). Learners will be challenged by discrepant events (Unit 3, Section 2) and encouraged to provide their own ideas (Unit 3, Section 6) about natural phenomena. During practical work (Unit 3, Section 4) learners explore phenomena in meaningful contexts, test their own ideas and are invited to participate in classroom discussions…

Section 5: Inquiry-based learning

Inquiry-based learning (IBL) is an example of a learner-centred pedagogy. IBL is specific to science education. Inquiry based learning means '*seeking knowledge by questioning'*. (Olson, 2000).

IBL means that students are encouraged to work together to find an answer to their questions rather than receiving direct instructions on what to do from the teacher. The teacher's job during inquiry-based learning is not to provide knowledge, but instead to help students to discover knowledge themselves.

When students are learning science in an inquiry-based lesson, they become "mini-scientists" because they apply the same approaches as scientists do when they are conducting research.

> "*Students should experience science in a form that engages them in the active construction of ideas and explanations and enhances their opportunities to develop the abilities of doing science*" (Council, 1996).

This means encouraging students to show curiosity, to define questions from their prior knowledge, to propose preliminary explanations (own ideas), to plan and conduct simple investigations, to gather evidence from observations, to formulate conclusions (Council, 2000a)…

According to the national research council (Council, 2000b), IBL has **five essential features** that apply across all grade levels:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop explanations.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in the light of alternative explanations.
5. Learners communicate and justify their proposed explanations.

You will notice parallels with sections from unit 3, such as the instructional model of the 5E's, using discrepant events to engage students, raising questions, practical work, using students' prior ideas … In unit 3, we will introduce various ways to make science lessons more inquiry based.

Teachers not feeling comfortable with IBL often ask, "*How much inquiry students need to do in an inquiry-based lesson?*" There is no clear answer to this question. It is widely acknowledged that there are several levels of inquiry in a classroom (Fay et al., 2007).

Table 2: Levels of inquiry

Level of inquiry	Description (Characteristic descriptions of each level are shown in bold)
0	The *problem*, *procedure*, and *methods to solutions* are **provided** to the student. The student performs the experiment and **verifies** the results with the manual.
1	The *problem* and *procedure* are **provided** to the students. The student **interprets** the data in order to propose viable *solutions*.
2	The *problem* is **provided** to the student. The student **develops** a *procedure* for investigating the problem, **decides** what data to gather, and **interprets** the data in order to propose viable *solutions*.
3	A "raw" phenomenon is provided to the student. The student **chooses** (or constructs) the *problem* to explore, **develops** a *procedure* for investigating the problem, **decides** what data to gather, and **interprets** the data in order to propose viable solutions.

Source: Fay et al., 2007

As seen in Table 2, the freedom and responsibility of students increase from Level 0 to Level 3. While Level 3 is regarded as the ideal level of inquiry-based science lessons, you can consider your lesson to be 'inquiry-based' if it is at Level 1. Note that Level 0 means 'no inquiry' in the lesson.

Although not all science lessons can and should be inquiry-based, Table 2 offers goals to which each teacher can work, according to one's skills, students' current level of understanding and the school environment. If your lessons are usually at Level 0, try to achieve Level 1 or Level 2. If you have already been working at Level 3, then you can still improve the quality of each activity.

Activity 8

Below you find descriptions of parts of a science lesson where IBL is applied. Which features of IBL (as described above) are present in each example? At what level of inquiry would you place each lesson?

Example 1: Start of a lesson by Mr. Hull

Mr. Hull begins most units with one or more short survey questions to get students to think about the kinds of situations, issues, and ideas they will be investigating for the next few days. Today, at the start of class, he asks his students: "What do you think about when you hear the word force?" Among the responses from students were: "gravity is a force," "pushing, like when I push a car," "a push or a pull on something," and "making somebody do something they don't want to." While students continued sharing their initial ideas, Mr. Hull wrote the ideas on the board. As he wrote, he organized ideas into two categories: kinds of forces and definitions of force (i.e., "force is…"). Mr. Hull wanted his students to be able to represent their understanding of forces, so he guided them in crafting their representations. He said: "It sounds like several of you are thinking of force as a push or pull. What are some properties of pushes and pulls?" … (Council, 2000a)

Example 2: **Fireproof balloon**

Light a candle on a paper and show students a paper burning. Then fill a balloon with water, light a candle on it, and tell the students to predict what will happen if the bottom filled with water is touched to the flame of a candle. Also ask them for an explanation of their prediction. After their presentations, show the counterintuitive result that the balloon filled with water does not burst, which will lead to the question why it does not burst.

Source: (*Fireproof Balloon | Science Experiments | Steve Spangler Science*, n.d.) (https://www.youtube.com/watch?v=1rmWwD5vJeo) (This is a discrepant event, see also unit 3, section 2).

Example 3: investigation of the candle experiment (*Primas Project*, n.d.)

The candle experiment is a classic example in natural science classrooms. When you put a glass above a candle in water, the light goes out and the water rises. Often, secondary school students immediately have an explanation for the 'magic' trick: 'The candle uses up the oxygen – air pressure in the glass decreases – the water rises.' When asked the logical question, 'when does the water rise the most?', students answered clearly with, 'while the candle is burning.' However, careful observation reveals that the liquid only starts rising when the candle flame begins decreasing. Therefore, depleted oxygen can be eliminated as the cause. This is when things really start getting interesting for the students: 'What makes the water rise?'

Students investigate this phenomenon in groups. All kinds of materials are made available: support stands, magnets, salt, hot air gun, sugar, weights, indicator paper... It was surprising how creative some groups were in planning their experiment, discussing in the team their preconceptions and thereby, including their knowledge of all the natural sciences.

See also https://www.youtube.com/watch?v=BSDK7KjcT6k ('Primas Project', n.d.) (use English subtitles)

Discussion

In the first example, the teacher engages students for the lesson topic by linking it with their prior knowledge from daily life. Stimulating learners to think about forces and organizing their thoughts can set the stage for experimental investigation and challenging their beliefs. (see 5 E's Instructional Model, Engage Phase, Unit 3, section 1).

In the second example, the teacher uses a demonstration that has a surprising result to capture students' interest in the topic at the start of the lesson. During the remainder of the lesson, they will learn the content of the lesson to find out why the balloon does not burst above the burning candle.

In the third example, another experiment with a counterintuitive outcome is used, but this time, it provides the starting point for students to investigate the correct explanation for the phenomenon. Students need to formulate the research question, design an experimental setup and interpreting the results. Therefore, this lesson is at a higher level of inquiry.

Discussion

Inquiry-based learning is perfectly possible during times of distance education and school lockdowns but requires good preparation and commitment from teachers and students. Of course, inquiry-based learning activities that require specialized equipment or materials will be difficult to organize when schools are closed, but there are inquiry-based projects that can be set up that don't require special materials. Some examples are activities related to Newton's Laws, Bernouilli's Law (physics), observing the leaves from various plants (biology). Good preparation is key to have a successful inquiry-based activity. Some guiding questions that can help you to be well prepared are:

- What do students need to read before starting the activity?
- What questions and tips can I formulate to guide them?
- What data can they collect and report on?
- Can they work in small groups or individually?

Activity 9

Exit ticket: Is inquiry – based learning possible when teaching at a distance during school closure? What possibilities and challenges do you see? Give examples.

Section 6: 5 E's as an Instructional Model

What and why?

In the mid-1980s, the Biological Sciences Curriculum Study (BSCS) (see: https://bscs.org/bscs-5e-instructional-model) designed the 5E Instructional Model that stimulates observation, questioning and thinking of the learners. The model has five phases: engage, explore, explain, elaborate, and evaluate (see Figure 7). It is based on our current understanding of learning processes and has been widely used and tested (Bybee, n.d.; Duran & Duran, 2004).

This section provides the key concepts and goals of the sections of unit 3, like Discrepant Events (Section 2), Raising questions for learners (Section 3), Practical work (Section 4), Questioning (Section 1), ….

Figure 7: The 5E's instructional model

Activity 10

In pairs or small groups, use post-its or flash cards to write what you do and why for each stage of the lesson plan, using following guiding questions:

1. How do you introduce your science or maths lessons? What is the purpose of the introduction?
2. What kind of activities do you do in the development part? Why do you organize those activities?
3. What do you do in concluding part? What is its purpose?

Stick your cards in the right column (introduction, development, and conclusion).

How?

The 5E model can be applied at several levels. You can introduce one step of the model per lesson, or you can integrate all the steps in one lesson. In this section, we will focus on how you can use one full 5E cycle in one lesson. This is not always necessary. Sometimes it is more interesting to run through several small 5E cycles in one lesson, or to focus in one lesson on one or two steps of the model.

Although the general principles of the 5E's instructional model are followed, the practical implementation has been adapted to the school context in Rwanda, considering that there are often few didactical materials and that not all learners have a textbook.

Phase 1: Excite and Engage

The objective of the first phase is to engage students in the topic of the study and the learning task at hand. Students focus on an object, problem, situation or event and formulate their first understanding. Asking a question, defining a problem, and showing a discrepant event (see Unit 3. Section 2) or acting out a problematic situation are ways to engage students and focus them on the instructional task. As a teacher, ask yourself why it is important for students to know about the topic of the lesson. The goal of this phase is to engage students with the subject, show them the need to learn the topic and find a good question to explore during the second phase. The role of the teacher is to present the situation and help students to formulate a key question.

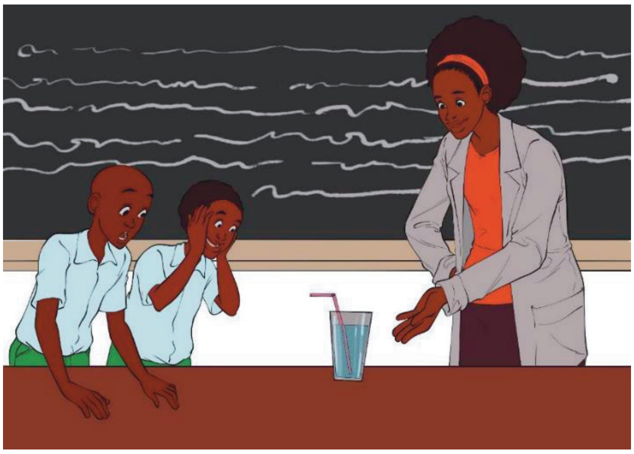


Figure 8: During the excite/engage phase, the teacher instils a sense of excitement with the learners

Table 3: Teacher and learner activities during the excite and engage phase

Teacher activities	Learner activities
▪ Demonstrates a discrepant (counterintuitive) phenomenon, defines a challenging problem, talks about a special (historical) event, shows a picture or video… ▪ Activates prior knowledge of the learners. ▪ Stimulates learners to observe and formulate interesting questions. ▪ Helps learners to select a good key question.	▪ Try to get a first understanding of the phenomenon. ▪ Ask questions (Why…? How…? …) ▪ Formulate a key question.
Outcome: engaged learners, a key question for the lesson	

Successful engagement results in learners being challenged by and actively motivated in the learning activity. Also, a **key question** is formulated. A key question is the central question related to the learning outcome of the lesson. It should be at the level of the learners as they are guided to formulate this question themselves. A picture or event is followed by the students' discussion on 'why', 'what if', stimulating students' thinking. Through these activities, the teacher focuses the discussion on the key question.

Examples of good key questions:

- How does a mirror reflect light rays?
- Why doesn't the balloon filled with water burst when heated?
- Why does a solar eclipse happen?
- How does air enter the lungs?
- What are the functions of the roots of a plant?
- What causes the surface tension of water?
- What is burning phenomenon?
- Why does salt dissolve in water?
- Why doesn't pure water conduct electricity?
- Does multiplication always increase a number?
- How to write $(A + B)^2$ without the ( )?
- Toss two coins – what is the probability of getting one head and one tail?
- How much toothpaste will I consume during my lifetime?
- When are fractions equivalent?
- How do you multiply 2 fractions?
- What is the surface area of a cuboid?

The key question of an inquiry-based lesson is directly associated with the objective of that lesson. In other words, a key question should be set out in a way that students achieve the lesson objective in the process of answering the key question.

For example, if the learning objective of a physics lesson is: "Students will be able to explain how the period of pendulum is affected by the length of a pendulum", then the key question can be: "In order to change the period of swing in a pendulum, what should we do?" In this lesson, students will conduct experiments to identify the factors that affect the period of a pendulum by using different masses and lengths of the pendulums.

Ideally students themselves formulate the key question of a lesson, because they will be more motivated to investigate a question if it results from their curiosity and are eager to know the answer to the question. In most cases, the key question is prepared by the teacher and he/she guides the learners to formulate that question. But, in an experienced class, the question can be completely determined by the learners' interest.

Learners need to be trained to ask questions and to formulate investigable questions. We will discuss how you can achieve this in Section 3: Raising Questions for Learners of Unit 3.

Phase 2: Explore

Once we have engaged students, they feel a psychological need to explore the key question. Exploration activities are designed so that the students can build their own understanding and have a common experience that can be used later during the Explain phase. The Explore phase should be as concrete as possible. The teacher can, depending on the available materials, use demonstrations or group work (see Unit 3, Section 4: Demonstrations and Practical Work), to stimulate the exploration. When experiments are used, teachers should help learners to formulate investigable questions (see Unit 3, Section 3: Raising Questions for Learners). Also, handbooks or other sources of information can be used where students can find answers to their questions. The aim of the exploration is to answer the key question. However, additional questions are often formulated during this phase. The key message during this phase is that students work collaboratively and actively. They investigate a scientific or mathematical concept in depth, while they practice skills, think, try and ask questions.

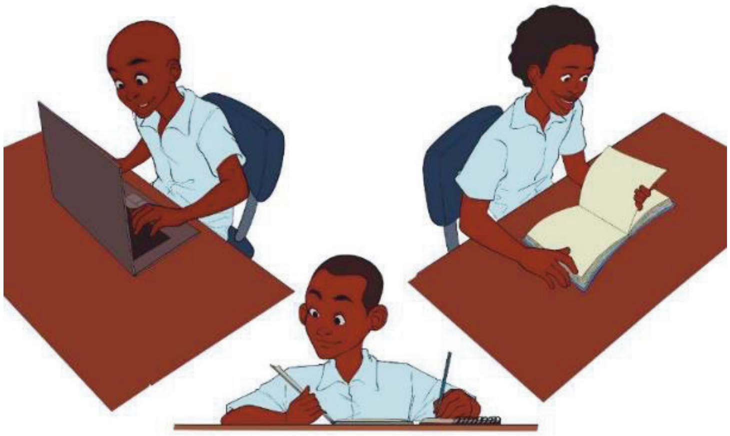


Figure 9: Learners engage with various resources about the lesson topic during the explore phase

The teacher's role in the exploration phase is that of facilitator or coach. Of course, the teacher needs to be aware of the challenges that learners may face to answer the key question. The teacher collects insights on students' ideas or misconceptions, initiates learning activities, asks scaffolding (guiding) questions and gives learners the time and opportunity to investigate materials or models. If called upon, the teacher may coach or guide students as they start to construct explanations.

Table 4: Teacher and learner activities during the explore phase

Teacher activities	Learner activities
Provides hands-on opportunities for exploration (e.g. experiments, pictures, worksheets, handbooks …) and sufficient time. Stimulates active work by students	Explore the materials that the teacher provides, meanwhile they: conduct an experiment, make drawings, do some calculations, make observations, make

(observation, calculations, drawings, measure, perform experiments, draw conclusions …) through scaffolding (guiding) instructions.	conclusions, read, listen, share, … in order to try to formulate answers to the key question or formulate new questions.
Outcome: written reports or drawings of learners, first answers to the key question, extra questions of learners …	

It is important that during the first phases of 5E (Engage/Excite and Explore) you do not explain anything yet. These phases allow students to explore a concept together or independently. During the Engage phase, present learners something that they are willing to work on and then encourage them to work together to figure it out during the Explore phase.

Phase 3: Explain

In this phase, the teacher directs students' attention to specific elements of the engagement and exploration experiences. First, the teacher asks students to give their explanations for the key question. Second, the teacher introduces scientific, mathematical or technological explanations in a direct, explicit (definitions, Laws, concepts) and formal (scientific or mathematical notations) manner.

Explanations are ways of ordering the experiences from the exploration phase. The teacher should start from students' explanations and clearly connect the explanations to experiences in the engagement and exploration phases of the instructional model. The key to this phase is to present concepts, processes or skills briefly, simply and clearly. The teacher should encourage learners to link explanations to the experimental evidence and models that are already known (see Unit 3, Section 7).

Figure 10: During the explain phase, the teacher helps learners to formulate explanations, introducing new content

Teachers have a variety of techniques and strategies at their disposal to extract and develop student explanations. Teachers commonly use verbal explanations, but there are many other strategies, such as videos, poster and animations/ simulations.

During this phase the process of mental ordering continues, and the teacher provides terms for explanations. In the end, students should be able to make sense of exploratory and engaging experiences by using common language. Students will not immediately express and apply the explanations—learning is a process and takes time.

Table 5: Teacher and learner activities during the explain phase

Teacher activities	Learner activities
Asks explanations from learners. Asks thinking and probing questions: e.g. confront explanations from learners with the evidence obtained in the explore phase. Guides learners toward coherent generalizations and helps them understand and use scientific vocabulary to explain the results of their explorations. Helps learners to write down a good scientific explanation.	Try to answer the key question Listen to the answers of other learners, help them to find the scientifically correct answer. Write down the answer and the relevant evidence and models.
Outcome: written explanation, learners understand the explanation.	

Phase 4: Elaborate

Once students have an explanation and terms for their learning tasks, it is important to involve students in further experiences that extend or elaborate the concepts, processes or skills they have learned during the explain phase. During the elaboration phase, the teacher focuses on the transfer or application of the lesson concepts to closely related but new situations. In some cases, students may still have misconceptions, or they may only understand a concept in the narrow terms of the exploratory experience. Elaboration activities provide further experiences that contribute to a deeper understanding.

Figure 11: During the elaborate phase, learners apply what they have learned to new contexts and situations

During the elaboration phase, you can engage learners in discussions and information seeking activities. This phase is an opportunity to involve students in new situations and problems that require the transfer of identical or similar explanations. Generalization of concepts, processes and skills is the primary goal during this phase.

Table 6: Teacher and learner activities during the elaborate phase

Teacher activities	Learner activities
Challenges learners with new problems, experiments, discrepant events … Coaches learners in solving thinking questions.	Apply their understanding to new challenges and situations. Use all available resources (teacher, other learners, handbooks, external experts) to solve the challenges.
Outcome: solved challenges, learners have a deeper understanding of the concepts.	

Phase 5: Evaluation

It is important to provide opportunities for students to apply the skills they have acquired and to evaluate their understanding. In addition, students should receive constructive feedback on the correctness of their explanations. Informal evaluation can occur at the beginning and throughout the 5E cycle. The teacher can complete a formal evaluation after the elaboration phase. As a practical educational matter, teachers must assess educational outcomes. During this phase, teachers administer assessments to determine each student's level of understanding. Evaluation is not only about evaluating your learners, but also about evaluating your teaching. During the evaluation phase, the teacher gets feedback from the learners on what they have learned. That information can be used to improve the lesson.

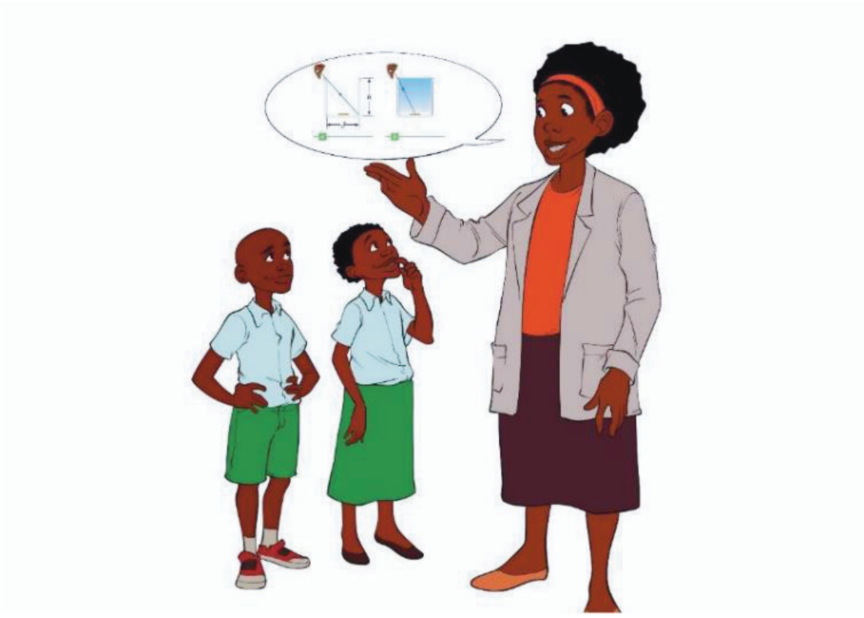


Figure 12: During the evaluate phase, the teacher uses well-chosen questions to assess learners' understanding of the lesson content

Table 7: Teacher and learner activities during the evaluation phase

Teacher activities	Learner activities
Provides the learners with testing questions (prepared in advance). Observes how learners solve these questions. Uses test results to provide feedback to the learners and to improve his/her own lessons (Unit 5).	Apply their current understanding to the questions. Analyse their mistakes, trying to improve their understanding.
Outcome: test results, feedback for both teachers and learners.	

The 5E's lesson plan structure

The 5E's instruction model can easily be used in your lesson plan format in Rwanda. The lesson plan structure contains:

- Introduction: Excite/ Engage phase
- Development: Explore, Explain and Elaborate phases
- Conclusion: Evaluate phase

Examples for physics, biology, chemistry and maths are found in the Appendix.

Activity 11

In pairs, develop a short description of every phase in the 5 E Instructional Model for the following lessons:

- Structure of the human urinary system (Biology, Senior 2, student book p. 155)
- Rate of reactions (Chemistry, Senior 3, Unit 5, student book pp. 157 – 170)
- Refraction of light through a prism (Physics, Senior 3, p.355 - 359)
- Pythagoras' Theorem (Maths, Senior 2, p. 105-107)

Micro teaching exercise

Activity 12

In groups of 3, prepare an **inquiry-based science lesson**, using the 5E's instructional model for a topic suggested by the facilitator.

- You will teach 15 minutes of the lesson
- You will explain in 10 minutes how you will teach the rest of the lesson (referring to each of the 5 E's)
- Afterwards, there are 20 minutes for feedback and discussion.

Integrate ideas and methods that you learned during this Programme.
In Appendix 2, a set of questions is included that can guide the feedback on the lesson.

UNIT 3: KEY ASPECTS OF THE 5 E's INSTRUCTIONAL MODEL

Introduction

The 5E's instructional model forms the basis for unit 3. This model supports teachers to apply the pedagogical approaches of IBL and learner centred pedagogy. It gives teachers concrete tools to prepare competence-based science and mathematics lesson plans.

The techniques that we will discuss in Unit 3 are all connected to one or more stages of the 5E model. In Table 8 you find a summary of how the different sections of this unit are related to the phases of the 5E's model. The letter *X* means that the materials of this section should be used in the corresponding phase of the 5 E's. The letter *a* indicates an optional connection between the technique and the phase.

Table 8: How do the sections of unit 3 link to the 5E phases?

X: use this section in this phase as much as possible

a: possible to use this section in this phase

	Section	Excite/ Engage	Explore	Explain	Elaborate	Evaluation
1	Questioning	X	X	X	X	X
2	Discrepant Events	X	A		A	a
3	Raising questions for learners	X			A	
4	Demonstrations and Practical Work		X			
5	Using students' ideas	X	X		A	a
6	Computer-based measurements		A		A	a
7	Models, animations and simulations		X		A	
8	Using Contexts	X	X		X	

Learning Outcomes

At the end of this unit, you will be able to:

- Apply different key aspects of IBL in order to use the 5E's instructional model in your lessons;
- Improve the quality of your questioning (Section 1);
- Excite and engage the learners using discrepant events (Section 2);
- Train learners in asking (investigable) questions (Section 3);
- Design demonstrations or practical work for the Explore phase (Section 4);
- Actively use students' ideas in the setup of your lessons (Section 5);
- Explore the potential of computer-based measurements with smartphones and Pocket Lab (Section 6);
- Use models as an interactive tool (Section 7);
- Using different contexts to elaborate the lesson content (Section 8);

Section 1: Questioning

What?

In a science lesson, students must not only be able to carry out experiments, but also to explain the results or give explanations for their observations**. In an inquiry-based lesson, the teacher uses questioning to guide learners during the explore and explain phases towards new insights and knowledge.** The teacher does so by asking well-chosen questions that make learners use and relate knowledge they have already learnt with new observations, results and findings. In this way, teachers avoid in the explain phase to give the explanation themselves. Instead, they guide learners with well-chosen observation and thinking questions to the explanation. **This sequence of well-chosen questions is called questioning**. Good questioning is important in every phase in the 5 E model.

Why asking questions?

Activity 13

Think about the reasons for asking questions in your lessons. Use voting cards to choose between:

A. To check whether students remember what they just learned.
B. To recall prior knowledge so they can understand the content of the lesson.
C. To 'wake up' students.
D. To engage them with new knowledge.
E. To focus their attention on what is important.
F. To encourage thinking and exploration.
G. To let them develop new ideas.
H. To connect their old knowledge with new knowledge.

In the activity above, reasons A – C are about **checking learners´ understanding** while reasons D – H focus on **how to get and keep learners thinking**. This section focuses on the latter reasons. You will find more information on how to check understanding in the unit on assessment (unit 5).

Questioning is a key skill for teachers. In each lesson, teachers ask tens of questions (Lemov, 2015). But what makes a question effective? And how can you use questioning to stimulate thinking, collaboration and motivation in your lessons?

Asking and answering questions is the essence of learning. We list the different reasons why questioning is important in a lesson (Table 9).

Table 9: Benefits of Questioning

Questioning enables the teacher to…	Questioning enables the learner to…
involve learners (foster commitment),	be more involved and participate more,
focus the attention of the learners on what is important,	be more concentrated and focused,
encourage thinking and exploration by the learners,	identify thinking processes and become aware that knowledge can be acquired by seeking answers on well-chosen questions,
let learners develop new ideas,	**"construct" explanations** to solve the task at hand, prompting them to build on and improve their current knowledge,
connect learners' existing knowledge with new knowledge.	see the connections between ideas,
encourage learners to formulate ideas or possible explanations	be motivated to search for answers by themselves when they deal with a new problem or question.

source: Lemov, 2015; Martino & Maher, 1999

Research has shown that **teachers ask many questions to check understanding, whereas they ask relatively few questions to get and keep learners thinking** (Wiliam, 2016). Good questioning stimulates the 'student voice' and reduces the 'teacher voice' (Burns, 2015).

Unfortunately, many teachers don't use the power of questioning to stimulate thinking and learning fully. Upon hearing a correct answer, many teachers are happy to move on. Upon hearing a wrong answer, they correct it or ask another learner to give the correct answer. Some teachers consider a wrong answer as something that needs to be avoided as much as possible. Often, teachers move on without knowing why a learner gave an answer or if anybody else had other thoughts. However, answers of confident students are a bad guide to what the rest of the class is thinking (Wiliam, 2016).

In this section, we will underline the importance of slowing down and **asking further questions no matter whether the response is correct or not**. Questions are not only about getting the right answer from learners but are about developing reasoning skills and the capacity to formulate one's thinking accurately.

Learners might not yet be used to questioning that requires higher order thinking skills. They need to move from a passive role, absorbing and reproducing information, to an active role. They will push back, but gradually they will get used to this approach. It is therefore **important to create a safe environment for learners to make mistakes**.

How asking questions?

The **main types of questions** are knowledge questions, observation questions and thinking questions.

- **Knowledge questions** let learners recall knowledge that they have already learned. Sometimes it is useful to refresh knowledge that is needed to come to an answer learned a long time ago. The more frequently we are confronted with learning content, the stronger and more robust our memory becomes (Benjamin & Tullis, 2010). However, too many knowledge questions can ruin the process of building the knowledge by the learners, so limit these questions to those that are important for the further development of the conversation.

  A mistake that teachers often make is to ask for knowledge that is not yet learnt or known from daily life and can't be constructed by reasoning by the learners. Only ask questions that can be answered by observing, reasoning or recalling knowledge that is already learnt.

- **Observation questions** help learners to observe the learning content more closely. Such questions are focused on the use of the senses: What is the colour of this? What difference do you note between… and…?, Which form has it?, How does it feel?, How does it smell?, What do you hear?....

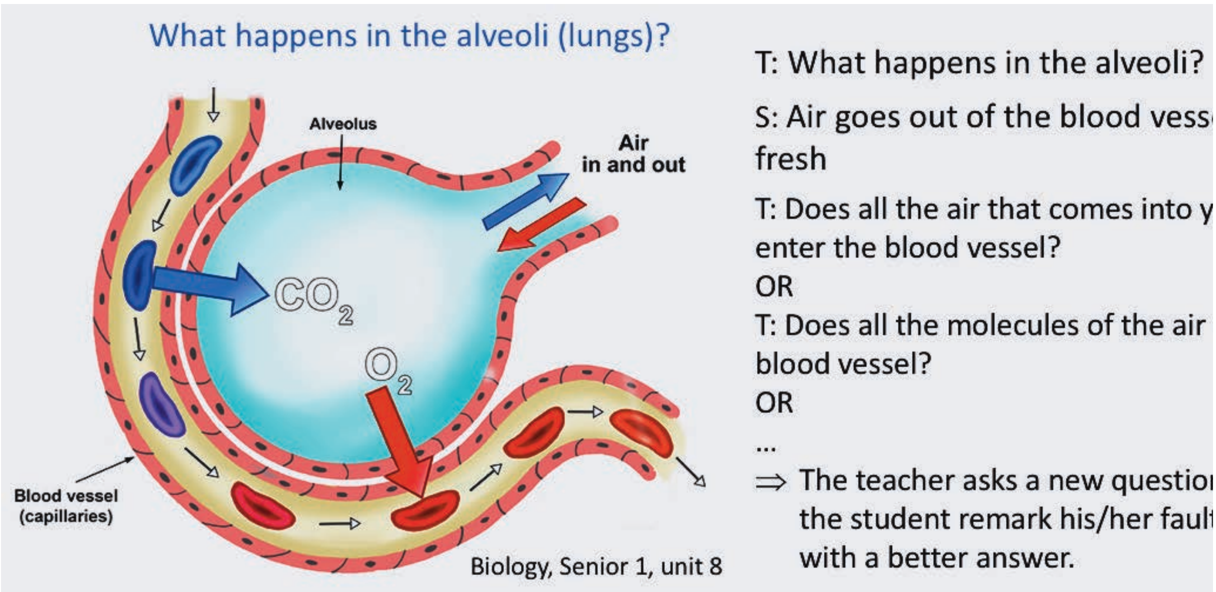


Figure 13: An example of observation questions (Biology, Senior 1, Unit 8)

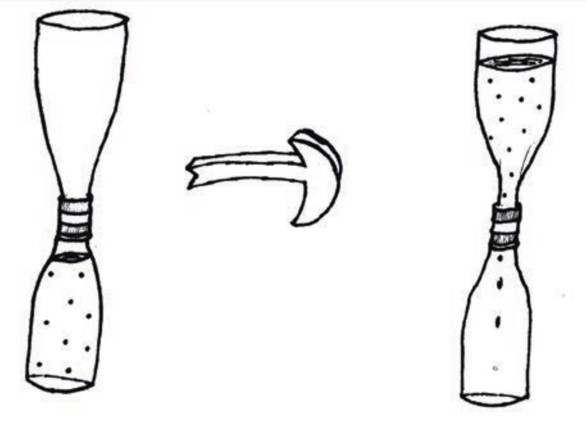
The facts that are collected with observation questions can then be used to introduce thinking questions.

- Well-chosen **thinking questions** are the most important part of questioning by the teacher. Good thinking questions usually start with: What happens ...?, How come ...?, What can you determine ...?, Explain ..., What if ...?, What is the point of that?, How can we investigate ...?, Compare, Why do you think…, In the example of fig 13, what happens in the alveoli, an example of thinking question can be: how does COVID-19 affect the lungs?

The **answers** of learners are **further processed and built upon**. For example, when a learner gives an incorrect answer, the teacher asks him/her another question that will help the learner realize the mistake and help him/her to find the correct answer. The teacher can also ask other students to formulate their opinion and involve all students by letting them vote on the answers of a few learners. It is important to let students always explain their answer: Why do you think this is right? Why is this answer correct (or incorrect)?...

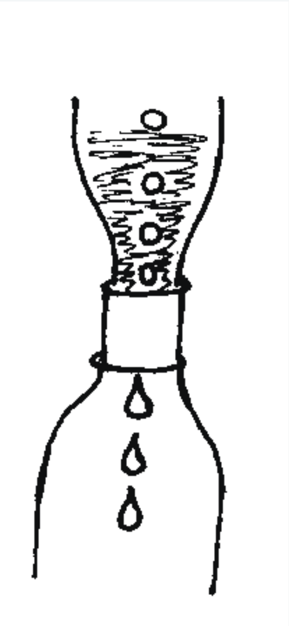
Remark in the following examples that the teacher is providing the name of the process or the new concept. The names of new concepts can't be formulated by students by observing or thinking,

An example of a questioning sequence by the teacher (Physics, Senior 1, Unit 8)



Two bottles are connected by a ring with a hole in it. Put water in the lower bottle.

T: What do you think will happen if we turn the bottles upside down? (Thinking question = Tq)
L: The water will fall down.
The teacher turns de bottles upside down.
T: Can you describe what happens? (Observation question = Oq)



L: The water stays in the bottle.
T: Do you observe something else? Look more closely. (Oq)
L: Sometimes some drops are falling, and we see some air bubbles going up.
T: What was the content of bottle A before turning the bottles? (Kq)
L: Air
T: Can you explain why the water isn't falling? (Tq)
L: Because air is filling the space.
T: Yes, air isn't nothing. We do not see it, but it is there, and it takes volume. It cannot disappear. Can you link this idea to an observation of the experiment? (Tq)
L: If some water droplets are falling, some air bubbles have to go up. They compensate each other.
T: Can you think of a way to accelerate this process? How can we fill the lower bottle of water in just some seconds? (Tq)
L: By making a hole in the water, so the air can easily go up.
T: Look what happens if I turn the bottle upside down very quickly…

An example of a questioning sequence by the teacher (Mathematics, Senior 5, Unit 2, p.41)
Demonstration for illustrating **geometric sequences**. Folding a paper once, twice, …, n^{th}, … we get a geometric sequence with ratio:

$$\left\{\frac{1}{2^n}\right\}_{n\notin ¥} = \left\{\frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \dots \frac{1}{2^n}, \dots\right\}; \quad \lim_{n\to\infty} \frac{1}{2^n} = 0$$

When we continue folding, we find that the limit of this sequence converges to zero.
A possible questioning sequence:

- T: How much has the size reduced when we fold the paper once?
- L: The size has reduced by half
- T: What happens if you fold it again?
- L: the size will reduce by half again.
- T: How much has the whole paper reduced in size then?
- L: The paper has reduced into a quarter (¼).
- T: What will happen to the whole paper if you fold it for a third time?
- L: The paper will reduce to an eighth (⅛).
- T: What will happen if you fold the paper n times?
- Learners are expected to explore the pattern and formulate a general expression as an answer
- T: What will happen when n becomes very large?
- L: The size will be very small.

Explanation:

- An example of a good explanation of geometric sequences: https://www.khanacademy.org/math/algebra/x2f8bb11595b61c86:sequences/x2f8bb11595b61c86:introduction-to-geometric-sequences/v/geometric-sequences-introduction

An example of a questioning sequence by the teacher (Biology, Senior 2, unit 7, 7.1)
The learners learned already that plants need water and minerals to stay alive and grow. The teacher just carried out an experiment to investigate the necessity of chlorophyll for photosynthesis (Activity 7.2). The purpose of the next questioning sequence is to let students discover that chlorophyll is responsible for the production of starch in a leaf. You can find more information about this experiment on https://classroomexperiments.org/2015/12/15/testing-leaves-for-starch/ .

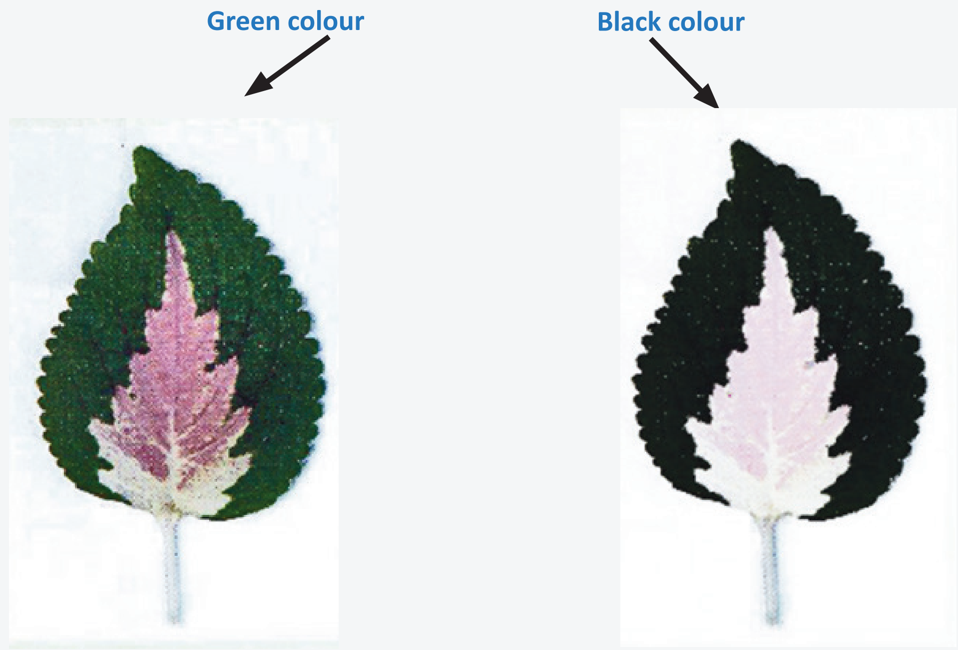


Figure 14: Result of experiment to identfy chlorophyll in green leaves

T: Compare the leaf before and after the treatment. Which change of colour do you notice when we apply iodine solution to the leaf? (Observation question (Oq))

L: The parts that were green, become black.

T: Why does the colour of the leaf change? (Thinking question (Tq))

L: These parts contain starch.

T: Is there a part of the leaf that doesn't contain starch? (Oq)

L: The part that was white.

T: Do you remember what is needed to form starch? (Knowledge question (Kq))

L: Sunshine

T: Which part of the leaf received sunlight? (Tq)

L: The upper part.

T: So what can you conclude from this? (or if too difficult: Is sunlight the only factor that is needed to form starch?) (Tq)

L: Only green parts of leaves can form starch with sunlight.

T: Correct, last year, we studied the parts of the plant cell. Who remembers which parts of the plant cell give the green colour to the leaf? (Kq)

L: The chloroplast with chlorophyll.

T: Good, so look back to the result of the experiment. Can you tell me something about the role of chlorophyll? (Tq)

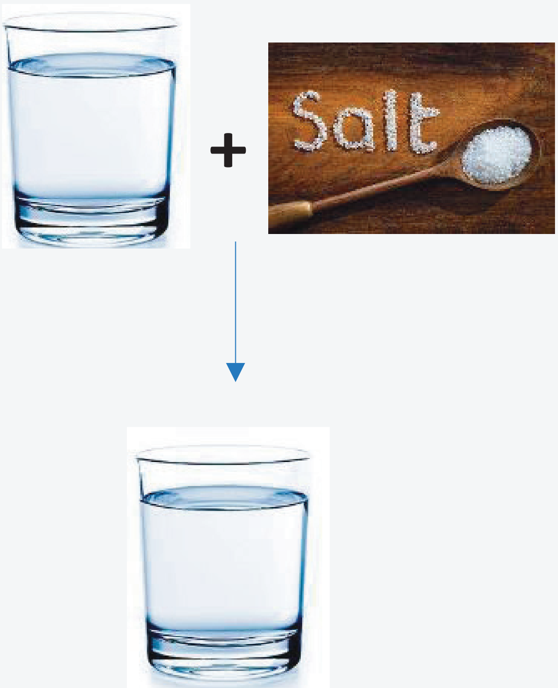
L: The chlorophyll forms starch when receiving sunlight.

T: Indeed, and the process of forming starch in green leaves that grow in the sun, is called photosynthesis.

Figure 15: Plant cell with chloroplast

An example of a questioning sequence about solubility of salts by the teacher (Chemistry, Senior 2, topic area 4, unit 6, 6.1). This is also an example of IBL and takes place during the Explore phase.

The teacher conducts the experiment while all students observe closely. The teacher adds 1 spoon of salt into a glass of water and asks:



T: *What do you observe? (Oq)L: The salt disappears*

T: Can substances disappear? (Tq)

L: No

T: Can the particles of a substance disappear? (Tq)

L: No

T: So, does this mean that the salt is still in the water, but we don't see it with our eyes? (Tq)

L: yes

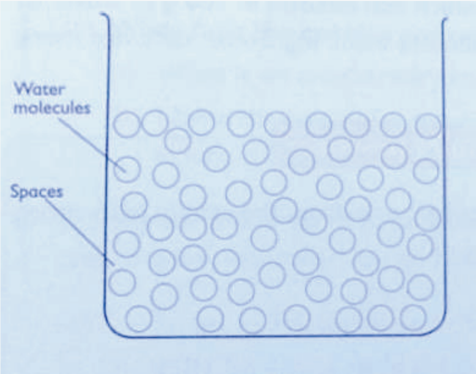
T: This means we have to look for an explanation on another scale. Which scale? (Tq)

L: Molecular scale

T: Correct!

Next, the teacher shows this diagram (from chemistry textbook) and says:

T: This is how the water looks like on the scale of molecules before adding salt. Can you describe what's in the glass? (Oq)



(i) Water

L: Water molecules and spaces

T: Good, what are these spaces? (Tq)

L: Air

T: Does air consist of molecules? (Kq/Tq)

L: Yes

T: Do you see air molecules on the drawing? (Oq)

L: No

T: If there are no molecules, can we then say that there is a substance? (Tq)

L: No

T: So, what's in the spaces? (Tq)

L: Nothing!

T: Is salt made of particles? (Kq)

L: yes

T: How would you draw salt on a molecular scale? (Tq)

L: Balls, just like the water molecules

T: Are the salt particles the same as the water molecules? (Tq)

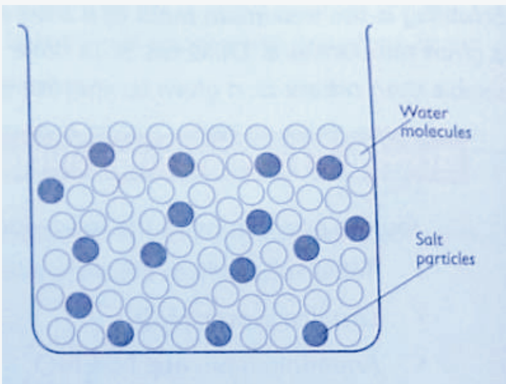
L: no

T: Correct, otherwise it would be water! So, we are going to draw them in a different way.

Teacher draws an example of a salt particle (black ball) next to the drawing and names it 'salt particle'.

T: Try to draw the situation of the salt solution on a molecular scale. (Inquiry based learning)

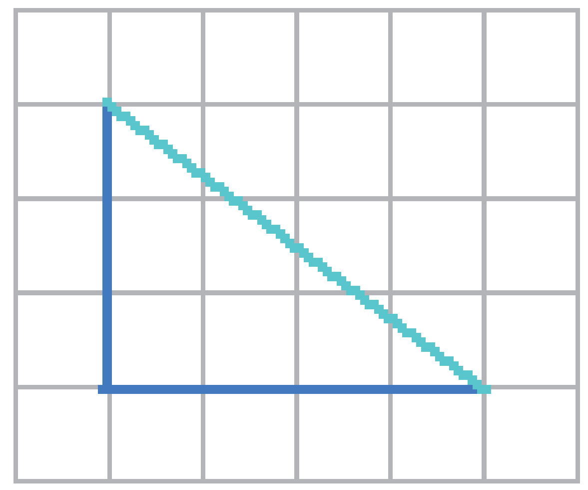
Learners draw individually or with 2 persons together their hypothesis on how they think it is. After that, the teacher shows this diagram and asks who has the same.



(ii) Salt solution

An example sequence of questioning about Pythagoras' theorem (Math S2, Unit 6)

The teacher gives the following instruction: draw from one point a vertical line upwards and a horizontal line using a ruler and a T-square. You can freely choose the length of each line, but make sure you end the lines at a grid point. Now connect the end points of both lines with a third line.



Possible result:

T: What kind of polygon appears? (Oq)

L: A triangle

T: Be more precisely! (tip: look at the type of angles of your triangle) (Kq)

L: A right triangle.

T: How can you be sure that it is a right triangle? How do you know? (Kq)

L: Because of the grid paper: horizontal and vertical lines always have right angles.

T: Now you must count or measure the length of the line segments. What are your results? (Oq)

L: Different answers, depending on the length of vertical and horizontal lines.

T: So, everyone has a vertical, a horizontal and a third line segment. The third line segment is called hypotenuse. How are the lengths of these three-line segments related? Look also at your neighbours' results. Try to make a generalization and be as precise as you can. (Tq)

L: Sometimes the vertical line is longer than the horizontal, sometimes the opposite. But it looks like, the length of the hypotenuse is always the longest.

T: Ok, the hypotenuse is always longer than the others, but is there a limitation on the length? Maybe you can draw some other right triangles to find out? (Tq)

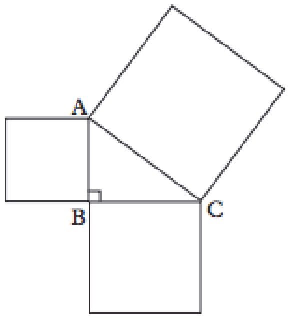
L: It looks like the length of the hypothenuse can never be equal of bigger than the sum of the vertical and horizontal line segments.

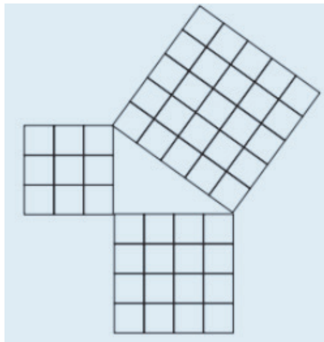
The teacher confirms these conclusions and tells that we must search for a relationship between the line segments of a right triangle. The teacher gives following instructions: Now draw a new triangle with a horizontal line segment of 4cm and a vertical line segment of 3 cm. Draw also the hypotenuse.

T: Measure the length of the hypotenuse. (Oq)

L: 5cm

T: Draw a square on each side of the triangle. This is very easy for the vertical and horizontal lines, but make sure you draw a square with right angles on the hypotenuse side. Now find out the areas of each square (Tq). (tip: very easy for the vertical and horizontal squares, but you may need to calculate it for the square on the hypothenuse).





T: Now do you notice a relationship between the areas of the squares? (Oq)

L: 25 cm^2 = 16cm^2 + 9 cm^2 or in words: the sum of the areas of the two small squares equals the big square.

T: Ok, we are getting close, but we need to find a relationship between the line segments of a right triangle. Label these segments with a (horizontal), b (vertical) and c (hypotenuse). How would you write algebraically the area of the squares? (Kq)

L: a^2, b^2 and c^2

T: How do we call these? (Kq)

L: the square numbers

T: Very logically of course… A square is graphic representation of the square number a^2, with edge a. So now can we generalize the relationship between the segments a, b and c of a right triangle? (Tq)

L: $a^2 + b^2 = c^2$

T: Indeed, this relationship is called the Pythagoras' Theorem. Can you express it in words?

L: In a right triangle, the square of the hypotenuse is equal to the sum of the squares of the other sides.

T: How can you use this theorem in exercises? (Tq)

L: We can use this relationship to find the length of any side of a right triangle when we know the lengths of the other two sides.

T: If I draw a triangle with sides 3, 4 and 6 cm, what can you tell me about this triangle? (Tq)

L: Looking at the Pythagoras' theorem, it seems that the relationship between the sides is not correct. This means that the triangle is not a right triangle.

Guidelines for effective questioning

1) ***Make sure that learners understand the question***

Do learners understand every word of the question? If not, explain first these words or use easy words in the question. Make sure that you only ask questions that learners could possibly answer.

Not a good question (Biology): *Do you see something remarkable happen when we hold the cobalt chloride paper against a potato?*

- ⇨ Do learners know what a 'cobalt chloride paper' is and what the change of colour means?
- ⇨ explain first that dry paper soaked in cobalt chloride is an indicator for water. When the 'cobalt chloride paper' is/stays blue, there is no contact with water, but when it turns to pink, the paper came in contact with water.

Not a good question (Physics/Chemistry): (see ***Figure 16***) How can you use the colours of the plasma streamers to determine the noble gases (Ar, Xe, Ne) inside the ball?

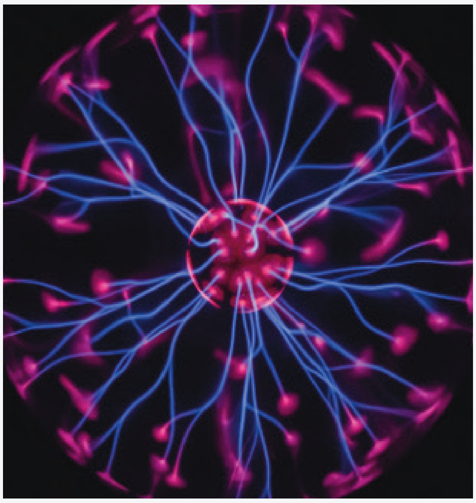


Figure 16: Plasma sphere

- ⇨ Do learners know what a 'plasma streamer' is and that Ar, Xe, and Ne are noble gases?
- ⇨ Explain that every element in the plasma state has a specific colour.

2) ***Use open questions***

A question can be a yes/no question, a closed question or an open question. Open questions are questions where the answers are not limited to a few possible answers.

Examples related to a set of leaves you bring with you in the classroom:

- Do the leaves have different shapes? (Yes/No question)
- How many leaf shapes do you count? (Closed question)
- Compare the leaves, which differences do you notice? (Open question)

Examples related to ***Figure 16***:

- Do you see the streamers moving? (Yes/No question)
- How many streamers do you count? (Closed question)
- Compare the streamers, which differences do you notice? (Open question)

Open questions are often a good way to initiate thinking and start a deeper conversation. An open question encourages a variety of approaches and responses.

Open questions help teachers build self-confidence with learners as they allow them to respond at their own stage of development. They allow for differentiation, as responses will reveal individual differences. These may be due to different levels of understanding or readiness, the strategies to which the students have been exposed and how each student approaches problems in general. Open questions teach students that a range of responses are expected and, more importantly, valued. By contrast, yes/no questions tend to limit communication and do not provide teachers with as much useful information. Learners may respond correctly but without understanding.

Some **examples of prompts** for open-ended questions are:

- How else could you have …?
- How are these the same/ different?
- What would you do if …?
- What would happen if …?
- What else could you have done?
- If I do this, what will happen?
- Is there any other way you could …?
- Why did you …?
- How did you …?
- How do you know?
- Could you use some other materials to …?
- How did you estimate what the answer could be?
- Show me an example of…
- What is wrong with the statement? How can you correct it?
- Is this always, sometimes or never true?
- How can we be sure that…?
- Convince me that…
- Give a reason why…
- Tell me more about…

After asking an open question, it is important to welcome and encourage answers, and not immediately judge them. "Thanks, that is a really interesting answer. Does anyone have something different?" will generate discussion, whereas "That is a really good answer." will not lead to any discussion, because learners with alternative ideas will remain silent. Therefore, **judgements should be kept until the end of a discussion**.

3) *Provide waiting time after you ask a question*

Many teachers are uncomfortable with silence. So, they quickly repeat the question, jump in with a prompt or grab the first hand that goes up. By merely **waiting a few seconds**, several things usually happen (Lemov, 2015):

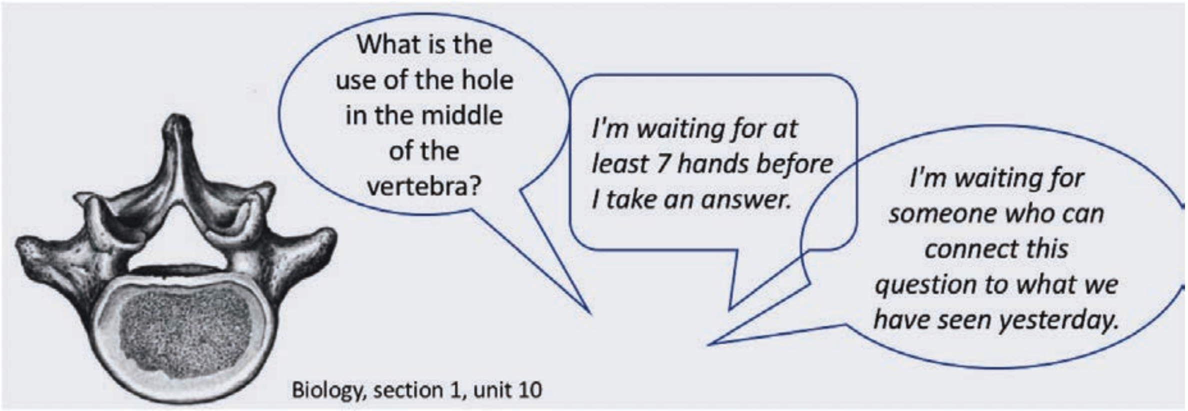


Figure 17: Providing waiting time

4) *Not Tennis but Volleyball*

When you ask a question and a student answer, you can stop all discussion by saying "correct," and move on. But you can also ask to another student: "Do you agree with this answer?" or "What is your opinion?" or "Can you adjust the answer to make it more correct?" or "Which part of the answer is correct and which part not?",...

The students' answers pass through you, but you immediately pass them on in the form of a new question to another student (Figure 18). Of course, you don't have to do this if the question is simple.

This will stimulate learners to listen to each other, think actively about each other's responses and develop their reasoning skills.

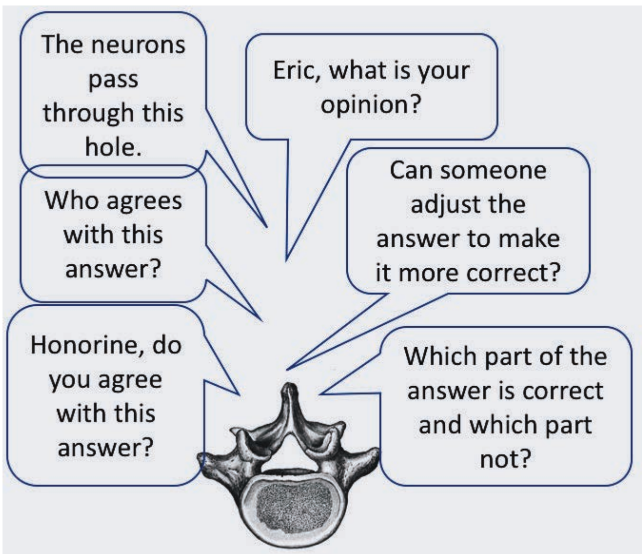


Figure 18: Not tennis but volleyball example for biology

5) *Right is right*

"Right is right" means that when teachers ask a question, they hold out for a complete answer, or one that would be acceptable on a test, with that student. Students often stop thinking when they hear that their answer is "right." However, many teachers accept answers that are partially correct or not complete. They affirm these answers by repeating them and then adding information to make the answer completely correct. The key idea behind this technique is that the teacher should set a high standard of correctness by only naming "right" those answers which are completely right (Lemov, 2015).

T: Can someone give the definition of volume?
L: The volume is equal to L x W x H
T: That's the formula. I'm asking for the definition.

In many cases, teachers would praise the answer of the student even though they did not answer the question directly.
The "right is right" technique involves:

1. **Hold out for all the way**. When students are close to the answer, tell them they are almost there but let them know that they still have more to do. For example, "What you say is correct, but is not the whole answer. Can you complete your answer?"

2. **Focus on answering the question**. Students learn quickly that if they don't know an answer they can answer a different question, particularly if they relate it to their own lives.

3. **Right answer, right time**. Sometimes students get ahead of you and provide the answer when you are asking for the steps to the problem. While it may be tempting to accept this answer, if you were teaching the steps, for example for calculations in physics and chemistry, then it is important to make sure students have mastered those steps. "My question wasn't about the solution. It was, what do we do next?"

4. **Use vocabulary for a certain purpose**. To check if students really understand a concept, accept answers with 'daily words'. For example: "Volume is the amount of space something takes up." But to strengthen their STEM vocabulary, you can push for precise technical vocabulary. Same example: "Volume is the cubic units of space an object occupies."

Example: https://www.youtube.com/watch?v=DYZjfEOg-lI

6) *Stretch learners to refine or deepen their answers*

Rather than stopping after a student gives you the correct answer, follow up with questions that extend knowledge and check for full understanding. You can do this by asking students how they got the answer, to give another way to get the answer, why they gave the answer they gave, how to apply the same skill in a new situation, or what more specific vocabulary they could use. This both challenges students to extend their thinking and checks that students don't get the correct answer by luck, memorisation or partial mastery. This technique sends the message that learning does not end with a right answer. This technique is especially important for differentiating instruction (Lemov, 2015).

Prompts or **questions** that you can use to stretch your students are (Figure 19):

- Asking how or why
- Ask for another method to get to the answer
- Ask for a better word or a more precise expression
- Ask for evidence
- Saying "tell me more" or "develop that"

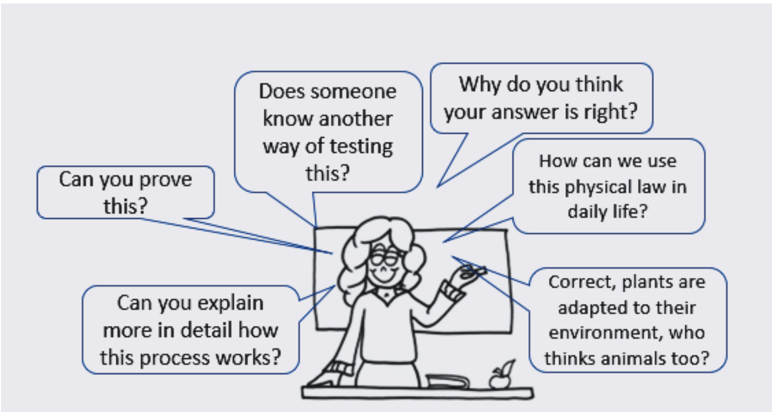


Figure 19: Stretch learners to refine or deepen their answers

This technique works best when you use it frequently. Avoid using it only when a learner has made a mistake. Learners will quickly realize that you ask these questions to indicate that the learner has made a mistake. You should be asking this question regardless of whether the answer is correct or not.
Example: https://www.youtube.com/watch?v=8P1o8y9ZXWY

Activity 14

Work in groups of 4. One member plays the teacher, three members play learners as well as observers/evaluators of the micro teaching.

The 'teacher' designs a questioning sequence with the accompanying experiment, model or picture and tries it out on the three 'learners'. Try to use all advice of this unit about questioning. Afterwards, the 'learners' comment on what was good and what can be improved. Discuss together how to improve the questioning!

Example of good questioning: Adaptation of a Xylem Vessel
Biology, Senior 1, student book p.94

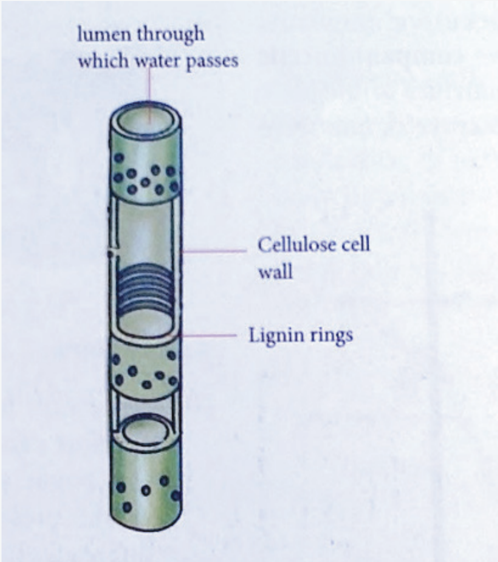


Figure 20: Cross section of xylem vessels

- What is special (unique for xylem) in the structure of this tissue?
- This tube is created out of a row of cells, so what is lacking in the row?
- What is the advantage of the lack of cross walls?
- What could be another advantage if you keep in mind that water has to pass through?
- What could be the function of the pits?
- The lumen is very narrow, this is also an adaptation of the xylem for his transportation function. Who can explain this?

Start with observation questions and then move to thinking questions. You can provide some additional information through the thinking questions.

Example of good questioning for mathematics:

For Linear Functions, Equations and Inequalities S1 Unit 3, p.64 Algebra
Use questioning to guide learners from observations to interpretation and hypothesis formulation:
Ask learners to look at the following equation: $y = mx + b$

- What does this equation represent? (Kq)
- How does the slope change when the coefficient m of x changes: ($m<0$, $m>0$, $m=0$, $m\to\infty$)? (Oq)
- What is the effect of the change of the independent term (b) on the graph: ($b>0$, $b<0$, $b=0$)? (Oq)
- What happens when $m=\pm1$? and $b=0$? (Oq)

Useful simulation to guide the questioning:
https://phet.colorado.edu/sims/html/graphing-slope-intercept/latest/graphing-slope-intercept_en.html

For Linear and Quadratic Functions (S3, Unit 6, p.85)
Ask learners to look at the following equation: $y=ax^2+bx+c$

- What does this equation represent? (Kq)
- How does the concavity and the opening of the graph change when the coefficient a of x2 changes: (a<0, a>0)? (Oq)
- What is the effect of the change of the coefficient (b) of x on the graph: (b>0, b<0, b=0)? (Oq)
- How does the graph position change with respect to y axis when the independent term c changes? (OQ)
- What happens when a=0? (Oq)

Useful simulation to guide the questioning:
https://phet.colorado.edu/sims/html/graphing-quadratics/latest/graphing-quadratics_en.html

(NB: for S6 Unit 8: the emphasis will be on Focus, Directrix, Opening (Latus-Rectum), Vertex of parabola)

Techniques to promote responses from all learners

1) *Don't let only learners answer who have raised their hands*

The first rule to ensure participation from all learners is not to let learners raise their hands when you ask a question. When you only let learners who have raised their hands, answer questions, it is easy for other learners not to be involved (Lemov, 2015). Also, as boys are often more vocal and eager to raise their hands, you risk giving girls fewer opportunities to answer (Consuegra, 2015). It is better to choose yourself who answers a question, or you can let all learners answer at once by letting them raise a card or their hands to vote.

Not focusing on learners who raise their hands has four advantages:

- It allows you to effectively and systematically check for understanding with all learners. You don't just check the learners who volunteer. You also want to know how the other learners are doing.
- All learners need to think and have an answer ready in case the teacher calls on them to respond. It increases engagement because students don't know when they will be called on.
- It increases the pace of questions and answers.

- It distributes work more equally among learners. It encourages those students who would not volunteer, but know the answer, to participate. You also let them know that you value their contribution. It allows you to make sure that boys and girls, introverts and extraverts have equal opportunities to answer.

2) ***Let Learners Vote***

This technique gets students to actively think and make judgements about their peers' answers. "Stand up if you agree with Honorine" or "Thumbs up if you think Eric is right." The answers will help to inform your teaching, especially if you ask students to defend their answers, "Why is your thumb down, John?"

Figure 21: Voting cards for student-centred learning

Questions can be evaluative ("How many of you think Nicolette is right?) or analytic ("Can anyone see the flaw in Eric's logic?"). Voting helps students process content and helps a teacher check for understanding (formative assessment). The technique brings students' answers to the forefront and keeps them involved.

You can involve all learners by using multiple choice questions and let all learners raise their hands, for example, one finger for the first answer, two fingers for the second etc. You can ask a learner in each answer category to justify her answer. You can also use this technique by asking a question and collecting the various answers from learners. Simple cards can be used with different colours and/or letters for the different answer categories (Figure 21 and see Appendix 3).

A good way to use voting is to let learners evaluate statements or generalizations. Learners are asked to decide whether the statements are 'always', 'sometimes' or 'never' true, and (important!) give explanations for their decisions. Explanations involve generating examples and counterexamples to support or refuse the statements. In addition, learners may be invited to add conditions or revise the statements, so they become 'always true'. This type of activity develops learners' capacity to explain, convince and prove (higher-order thinking skill). The statements themselves can be formulated in ways that force learners to confront common difficulties and misconceptions. Statements can be formulated at any level of difficulty.

3) *Have learners use exercise notebooks or mini white boards*

Exercise notebooks or voting cards on which learners can write answers to questions can be a very powerful pedagogical tool. After asking the question, the teacher counts down and on 'zero' all learners raise their notebook or card simultaneously. Such exercise notebooks can be useful resources for STEM teachers because:

- When learners hold their ideas up to the teacher, he/she can see at a glance what every learner thinks.
- During class discussions, they allow the teacher to ask different kinds of questions (typically beginning with 'Show me . . .').
- They allow learners to simultaneously present a range of written and/or drawn responses to the teacher and to each other, thereby stimulating all learners to think.

Examples of questions that you can use for the exercise notebooks are:

- Estimate the numbers of organisms per food level (producers, primary consumers, secondary consumers) that are needed to maintain the given food web and visualize this by drawing a diagram that is visible from the front of the class. (Biology, Senior 2, unit 2)
- Draw the graph visualising the Law of Boyle-Marriotte.

As a follow-up, it can be helpful to write a few of the learners' answers (anonymously) on the board for discussion, both correct and incorrect ones. On the board, responses become 'detached' from learners and as a result, they feel less threatened when answers are criticised by others. This encourages risk taking. You can let learners vote about what they think the correct answer is and discuss in pairs. Some teachers also introduce answers that are not given by learners but which bring out some important learning points (frequent mistakes, misconceptions) that they wish to emphasise (Swan, 2005).

Section 2: Discrepant Events

What and why?

During the Excite/Engage phase, you can help learners to focus on the lesson subject with discrepant events. Discrepant events are short teacher activities that create a conflict between what is physically observed and what one thinks that will happen (Festinger, 1962). They have an unexpected outcome. This **conceptual conflict** will motivate learners to try to solve the discrepancy and engage them for the lesson subject (González-Espada et al., 2010). Discrepant events make the central problem or topic of the lesson visible. Therefore, they generate interest and **curiosity** with the students. Students need to have some level of knowledge or awareness before they can get curious (Loewenstein, 1994). We aren't curious about something we are unaware of or know nothing about.

Discrepant events also stimulate students **to ask questions**, formulate hypotheses and predict outcomes. Based on the discrepant event, the teacher helps students to formulate the key question of the lesson. By asking for predictions, the teacher becomes aware of the prior knowledge of the learners.

How?

Discrepant events can be introduced by:

- short teacher demonstration (preferably);
- a picture or a movie (e.g. https://www.youtube.com/watch?v=5C5_dOEyAfk) if materials are not available for demonstration.

In Figure 22, the picture on the top left shows a discrepant event to introduce a lesson on equilibrium (see Appendix P.4 for a detailed description of the experiment). The picture on the right shows the experiment with the balloon (see Appendix P.4 for a detailed description of the experiment). The bottom right picture shows a discrepant event to illustrate the First Law of Newton (see Appendix P.4 for a detailed description of the experiment). On the bottom left, the picture shows a tree with tree saps leaking out of it, three weeks after the tree is cut down. How is this possible?

Figure 22: Examples of discrepant events

These short experiments or pictures increase motivation and challenge students' prior knowledge and often their misconceptions (see Unit 3, Section 5). It is important that the experiments can be done with simple materials. In this way, the focus of the experiment is on conceptual understanding and not on the complexity of the experimental setup. Once the key question is clear, you can start with the next E of the 5E's instructional model: Explore.

It is easy to find discrepant experiments for physics and chemistry, but harder for biology and mathematics. However, to increase motivation and challenge their prior knowledge, a photo, short video, plant or animal or just a few good questions related to daily life can be used as well.

Example Physics

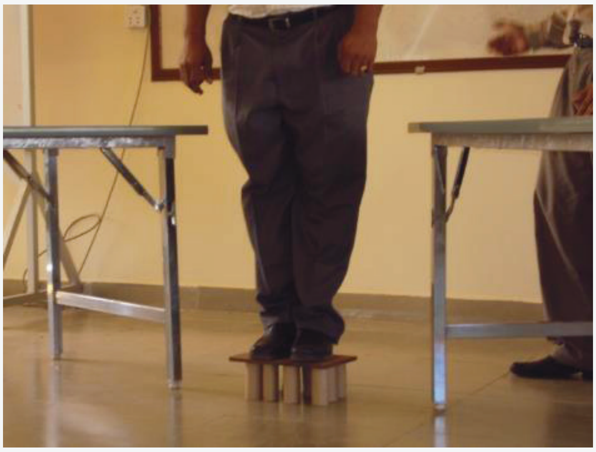


Figure 23: Standing on paper rolls, an example of a discrepant event for physics

Figure 23 shows an example of a discrepant event that can be used for a physics lesson on pressure. First, let students predict how many paper rolls are needed to support one person. Usually, they will overestimate the number. Then, stand (or let a student stand) on the rolls while another student removes one paper roll at the time.

Usually, one not too heavy person can be supported by only three paper rolls.

Invite students to ask questions and formulate a good key question of the lesson.

Learner: Why are the paper rolls so strong?
Teacher: Try to find out yourself. Is one roll supporting the whole weight of the person?
Learner: No, I can probably not stand on one roll.
Teacher: Try it out, if you are not sure.
One other learner tries to stand on one roll. The roll collapses.
Learner: So, the weight of the person must be divided over the different rolls. When is this happening?
Teacher: Yes: our key question can be to investigate the factors that are important to minimize the effect of a force?

Example Biology
Fatigue of the retina, an example of a discrepant event for biology

Figure 24: Test the fatigue of the retina

This discrepant event (Figure 24) illustrates the fatigue of the retina. Guided with this questioning, it can be used as a discrepant event before teaching about afterimage:

Teacher: Cover one eye, then stare at the white point in the centre of the black star. Then look to the zone right from the square. What do you see?
Learner: First I saw a white star with a grey dot in the middle but after 2 seconds, it changed to white, the colour of the paper. How come?
Teacher: What could have changed? Did the paper change?
Learner: No
Teacher: So where else do we have to search for an explanation?
Learner: In the eye.
Teacher: Ok. Which part of the eye?
Learner: The retina.
Teacher: Why the retina?

Learner: Because images are transformed into impulses in the retina.
Teacher: Good! We call the image we see afterwards, the afterimage. Can you formulate a key question?
Learner: How is an afterimage brought about?

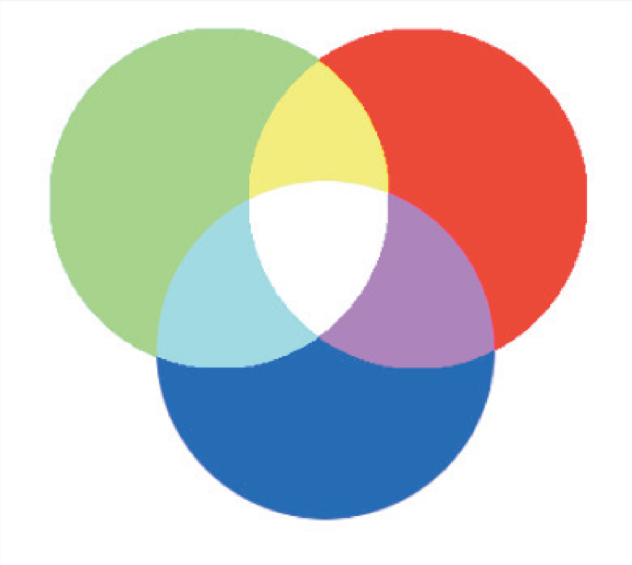


Figure 25: Diagram of Primary and Secondary Colours

This experiment can also be used with coloured images in the elaboration phase after students have learned about the functioning of the 3 different cones corresponding roughly to red, green, and blue sensitive detectors in the retina. They should be able to explain why they see the cyan colour (greenish-blue), by presenting them this figure in colour. The 3 primary colours distinguished by the cones: green, red and blue, with the secondary colours in between, each composed of 2 primary colours: yellow, pink and cyan.

Example Chemistry

Test the top of a match for magnetism. It isn't magnetic. However, after the match is lit, it becomes ferromagnetic

Figure 26: Matches become magnetic after burning, a discrepant event for chemistry

The yellowish colour of the burning match indicates that it has low oxygen, i.e. a reducing flame. It reduces the iron oxide to iron which is attracted by the magnet. Under normal circumstances, ferric oxide is not ferromagnetic, so an unused matchstick will not be attracted to a magnet. But when burnt, a matchstick releases carbon monoxide and carbon.

Both carbon and carbon monoxide are reducing agents and will reduce ferric oxide to pure iron, which is ferromagnetic.

The corresponding reaction is:
$Fe_2O_3(s) + 3CO\ (g)$ ----.> $2Fe\ (s) + 3CO_2\ (g)$

Other discrepant events for chemistry can be found in 'Invitations to Science Inquiry' (Liem, 1990)

Examples mathematics

A good discrepant event activity for teaching about Pascal's Triangle (S4) is the Galton board:
https://www.youtube.com/watch?v=Kq7e6cj2nDw

Figure 27: The Galton Board, linking Pascal's Triangle to the normal distribution

Because of the nature of mathematics, it is difficult to find discrepant events for each topic. In maths, discrepant events are often referred to as **paradoxes**.

- A lot of paradoxes are related to the **concepts of zero and infinity**. For instance, you cannot divide a number by zero, because it can result in both +∞ or -∞. The result is undefined (see https://www.youtube.com/watch?v=BRRolKTlF6Q&frags=wn). Another paradox is the fact that the number 0.999999… is equal to 1. (see https://www.youtube.com/watch?v=R2lJIXHZYwA).

- There are also several discrepant events related to the concept of **probability**. A nice one is the birthday paradox. This says that if there are 23 people in a room, there is a more than 50% chance that two people have the same birthday. When there are 50 people in the room, the chance is even more than 96 %. It seems counterintuitive because the probability of having a birthday on any particular day is only 1/365.

  But the difference relies on the fact that we only need two people to have the same birthday as **each other**. If, instead, the game was to get someone with a birthday **on a particular day**, such as March 14, then with 23 people, there is only a 6.12% chance that someone will have that birthday. In other words, if there are 23 people in a room, and you choose one person X, and ask, "Does anyone else have the same birthday as X," the answer will probably be no. But then repeating this on the other 22 people increases the probability every time, resulting in a net probability of more than 50% (50.7% to be more precise). (see https://betterexplained.com/articles/understanding-the-birthday-paradox/)

Example of a **discrepant event on isometries** (S2, Unit 9)

- ✓ Folding a sheet of paper with respect to a given fixed point for defining circle from a polygon.
- ✓ Instructions for this event: https://www.youtube.com/watch?v=fn1SreHn_8E . Materials needed: Paper and scissors.
- ✓ Ask learners to fold a paper into two equal halves, and to draw a labelled scalene triangle (triangle with all its sides of different lengths). With a scissor, ask learners to remove the surface area of that triangle, and then, ask learners to predict observable characteristics of the folded paper, if opened. Starting from answers given by learners, the teachers can teach the invariance metric properties (length, angle, area) and reverse of direction under reflection in line which is a negative isometry.
- ✓ Explanation: Circle is limit of polygon when the number of its sides increases without bound $\left(\lim_{n\to\infty} P_n = C\right)$, where P_n stand for a regular polygon with n sides and C is circle.

Keep in mind

- The focus of discrepant events is on explaining basic concepts. The experimental setup should be simple, so every experiment has a clear objective.
- Learners must be challenged. Important learner activities while demonstrating experiments are *asking questions*, formulating *hypotheses* and *predict* outcomes.
- The experiments help you to find out what learners already know about the concept (see Unit 3, Section 6).

- Learners have to construct their knowledge, not the teacher.
- Typical sequence for a demonstration:
    1. Introduce the experimental setup
    2. Ask for predictions
    3. Perform the experiment and let learners describe their observations
    4. If relevant, analyse the wrong predictions
    5. Stimulate learners to ask key questions.

Observations versus inferences (interpretations)

During discrepant events it is very important to teach your learners to observe carefully and to question their original ideas. They need to learn to **distinguish between observations and inferences**.

An **observation** is a description of an observed **pattern**. Observations can be done with our five senses (sight, smell, hearing, taste, touch). They can be **qualitative** or **quantitative**. Qualitative observations describe a pattern we observe and are usually expressed with adjectives, whereas quantitative observations measure what we observe and are expressed in numbers.

An **inference** is an interpretation or a conclusion that we draw from our observations. Inferences are not directly observable and are often assumptions about the observations. Inferences are based on our past experiences and our internal models about the phenomenon. They can change when we make new observations! For example, we don't observe pressure, but it can be an interpretation of observing bubbles in a liquid.

Activity 15

Describe your observations during the experiment with a candle and a glass (see https://www.youtube.com/watch?v=GYt1LKhK6P8).

- Individually, write down what you observe that the facilitator is doing.
- Write the different observations on the board
- Discuss which ones are real observations and which ones are inferences.

If you ask learners to analyse the above video, they will describe some elements of the video, but very easily talk about a candle. But what if it only looked like a candle and you eat the candle at the end of observation exercise (*NSTA News*, n.d.). The observation of a candle was actually an inference, so learners should be careful. Similarly, if you ask them to describe an Ampere meter indicating 1A, some of them may describe moving electrons, although they have never observed electrons.

Examples of discrepant events

- Websites:
  - Experiments of Tik Liem (Liem, 1990): https://sites.google.com/site/raftcaliforniage/tik-liem---the-first-and-best-everyone-steals-from-him
  - https://sciencing.com/list-discrepant-event-science-activities-8018044.html
  - https://www.scholastic.com/teachers/articles/teaching-content/40-cool-science-experiments-web/
- Videos:
    - compilation of 10 experiments: https://www.youtube.com/watch?v=sinQ06YzbJI
    - compilation of 15 experiments: https://www.youtube.com/watch?v=F9jMHZHXIu0
    - compilation of 32 experiments: https://www.youtube.com/watch?v=6xz_b_Tl3Il
  - Veritasium channel:
    - https://www.youtube.com/user/1veritasium?hl=nl&gl=NL

Section 3: Raising Questions for Learners

What and why?

> *'If I had an hour to solve a problem and my life depended on the solution, I would spend the first 55 minutes determining the proper question to ask because once I know the proper question, I could solve the problem in less than five minutes.'* (Albert Einstein)

Asking questions is a key skill of every scientist. Albert Einstein suggested that every problem has a proper question that leads you easily to the correct answer, but those questions aren't easy to find. In this section we will focus on raising questions and transforming questions into good or 'proper' questions. These are questions that will help you to solve the problem more easily. Learners should also be trained in asking questions and you can use this section with them. When the questions come from learners themselves, they will be more motivated to find the answer to those questions. And, like Einstein said, asking the 'right' question, is a major step towards solving the problem. They will gain a lot of insights in the problem.

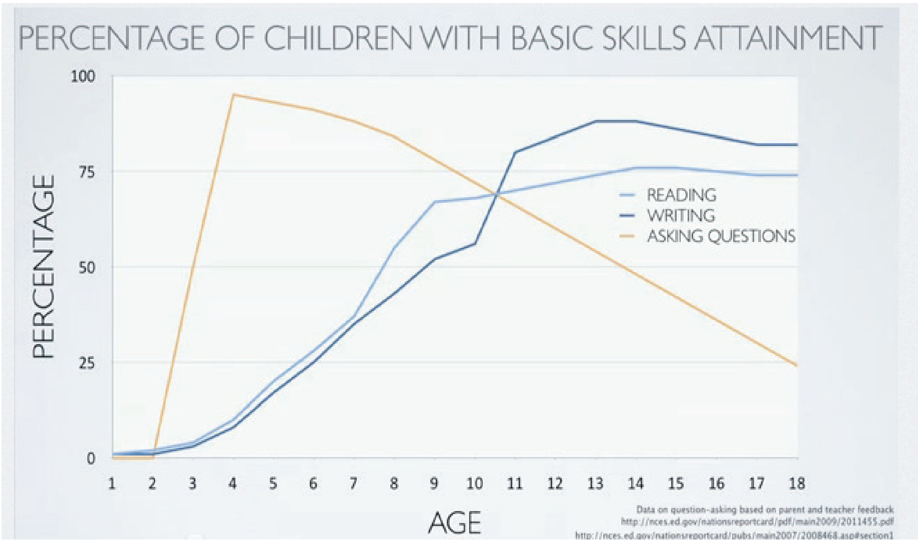


Figure 28: Percentage of children with basic skills attainment per age (National Centre of education statistics, 2009)

In Figure 28 you can see how the basic skills of learners change throughout their childhood.

While reading and writing skills are learned on schools, it looks like the art of asking questions is already present at a very young age, but that it diminishes with age and schooling. Of course, this doesn't mean that there is a causal relation between schooling and the disappearing of questioning skills. This disappearance can also be related to the fact that the need for questioning disappears as youngsters develop more insight in the world (Janssen & de Hullu, 2008). However, schooling is not able to stop this decline, and this is related to the fact that educational systems are focused on answering rather than asking questions. We know that our best scientists are very skilled at asking questions, so there is certainly a good reason to train these skills during science and mathematics lessons.

In this section 3, you will learn:

- to stimulate learners to ask questions,
- that questions can be either investigable or non-investigable,
- that non-investigable questions can be turned in investigable questions by searching for variables.

How to raise questions?

Activity 16

The facilitator chooses a daily-life phenomenon, like a piece of ice (put some water in a balloon and put it in the freezer) (https://www.exploratorium.edu/video/ice-balloons-activity-step-step-demonstration?autoplay=true ; https://www.youtube.com/watch?v=NYBCU86AiA8), some gel balls (https://en.wikipedia.org/wiki/Water_gel_(plain), a closed ecosystem, a burning flame ((https://www.youtube.com/watch?v=Nci6qS3DXYg), cow regurgitation (https://www.youtube.com/watch?v=v0TTaAsudYU), the dancing of raisins in lemonade (https://www.youtube.com/watch?v=mEGCvj977_A&frags=pl%2Cwn), …

Divide the class into groups of 4 and provide them with one version of the phenomenon so they can clearly observe the phenomenon. Provide every group with at least 10 small pieces of paper.

Take 15 minutes to observe the phenomenon (first only looking) and write down one question per paper.
Try to formulate at least 10 questions per group. There are no bad questions, as long they have something to do with the phenomenon. Stimulate participants to think out of the box.

After 5 minutes, learners may also use other senses (touch, smell, …) or they can use some tools or instruments that can offer a deeper observation (e.g. magnifying glasses, thermometers, extra light …) and formulate more questions

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3 This section is based on a workshop called 'Raising questions' designed by the Exploratorium (The Museum of Science, Art and Human Perception, San Francisco | Exploratorium, n.d.). You can download a full description of this workshop on https://www.exploratorium.edu/sites/default/files/pdfs/ifi/Raising_Questions.pdf

Activity 17

In this activity, we will reflect on the previous activity.

Discuss following questions:

- Was it easy? Why or why not?
- Was there a difference between using only your eyes and using other senses or instruments?
- Are there different types of questions in your group?
- Are there questions that you know the answer of?
- Are there many questions that you do not know the answer of?

Within each group, identify the most original question. The facilitator will write the most original questions on the board, so you can see different types of questions. Discuss what the essential conditions are to formulate new questions.

Discussion

Research shows that close observation helps to raise questions because the observer starts to realize that he/she does not understand all the details of the phenomenon. Questions are also influenced by the prior knowledge and interest of the learners (Figure 29). Questions often lead to more questions.

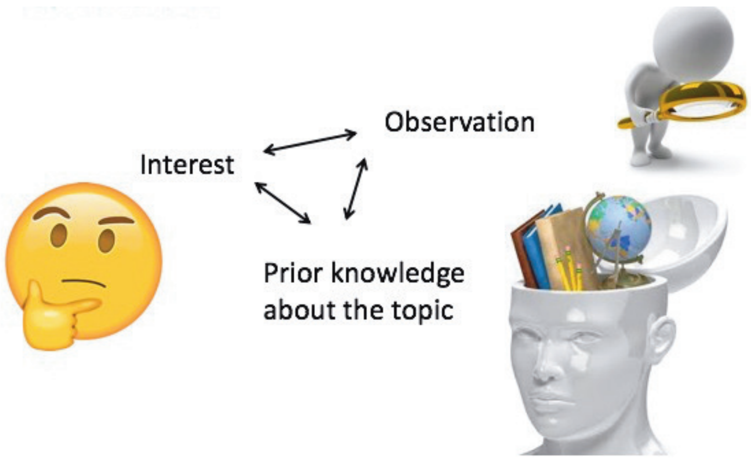


Figure 29: Conditions to formulate new questions (Exploratorium, 2006)

How to find the difference between investigable and non-investigable questions?

Activity 18

Review the questions from the previous activity. Take a few minutes to go through all questions and sort them into two piles. One pile is for the questions that you think are 'investigable' and the other pile is for questions you think are 'non-investigable'.

Once this done, let each group find the criteria when a question is investigable. Discuss criteria and create a list.

To clarify the terms used:

- **Investigable questions** are questions that you can answer with a concrete experiment and observe the results of this experiment.
  These questions start like:
- **what will happen if…**

Questions that lead to taking an action are considered "investigable." For example, questions that begin with "what will happen if" … or contain the phrase "does the … make a difference" can be investigated. The way they are phrased invites one to experiment with materials and phenomena. "What will happen if we put salt on the ice?" or "Does the temperature of the water make a difference?" indicate a clear course of action. Those questions relate to searching for patterns that result from direct observation.

- **Non-investigable questions** are questions that you cannot answer with an experiment in the school.

Questions that do not lead to taking experimental action are considered "non-investigable." For example, questions that begin with why—such as "Why is most of the ice balloon underneath the water?" or "Why are parts of the ice balloon cloudy?" are non-investigable. These questions are requests for information or explanations. Answering these kinds of questions usually requires obtaining information from a book, the Internet, or an expert. Those questions require models to find an answer. We will see that you need a model of the phenomenon to turn this type of question into an investigable question.

The way a question is framed affects how it can be answered. The technique to turn non-investigable questions into investigable ones, is called a **variables scan**. Let's have a look at how you can reformulate non-investigable questions into questions that can lead to experimental action.

Take the following situation: some learners are exploring how paper towels absorb water. They notice that paper towels seem to "suck up" the water. Someone asks, "Why does the water go into the paper towel?" If we want to turn this question into an investigable question, you need to scan the phenomenon for variables. The explanation must have something to do with how the water and the paper towel interact, so those are the variables we can change to help us learn more about the phenomenon.

Now, consider variable one: the liquid being absorbed and ask yourself the question 'What could be changed about the liquid?' The kind of liquid (orange juice, motor oil, etc.) or the amount of liquid or the temperature of the liquid. Immediately, you can produce several investigable questions, turning the original question: "Why does the water go into the paper towel?" into 'Would something different happen if the water were very hot or very cold?' or 'Would salt water result in a different outcome from fresh water?' or Will the water be sucked higher into the paper if we use tomato juice instead of water?

Consider the next variable: The material absorbing the liquid. What could be changed about the paper towel? The brand of paper towel, the way of wetting the towel (pouring the water onto the paper, dipping the towel into the water, etc.), the kind of material (cotton, wool, cardboard, etc.). Use this information to create some extra investigable questions.

Background Information

Paper towel absorbs liquids like water because it is made of cellulose or sugar molecules which makes it strong and absorbent. Cellulose is made of giant sugar molecules which are polar molecules. Think how easily normal sugar dissolves in water. When you get a paper towel wet, the water molecules rush in and cling to the cellulose fibres. Therefore, the cellulose structure weakens in water. This will not happen with oil.

More information: https://www.youtube.com/watch?v=a-KoPk_ThPY

Scanning for variables will help you to turn any question into an investigable question.

Some **examples**:

- Would something different happen if the water were very hot or very cold?
    - This a yes/no question. They can be used as a starter question, but the answer doesn't give all possible information. It is better to formulate the question broader: 'What would happen if the water were very hot?' Or using more variables: 'How will the absorption of the paper towel change as a function of temperature?'
- How will salt water influence the absorption strength of the paper towel?
- Will the water be sucked higher into the paper if we used fruit juice instead of water?

This is a first and very important step in finding the 'proper' question, like Einstein said. Investigating the relevant variables (like the quality of the paper, or the viscosity of the liquid) may lead to a deeper understanding into the mechanisms behind the absorption of water in tissues.

Activity 19

In this activity, you will practice the skill of reformulating non-investigable questions into questions that can lead to action.

Take a why question from your group or from another group and turn it into an investigable question.

Activity 20

Take a small piece of paper to write an *exit ticket* with following questions:

- What are the main ideas of this section for you?
- What would you like to do in your classroom? Note whether this will be practically possible.
- Formulate one question or an alternative idea.

Revisiting the quote from Einstein at the beginning of the section, we have made progress in formulating proper questions. Investigable questions give you an idea of what is important.

Letting learners formulate questions leads to more motivation and provides information to the teacher about students' understanding. Often, students' questions are too general. They need guidance in turning questions into "proper", investigable questions.

Try- out this activity in your class!

A rise in temperature (fever) has been one of the signs (symptoms) of COVID-19. Currently, you see the temperature sensor being used to measure the body temperature without touching the body!

Demonstration: You can use the sensor in a class and get the temperatures of different learners in class. Then, you will stimulate learners to ask questions of their observations.

Possible investigable questions that students may come up with are:

- Would the sensor work if someone is wet?
- What will happen to the sensor if a person moves close or far from it?
- What will happen if a paper is placed between the sensor and the person? Etc.

You can help learners to turn non-investigable questions into investigable questions. Next, you can select one or two investigable questions to experimentally investigate.

In the explore phase, learners can find explanations on their observations.

Conclusions

- Interesting phenomena can stimulate a rich variety of questions.
- Questions drive the investigation process.
- Questions can either be investigable or non-investigable.
- Non-investigable questions can be turned into investigable ones.

Section 4: Demonstrations and Practical Work

What?

Questions are raised when learners observe a discrepant event. Teachers guide the learners to key questions and investigable questions that can be solved in the Explore phase by **doing one or more experiments**. Experiments stimulate learners to observe, to ask questions and to think about explanations. If there is enough material and time, these experiments can be done by the learners. We call this practical work. If materials are limited, teachers perform the experiment. We call this a demonstration.

Activity 21

Discuss the following questions:

- Are you doing practical work in your lessons?
- Can you give an example?
- Why do you do practical work in your lessons?

Why?

The goal of the practical work defines the type of practical work and how it is organised. Therefore, before doing practical work, it is important to have a clear idea on the objective. The 3 types of practical work that correspond with its **3 main goals** are**:**

1. equipment-based practical work: the goal is for students to **learn to handle scientific equipment** like using a microscope, doing titrations, making an electric circuit, ….
2. concept-based practical work: **learning new concepts like density of material, pressure in liquid, ….**
3. inquiry-based practical work: learning **process skills**. Examples of process skills are defining the problem and good research question(s), installing an experimental set up, observing, measuring, processing data in tables and graphs, identifying conclusions, defining limitations of the experiment such as verification of Ohm's Law,….

Apart from these main goals, a well-constructed practical work **increases the motivation of learners and shows them how experimental science works.**

If you expect that learners won't learn more by doing practical work compared to observing a well-performed teacher demonstration, then choose the demonstration. Shortage of available materials, the cost of materials, hazardous materials or potential health risks can make a demonstration preferable. If there is a lack of time or available materials, a combination of demonstration and practical work (in stations, see further) can be a good solution: do a demonstration to teach the conceptual knowledge, and let learners do practical work to learn the procedural knowledge.

Always keep in mind that, as a demonstration is done by the teacher, the first goal will not be reached by the learners. The second goal will be reached with a demonstration and when the teacher asks the learners to formulate observations, to identify conclusions… then the third goal can also be achieved with a demonstration.

How to perform a practical work?

When practical work is not performed well, it won't bring any advantages compared with demonstrations or a teacher explanation (Hodson, 1993). Therefore, we describe some steps to follow and some **guidelines to keep in mind** (Berg & Buning, 2015):

Define the focus

- Define the goal and type of practical work and do not mix different types of practical work. It is impossible to carry out a concept-based practical work without skills or to perform an inquiry-based practical work without concepts, but the purpose is to focus on one type by choosing simple process skills for a concept-based practical work or using simple concepts for an inquiry-based practical work.
- Make the goals of the practical work clear to the learners.
- It is not possible to train all skills (handling equipment and process skills) or skills and concepts in one practical work. Choose 2 or 3 skills or clearly **define which concepts to focus on** and choose other skills or concepts to focus on in another practical work or demonstration.

Follow the basic structure of a practical work

The goal of the practical work defines the basic structure of a practical work:

1. A good equipment-based practical work consists of:
   - clear instructions to follow, often recipe based
   - enough exercises in order to learn the practical skills
   - reflection questions like 'Why do you do this in that way?'
2. A good concept-based practical work consists of:
   - starting with a context or defining the student ideas from which to start.
   - a series of activities, to construct or train a new concept.
   - a confrontation with alternative conceptions of the learners.

   Keep in mind that:

   - To learn the new concept by practical work, the lesson should start with the practical work and the theory can be explained by the teacher afterwards (explore – explain). First teaching the theory and then doing the practical work to prove what they have learned is demotivating and offers little added value for student learning.
   - Try to avoid complex arrangements or procedures. Use simple equipment or handling skills to make it not too complicated and keep the focus on learning the new concept.

- If this is not possible and it is necessary to use new equipment or handling skills, then first exercise these skills before starting the experiments of the concept-based practical work.
- The experiments should be useful for all learners and not only for aspiring scientists. Try to link the practical work as much as possible with their daily life and preconceptions.

3. **A good inquiry-based practical work** lets the learner make **choices** in the experimental setup and discuss the pros and cons of different experimental setups.

   It depends on the present process skills of the learners how 'open' the inquiry-based practical work can be. Over the course of lower and higher secondary school, teachers should work in small steps towards the following goals that should be reached by the end of secondary education (Council et al., 2012). Students should be able to:

   - Formulate a question that can be investigated in the classroom with available resources and formulate a hypothesis based on a model or theory.
   - Decide what data need to be collected, what tools are needed for the collection and how measurements will be recorded.
   - Decide how much data are needed to have a reliable measurement and keep in mind what the precision (accuracy) of the data is.
   - Plan procedures and identify relevant independent and dependent variables and, when appropriate, the need for controls.

Learners should have opportunities to plan and carry out several different kinds of investigations during their secondary education science lessons. In order to learn how science experiments work, learners must be asked or reminded in the lower secondary years why an experiment is set up this way or why the research question is built up in that way. In some cases, the procedures are so easy that learners in the lower grades can already plan the procedure by themselves. So sometimes these goals set for Senior 6 can already be reached in the lower secondary years, but always on the condition that the level of difficulty is adapted to the level of the learners.

Keep in mind that:

- Most process skills can be practiced separately, even without equipment. For example: interpreting tables and graphs, planning an experimental setup …
- It is preferable to use experiments with easy content when the purpose of the practical work is to elaborate research (process) skills.

Define how to order, analyse and interpret data

Once collected, data must be ordered in a form that can reveal patterns and relationships and allows results to be communicated to others. We list **goals about analysing and interpreting data** (Council et al., 2012).

By the end of secondary education, students should be able to:

- Analyse data systematically, either to look for relevant patterns or to test whether data are consistent with the initial hypothesis.
- Recognize when data conflict with expectations and consider what revisions in the initial model are needed.
- Use spreadsheets, databases, tables, charts, graphs, statistics, mathematics and ICT to compare, analyse, summarize, and display data and to explore relationships between variables, especially those representing input and output.
- Evaluate the strength of a conclusion that can be inferred from any data set, using appropriate grade-level mathematical and statistical techniques.
- Recognize patterns in data that suggest relationships worth investigating further. Distinguish between causal and correlational relationships.
- Collect data from physical models and analyse the performance of a design under a range of conditions.

Methods to organize practical work

There are 3 main methods to organize a practical work.

1. Each group does the same experiments at the same time

The logical sequence of the experiments can be followed by all learners, but this implies that a lot of material is needed (Figure 30). The best group size is 3, as all learners will be involved. With bigger groups, you can ask to do the experiment twice, where learners change roles.

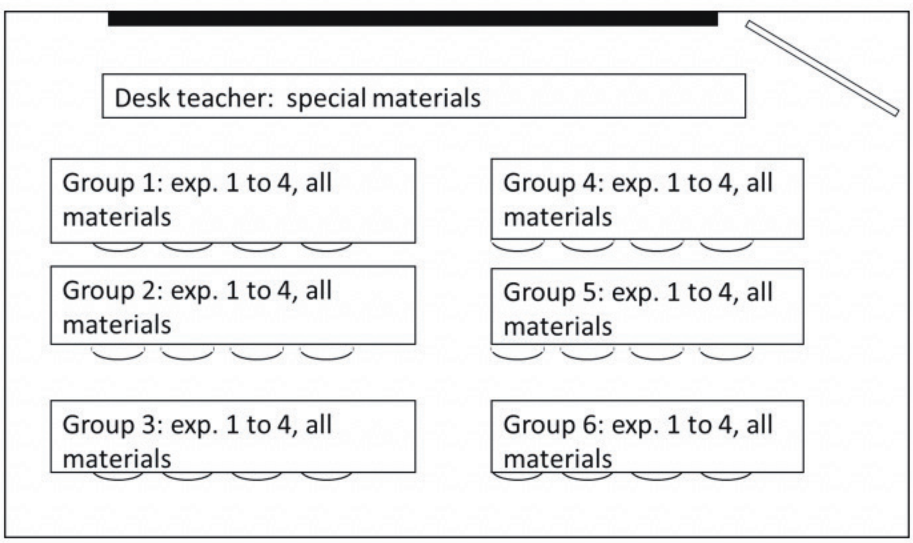


Figure 30: Method for practical work: all groups do same experiment at same time

2. Experiments are divided among groups

Each group does the assigned experiment and upon a signal by the teacher, moves to the next experiment (Figure 31). At the end of the lesson, each group has done every experiment. This method saves material but is not perfect when experiments are ordered in a logical way. In some cases, the conclusion of an experiment provides the research question for the next experiment. In that case, this method is not very suitable.

The organization is also more complex. Before the start of the lesson, the materials for each experiment should be placed on the different places where the groups will work. Also, the required time for each experiment should be about the same. Use a timer to show learners the time left for each experiment. Provide an extra exercise for fast groups.

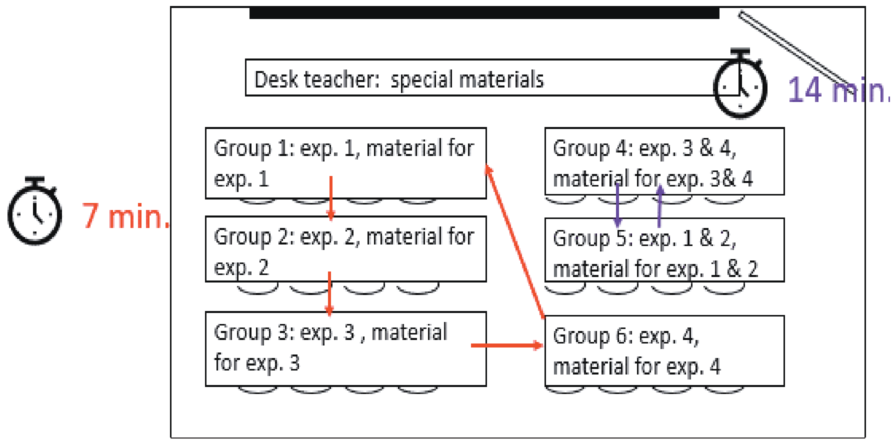


Figure 31: Method for practical work: experiments are divided among groups

3. All experiments are divided among groups

Each group does only one or two experiments. The other experiments are done by other groups (Figure 32). Afterwards, the results are brought together and discussed with the whole class. This saves time and materials, but it means that each learner does only one experiment and 'listens' to the description of the other experiments. The method is suitable for experiments that are optional or similar to each other. It is not a good method for experiments that all learners need to master.

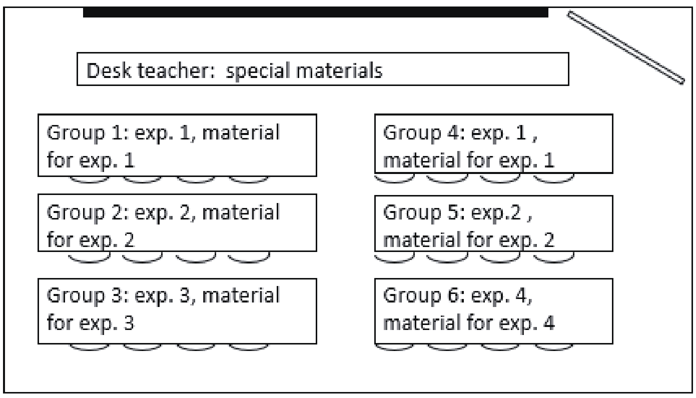


Figure 32: Method for practical work: all experiments are divided among groups

What steps are taken to prepare the practical work (Devoldere, 2017)

- Have a look to the available material at school and make a list of what you can use and what you need to bring.
- Determine the required quantities by determining the method (see above).
- Collect all materials for the experiments in one place. If the group of learners is small, then they can come to get the materials on that spot, but with more than 15 learners, this will create disorder. In that case, prepare for each group a set of materials and place it on their desk.
- Test all experiments and measure the required time for each experiment.
- Prepare a nice but educational extra task for learners who are ready before the end of the lesson.
- Write on the blackboard how groups of learners are formed.

In the **lesson plan** of a lesson with a practical work, there should be the following phases:

1. The **introduction** of the practical work, the Excite phase, consists of a question, discrepant event or a small conversation to motivate learners and make connections with daily life and learners' prior knowledge.
2. The discussion of **safety rules** for the practical work (Devoldere, 2017):
   - only work at the assigned place, don't walk around in the class if this isn't asked.
   - long hairs should be tied together, and safety eyeglasses should be worn for chemical experiments.
   - only the material needed for the experiment should be on the table.
   - …
3. The **instructions** for the practical work: how groups are formed, where they get the materials, special treatment of materials (if relevant), what they have to write down…
4. When the **materials** for the practical work aren't yet at the correct location, then **distribute** them now. Once learners have the materials, it is more difficult to get their attention.
5. Practical work: learners do the experiments, while the teacher coaches by asking questions (Explore phase).
6. Cleaning the workspace after the practical work (by the learners as much as possible).

The practical work should preferably be processed immediately with an Explain phase. If not, this should happen in the next lesson.

Worksheet for learners

Each group should have at least one worksheet that learners complete during the practical work. The worksheet consists of:

- the key question;

- hypothesis: learners write down what they think will be the answer on the key question and provide arguments for their prediction.
- materials needed
- procedure or, for an inquiry-based practical work, some questions that help the learners to find a procedure
- observations: learners write down their observations. The teacher can provide tables to write down the data.
- conclusion: learners write down the conclusion of the experiment.
- reflection: Did you expect other data? What went well? What could you have done better?…

Guidelines for **the role of teacher during practical work**

During practical work, the role of the teacher is to **coach** instead of helping with advice or questions. It is better to answer a question of a learner with another question than to give immediately the answer or advice. The additional question should help learners to find the answer themselves.

- Prepare some **questions** for each practical work, no matter what the type is:
  - to start the practical work: start with a discrepant event or questions that help defining the problem or questions that link the practical work with students' daily life or their initial conceptions about the topic.
  - to coach during the practical work: 'Why do you do this?', 'What is a control tube?', ''What is the purpose of the experiment?', 'How do you call this product?', 'What are your results?' …
  - to end the practical work: 'What was the meaning of the experiment?', 'What did we learn?', 'What do we know now that we didn't know at the start?', 'What surprised you?'…
- Announce the **end of the practical work** 10 minutes before in order to give learners enough time to finish their work and to clean their space.

Examples of a demonstration and an inquiry-based practical work

See Appendix biology for an example of an inquiry-based practical work on the growth direction of plants.

See Appendix biology for guidelines of a demonstration of the anatomy of a mammalian heart.
See Appendix biology for a learner experiment sheet of a dissection of the cow eye.
See Appendix chemistry for a practical work on the reaction rate (Example Lesson plan)
See Appendix maths for an example of practical work for algebra and Pascal's triangle.

Activity 22

In groups of 3, you get a worksheet with a description of an experiment or practical work. Do the following:

- Try out the experiment.
- Write down how the experiment will help to achieve learning goals of the curriculum.
- Reflect on how you would use the experiment in the classroom, as a discrepant event, demonstration, or practical work?
- What will be the goal of the experiment?

Next, demonstrate the experiment to the whole group and explain how you will use it in your lesson. React on the demonstrations from other groups:

- Do you agree with the suggested approach?
- Why? Or why not?
- Are there other possibilities to train inquiry-based skills with the experiments?
- Can we combine experiments?

Online references on practical work

- http://www.nuffieldfoundation.org/practical-biology/topics

On this site there are more than 100 class experiments and demonstrations that help to develop students' competences in biology.

- http://www.rsc.org/learn-chemistry/

This is a collection of more than 200 practical activities to demonstrate a wide range of chemical concepts and processes.

- http://practicalphysics.org/topics.html

This website contains about 800 experiments to contribute to students' skills and knowledge of physics.

- http://www.nuffieldfoundation.org/practical-work-learning

This website is for teachers of secondary science. It applies different pedagogical approaches to practical activities. The approaches are argumentation, model-based inquiry and science in the workplace.

- https://nrich.maths.org

Resource of the university of Cambridge for practical work in mathematics. Contains also some games.

- https://www.map.mathshell.org/lessons.php

Mathematical assessment Project from the university of Nottingham and the University of California (Berkeley). It contains complete lesson plans (all containing one or more exploration phases).

- https://mathcracker.com/

This website contains ideas for different topic areas of mathematics in secondary schools.

- http://www.arvindguptatoys.com/arvindgupta/maths-handbook-ncert.pdf

The link to the book with lots of ideas for practical work in mathemat

Activity 23

Take some time to investigate one or two references (links) above. Choose an interesting activity or experiment and present it to your colleagues.

Section 5: Using Students' Ideas

Why?

In this section, we introduce peer instruction and concept cartoons. These are techniques that will help you to make your lessons more learner-centred by combining individual thinking and group discussion and stimulating learners to express their ideas on scientific concepts.

Before explaining more about the techniques, we give a short introduction on alternative learner concepts.

What are students' ideas?

Activity 24

Read the questions below. Individually, use the voting cards to indicate what you think is the correct answer.

1. A boy tries to pull a dog, so he exercises a force on the dog (Figure 33). The dog also pulls back. They both remain at place. What is the exact reason for this?
    a) Both forces undo each other.
    b) The dog rest at place due to the friction force of the ground.
    c) Because the boy exercises a force that is less than the boy.

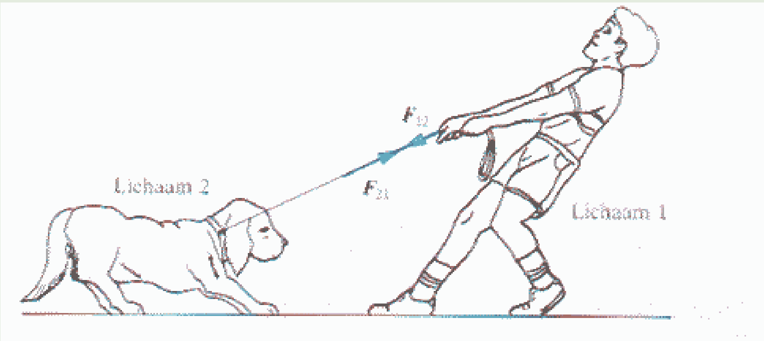


Figure 33: Example of a concept test (mechanics)

2. You have a lamp, a piece of copper wire and a battery (Figure 34). Make a drawing of a circuit so that the lamp will light up.

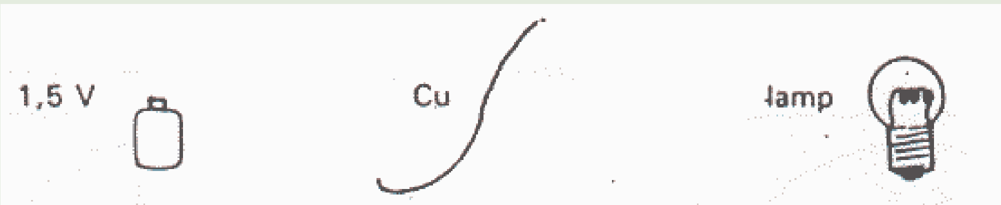


Figure 34: Example of a concept test (electricity)

3. What happens to the weight of iron nails when they rust?
    a) There is no change in the weight.
    b) The weight increases.
    c) The weight decreases.

4. After washing your trousers, you hang it outside to dry. A few hours later your trousers are dry. Which answer best describes what has happened to the water in the trousers?
    a) It soaked into the ground
    b) It disappeared and no longer exists
    c) It is in the air in invisible form
    d) It moved up to the clouds
    e) It chemically changed into a new substance
    f) It broke down into atoms of hydrogen and oxygen

5. Many strains of bacteria have become resistant to antibiotics. How has antibiotic resistance among bacteria become so widespread?
    a) Since a lot of people use antibiotics, bacteria need resistance to survive. As a result, they develop resistance.
    b) Antibiotic resistance is the next natural step for bacteria. This stage just happens to be occurring now.
    c) Now that many people use antibiotics, most non-resistant bacteria are dead. Most bacteria that are left are resistant.
    d) Individual bacteria that are exposed to antibiotics over and over eventually become resistant.

6. Which population would increase most if all insects were eliminated (See Figure 35)?
    a) Decomposers
    b) Producers
    c) Primary consumers
    d) Secondary consumers

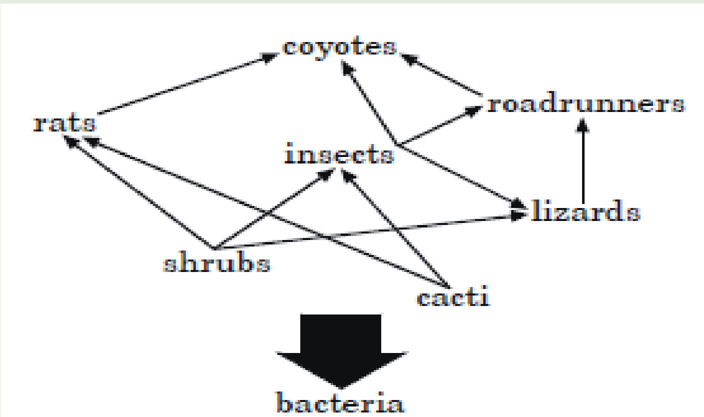


Figure 35: Example of a concept test (biology)

7. Which of the following is not true?
    a. Covid-19 is a disease caused by a virus which belongs to the group of RNA viruses
    b. Covid-19 disease can be present in both mammals and birds
    c. The virus causing Covid-19 belongs to the family of Coronaviridae
    d. Coronaviruses are named after the structure of the solar Corona (outer part of the sun)
    e. Coronaviruses can be seen using normal optical microscopes

These tests verify elementary scientific concepts. Many studies have used these kinds of 'inventory concept tests' (*AAAS Science Assessment ~ Home*, n.d.). The results are often very poor, even when done with professional scientists. It seems strange that elementary scientific ideas do not stick in students' minds. Don't worry if you made mistakes while answering these questions. The reason for this 'failure' is that the other answers (wrong ones) **seem** intuitively correct, as they are logical.

1) ***Answers for concept questions***

1. **Answer B**. Students with an understanding of physics Newton's Laws often refer to answer A (both forces are equal, Newton's Third Law). However, this is a common misconception. The action and reaction forces can't undo each other because they act on different bodies. Imagine the dog standing on the ice and the boy on the ground. That would make it easier to pull the dog if you are standing on solid ground. (see also https://www.youtube.com/watch?v=y61_VPKH2B4).
2. The common misconception is that learners do not notice that a closed circuit is a necessary condition to have electric current.

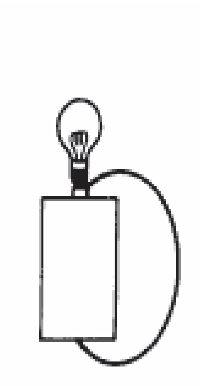


Illustration of a common misconception

3. As the nails go rusty, they get heavier. This is an important indication that the process is a chemical reaction and not just a physical change.
4. Answer C is correct. Answer D is also plausible, but it is more an end stadium of the process. First, it will be in the air.

5. Answer C is correct. It contains the idea of random mutations. Mutations that are strengthening the bacteria's chance on survival and reproduction (here resistance to antibiotics) will become more dominant in the population. The other options consider the development of resistance as a kind of deliberate process or suggest that bacteria can somehow decide to become resistant.
6. Answer B is correct. It tests if learners understand the concepts of producer, consumer and decomposers and how a food web works.
7. Answer A and E are correct. Coronaviruses can be seen using normal optical microscopes (See also https://www.wormsandgermsblog.com/2020/11/articles/animals/birds/covid-in-animals-review-part-8-birds/)

2) ***How do students construct alternative conceptions?***

Students come to class with prior knowledge on the lesson topic, with preconceptions about how the world works, even when they never had any scientific class. They acquire this from

- Own observations and daily experiences;
- TV, family, books, culture;
- Prior lessons.

Sometimes, this knowledge is incomplete or incorrect. Sometimes it makes sense to the students because it is more intuitive or because they have been familiar with it for a long time. This means that the construction of these misconceptions is part of the normal cognitive process. Unfortunately, on an educational level, these ideas often contradict the scientific concepts. When students are told they are wrong, they often find it difficult to give up their misconceptions.

Let's give some examples:

- Newton's First Law: When observing an object in rest on a table, it is more intuitive for students to assume that no forces are working on the object than accepting that there are multiple forces keeping each other in balance.
- Newton's Second Law: When coming to school by bicycle, you must keep on pedalling to remain at constant speed. This indicates that a force is needed to move at constant speed (counterintuitive to Newton's Second Law).
- Every morning I notice that the Sun rises in the east and sets in the west. I conclude that the Sun revolves around the Earth.
- Respiration and breathing are synonyms so scientifically they are the same thing.

Misconceptions about COVID-19

In times of pandemics, not only the SARS-CoV-2 virus but also misinformation spreads quickly. The World Health Organisation (WHO) keeps a useful list of misconceptions and fact checks on their website.

Some popular misconceptions are:

1. COVID-19 only affects the old.
2. There is nothing we can do until a vaccine is invented
3. Adding pepper to your soup or other meals does prevent or cure COVID-19
4. COVID-19 is transmitted through houseflies.
5. 5G mobile networks can spread COVID-19.
6. Exposing yourself to the sun or to temperatures higher than 25 degrees Celsius can prevent the coronavirus disease (COVID-19)
7. The new coronavirus can be transmitted through mosquito bites.
8. Only older people are affected by the new coronavirus.
9. Some antibiotics are effective in treating the new coronavirus.
10. If you don't have any symptoms, it means that you don't have COVID-19.
11. Digital thermometers are 100% effective in detecting COVID-19 patients
12. COVID-19 pandemic is caused by a Chinese virus

Have you encountered others in your school? Mention them.

Source: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public/myth-busters

3) ***How to deal with student alternative conceptions?***

For a teacher it is important to acknowledge this prior knowledge and to plan instructional strategies to make it explicit and change it. Merely telling students that their viewpoint is incorrect will not change it but will create a difference between their "school view" and their view "outside school". They will accept Newton's Laws in the class but will return to and use their old views outside class.

To summarize, we must **use these alternative ideas** in classroom. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for a test but go back to their preconceptions outside the classroom. Posner (1982) has proposed a strategy to use misconceptions and turn them into the new (correct) scientific concepts. This strategy assumes that a naïve or scientific idea will only be accepted if it fulfils the following conditions.

The concept must be:

- Comprehensible: not abstract, in comprehensible language for students, using familiar concepts;

- Reasonable (logic);
- Effective: students must be able to explain daily observations by using this new concept.

The reason why students have a hard time giving up these misconceptions is because their own ideas are comprehensible, reasonable and effective.

The scientific framework can only be taught if students **reject their own naïve ideas**. But how can this 'rejection' be obtained? By presenting a motivating problem, a conceptual question or a surprising experiment that cannot be explained by their own ideas (or misconceptions). This is called a cognitive conflict. Only when students experience conflict with their own ideas, can new, scientific ideas be taught (Figure 36).

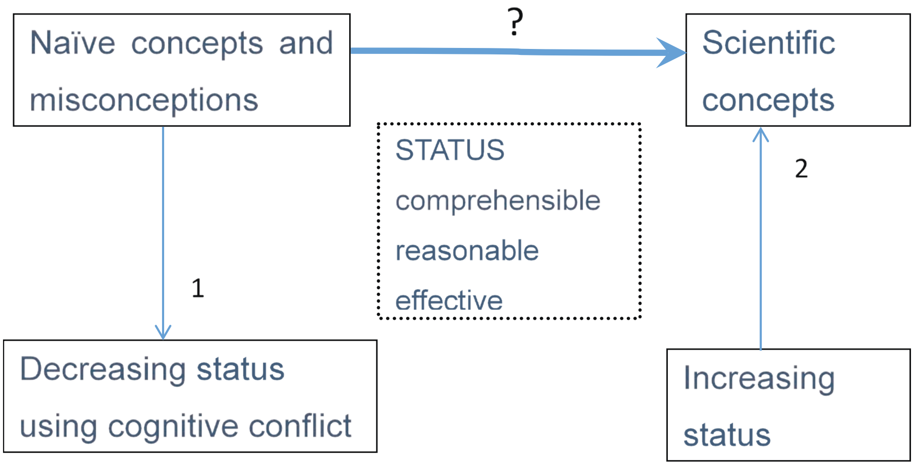


Figure 36: How to change naïve concepts and misconceptions into scientific concepts (Posner, 1982).

In conclusion, teachers must challenge prior beliefs and prior knowledge of learners. In a teacher-centred approach a teacher would only point out these 'mistakes' or naïve concepts by telling learners that their viewpoint is incorrect. However, research has shown that this approach does not lead to durable conceptual change. In a learner-centred approach a teacher uses these ideas to create a cognitive conflict in students' minds.

Peer instructions and concept cartoons are concrete, learner-centred techniques for teachers to elicit students' alternative conceptions and confront them with their naïve ideas.

Peer Instruction

Once a teacher has insight in misconceptions among learners, the next step is stimulating learners to reject these 'wrong' ideas (see theory of cognitive conflict). Sometimes, but not often, presenting or confronting the bad results in class can cause this 'rejection' ('*I didn't expect these bad results, I thought I was right, …*'). However, effective use of conceptual questions in the classroom must be supported by other techniques. Professor Eric Mazur, physics professor at Harvard University, has developed a learner-centred approach called '**peer instruction'** (Crouch & Mazur, 2001; Lasry et al., 2008; Mazur, 1997a).

Peer instruction is a learner-centred approach to introduce *conceptual questions* in the class.

It is similar to the think-pair-share technique. After a conceptual multiple-choice question is presented, students are stimulated to formulate their own ideas by discussing the question in pairs or small groups.

A peer-instruction sequence has the following structure (Figure 37):

1. Present a conceptual multiple-choice **question** (conceptual question).
2. Provide some time, so students can think independently and find the right answer. (Several answers may be correct, depending on the question)
3. After a short time, **ask** your students for their **answers**. This can be done by a hands-up method or **voting** by cards (see appendix 3). It is better if voting cards are used, because in this case there will be less influence between students. It is very important that students tell their own ideas. By raising hands, it happens that a weak student just follows a stronger student.
4. The outcome of the vote determines your subsequent actions. If most students (more than 90%) know the correct answer, you can quickly affirm why it is correct and continue with the lesson (or you can let one student explain the correct answer). If several answers are chosen, divide students in small groups (3 to 4) and stimulate group discussion. In each group students must try to reach consensus with their neighbour(s). During argumentation periods, move around the class and listen to the conversations. Make a mental note when students make a wrong argument, but don't interfere in the discussion.
5. Afterwards, ask the question a second time to assess evolution in class understanding. Again, students must answer independently.
6. If after the second vote you are not satisfied with the students' performance, you need to slow the pace and provide additional instruction.

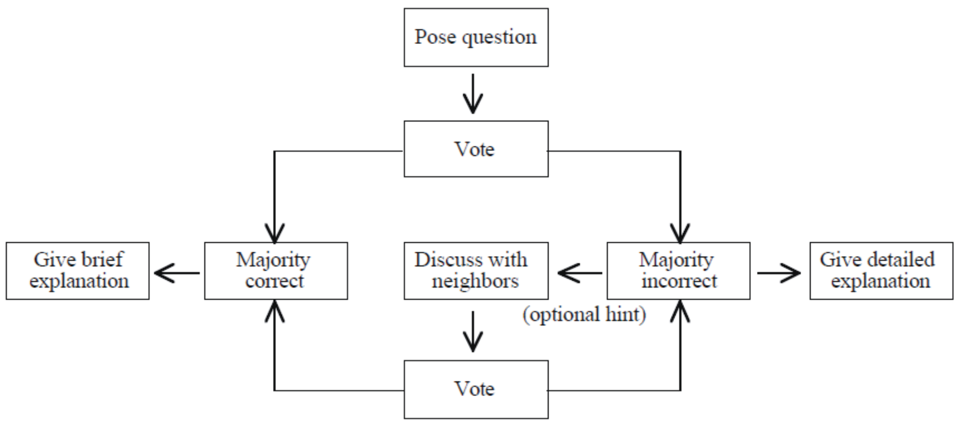


Figure 37: How to use peer instruction in the classroom (Mazur, 1997b)

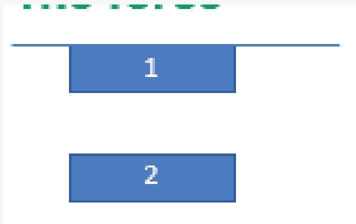
Examples

1. Archimedes' Law

Imagine holding two identical bricks under water. Brick 1 is just beneath the surface of the water, while brick 2 is at a greater depth. The force needed to hold brick 2 in place is:

A. larger
B. the same
C. smaller

than the force required to hold brick 1 in place.



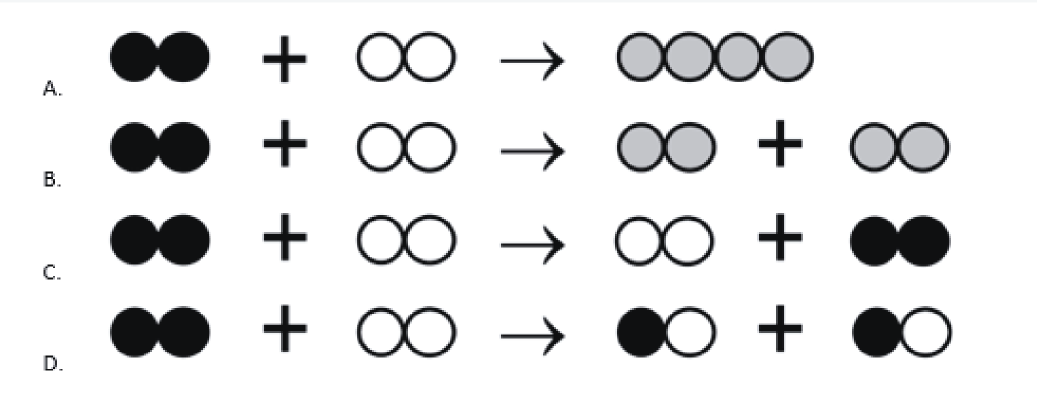
2. *Plant Respiration*

Which of the following statements is true about the carbon dioxide that is used by plants?

A. It is combined with oxygen to make sugar molecules.
B. It is absorbed through the roots of plants.
C. It comes from the air.
D. It is food for plants.

3. Chemical reactions

Which of the following could represent a chemical reaction? Atoms are represented by circles, and molecules are represented by circles that are connected to each other. The different coloured circles represent different kinds of atoms.



Activity 25

Below are some STEM topics that may be confusing to learners. Can you think of alternative conceptions that students have about these topics? Think of possible conceptual questions that you can use to expose and address these conceptions.

- Water pollution and eutrophication (S6, Unit 3, S4, Unit 10, S2, Unit 3)
- Depletion of the ozone layer (S5, unit 4; S4, Unit 10)
- Relation between global warming and the greenhouse effect (S5, Unit 4)
- Consequences of global warming (S5, Unit 4)
- Acid rain (S4, Unit 10; S1, Unit 8)
- Effective management of hazardous waste (S2, Unit 4; S1, Unit 2)
- Similarity, right angled and trigonometry (S3, Unit 8) (See more on: http://mathmistakes.org/category/grade-1/operations-algebraic-thinking/)

Solutions examples peer instruction

1. **Correct answer is B**. The Buoyancy force is equal in magnitude to the weight of the fluid displaced by the object. The buoyancy force is independent of the depth of the brick.

2. **Correct answer is C**. Carbon dioxide is used from the air, during photosynthesis, to make glucose.

3. **Correct answer is D.** A and B are wrong because there is no conservation of mass. In C the molecules didn't change.

More examples can be found in appendix P4.

Important online resource: http://assessment.aaas.org.

This website from the American Association for the Advancement of Science (AAAS) provides free access to more than 600 items. The items are appropriate for lower and upper secondary school students. The items test student understanding in physics (physical science), biology (life science), chemistry (physical science), earth science and the nature of science (Figure 38). The items test for common misconceptions as well as correct ideas. For each item, there is information on how students' responses are typically distributed (Figure 39). The website also a list of references on student misconceptions (http://assessment.aaas.org/pages/references)

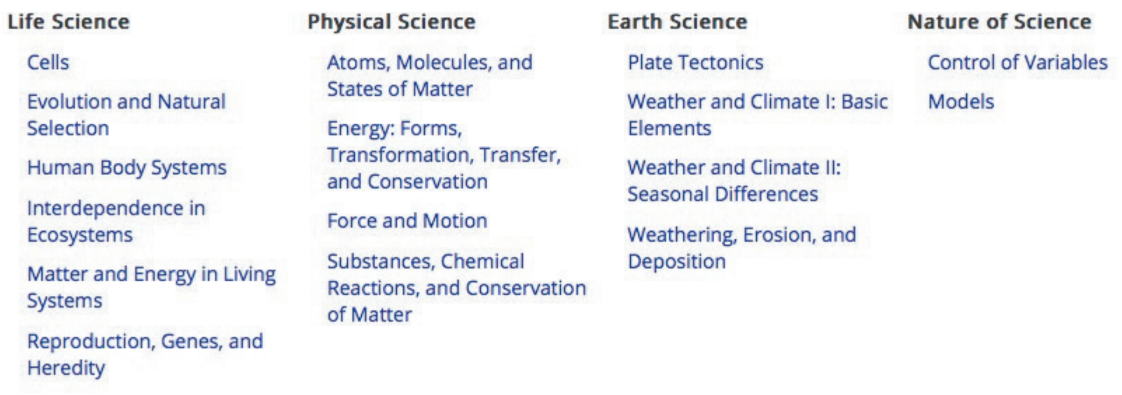


Figure 38: Overview of AAAS Assessment website

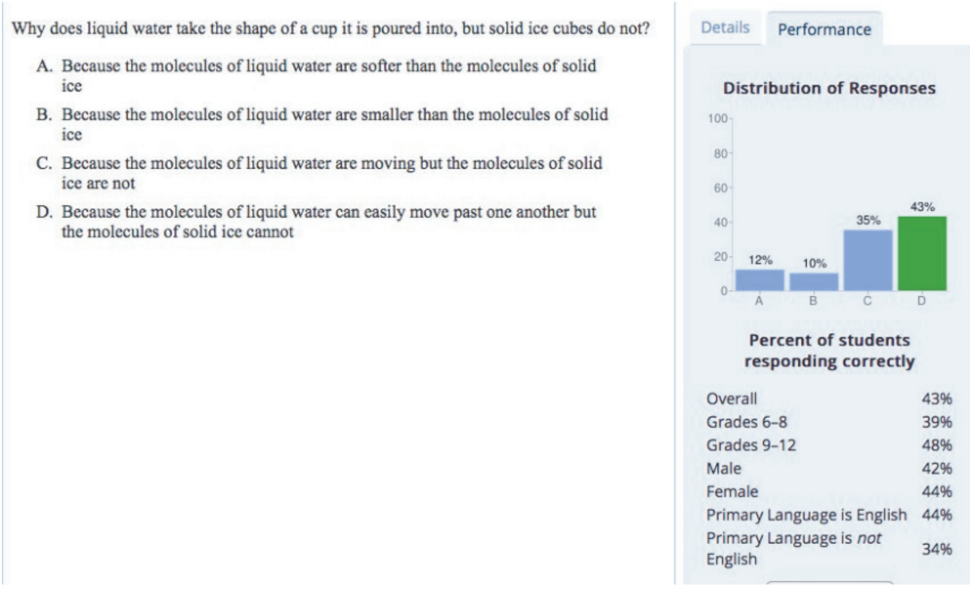


Figure 39: Example of a concept test on the AAAS Assessment website

Online resource for mathematics: http://www.counton.org/resources/misconceptions/
List of common misconceptions in mathematics.
Some examples discussed in this resource are:

- What is 14 489 to the nearest 1000?
- Does multiplication always increase a number?
- What is 0.1 x 0.1?
- What is the value of 3 ÷ 1/4 ?

Concept cartoons

Another tool to deals with students' alternative conceptions are concept cartoons. Concept cartoons are simple drawings which put forward a range of viewpoints about the science involved in **everyday situations**.

Figure 40: Concept cartoon about shadows at night

In this example (Figure 40), an experiment about shadows is described. Four cartoon characters predict the result of this experiment, based on their ideas about shadows. These possible answers are based on research about popular student misconceptions (e.g., Driver, Squires, Rusworth, & Wood-Robinson, 2000). In this way, the opinions expressed sound familiar to learners and they easily identify themselves with one of the viewpoints.

The main objectives of concept cartoons are **stimulating learners to think, discuss, raise questions, investigate and formulate scientific arguments** (Keogh & Naylor, 1999). Concept cartoons are more than just multiple-choice questions. They are instruments to trigger student involvement, thinking and exploration. All answers represent frequent misconceptions that occur among learners and should therefore be given attention (why are they incorrect?) during the lesson.

It is very important to notice that all possible answers in the cartoon have equal status. Learners have to select and specify the best concepts about the situation. This process of conflict between different viewpoints is an important aspect of gaining scientific knowledge. For this reason, this method is appropriate for learner-centred teaching.
Concept cartoons can achieve different objectives (Keogh & Naylor, 1999):

- Making students' ideas explicit (so that misconceptions can be identified);
- Challenging and developing students' ideas;
- Stimulating scientific discussion;
- Providing starting points for exploration;
- Increasing involvement and motivation;
- Deepening understanding of science concepts.

1) ***How to use concept cartoons?***

Concept cartoons can be used with different teaching methods. An often-used sequence is the following:

1. Introduce the topic and show the cartoon.
2. Organise a brief period of individual thinking. Collect some brief feedback to see what range of views is present – perhaps a vote on the alternatives.
3. Encourage discussion in small groups (4-6 learners) and invite groups to see if they can reach consensus.
4. Let groups share the outcomes of this enquiry and organize a short whole class discussion, including which alternative(s) seem(s) acceptable and what further information we might need to be sure.
5. Draw ideas together and provide an explicit summary of the initial problem, the enquiry, the outcome and what has been learnt from the enquiry.
6. Consider how students' views might have changed and what has led the change in their ideas.

The cartoons must be clearly presented in the classroom. A projector is useful but if this is not available, the cartoon can be printed or perhaps drawn on a blackboard.

Depending on which cartoon you will use and how you will use it, you will need some additional resources such as materials for experimental investigation.

The next examples show **three teaching methods** to use concept cartoons. Try them out and adapt them to your context.

Example one: Size of shadows (Physics)

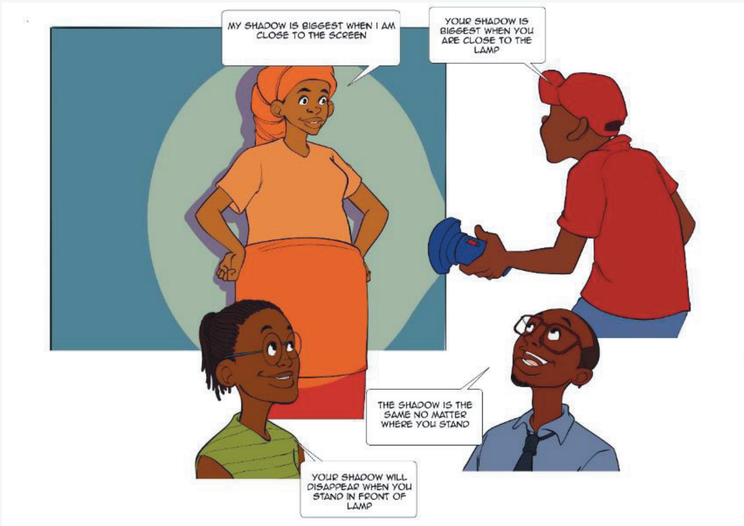


Figure 41: concept cartoon on size of shadows (physics)

Step-by-step instructions

1. Show the concept cartoon (Figure 41) to the students and explain the context.
2. Give students a short time for **individual reflection**, while they read the statements and try to answer these questions:
    a. With whom do you agree?
    b. Is more than one idea, correct? *Why is this question important? Students need to think about why a certain answer is correct or not. A statement may be only partly true. This reflection time can be accompanied by small experiments.*
    c. Try to construct a definition of shadow.
3. Do a **quick scan** to see what the group is thinking (e.g. by raising hands or using voting cards).
4. Organize a **discussion** with the whole class. All possible answers are discussed. Use questions to help students constructing the correct reasoning. For the example on shadows, questions that can be used are:
    a. What happens if we move our hand closer to a light source?
    b. Is there still a shadow if you cover the light source completely? And what if you turn out the light?

c. Can you think of a situation where the size of the shadow doesn't change?
d. Can you explain why?
e. How can the size of a shadow cast by the Sun change?

Explanation of statements

My shadow is biggest when I am close to the screen.
Your shadow is biggest when you are close to the lamp.
These two answers are best discussed together because they represent opposite views. It's very unlikely that a student will agree with both ideas.

Let students discuss and develop a plan how to check which answer is correct. The answer can be found by experimenting and/or by using theory and reasoning. A short experiment with the light source and hands quickly shows that a shadow is bigger if the object is closer to the light source. It can also be explained with the fact that light travels by straight lines and that a light source diverges light in all direction.

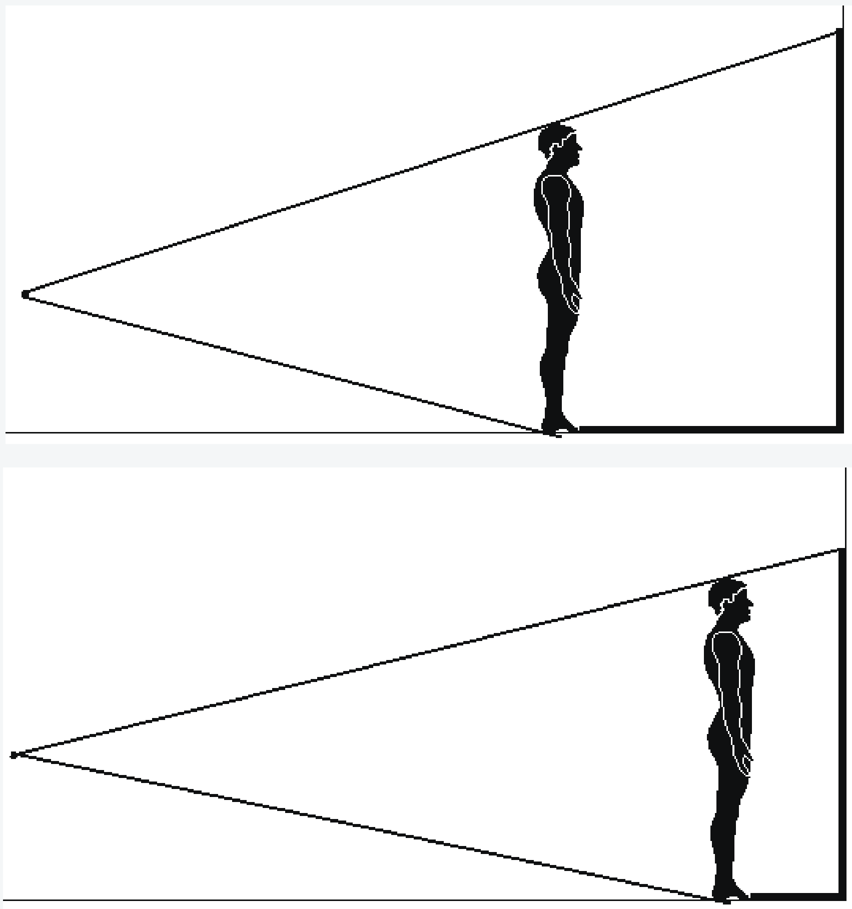


Figure 42: The closer the object to the light source, the bigger its shadow

The shadow is the same no matter where you stand.

With a light source, you can demonstrate that this is not true. If you move your hand, the size of the shadow always changes. Students may notice correctly that the size of a shadow doesn't change if you move around in sunlight. However, the Sun is a light source at a great distance. The light rays from a distant source travel parallel. With the same drawing as before but using parallel rays, you can demonstrate that the size doesn't change.

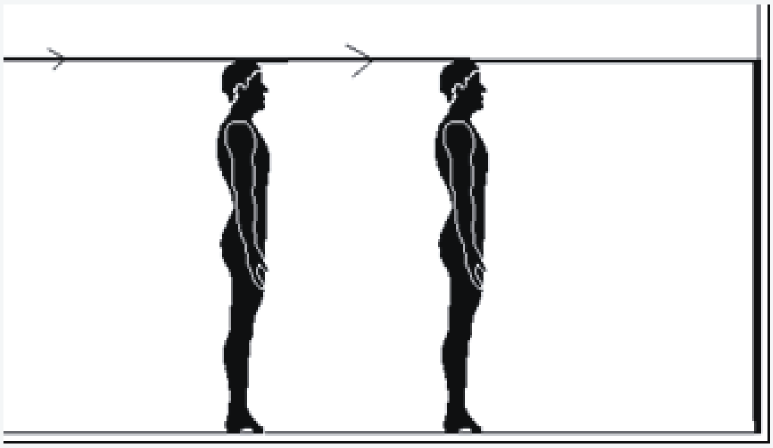


Figure 43: The shadow doesn't change with a distant light source like the Sun

Your shadow will disappear when you are close to the lamp.

When you cover the light source completely, the shadow spreads itself over the whole wall or classroom. The shadow doesn't disappear, but everything becomes shadow. Some students may think that the shadow disappears because the boundary between light and shadow is gone. With this statement you can start an in-depth discussion about the definition of the concept shadow.

You can start this discussion with the following question:
"What is the difference between covering the light source totally and putting the lights out?"

Conclusion

This concept cartoon shows the need for a good description or definition of the concept shadow. Moreover, students are stimulated to think about scientific concepts and how to test their hypothesis. A first conclusion is that in order to have a shadow, you need a light source and an object. A second conclusion is that a shadow is the place where there is no light from the light source.

The step-by-step instructions illustrate that it is important to discuss all the statements in the cartoon, also the ones that are not correct (Chang et al., 2010). Students need to be stimulated to think about the statements, to argue why they are (not) correct, try to design experiments to test the validity of each statement and formulate definitions of concepts in their own words.

Example two: Biology

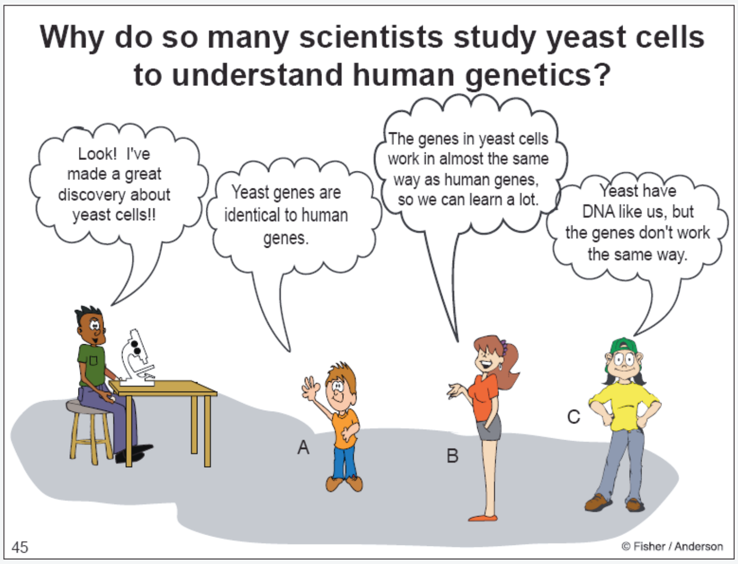


Figure 44: concept cartoon on yeast cells and genetics (biology)

Step-by-step instructions

1. Show the concept cartoon to learners.
2. Give learners a short time for **individual reflection**, while they read the statements and try to answer these questions:
    a. With whom do you agree?
    b. Is more than one idea, correct? *Why is this question important? Students need to think about why a certain answer is correct or not. Maybe a statement is only partly true. This reflection time can be accompanied by small experiments.*
3. Let the learners write on their personal space on a large piece of paper with whom they agree and why they do so.
4. Give time for a small group discussion: let them try to reach consensus in their group. The consensus motivation is written in the middle (Figure 45).

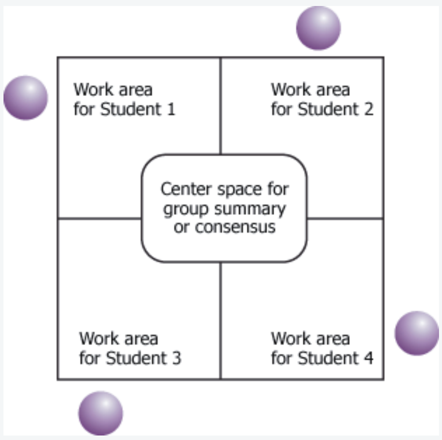


Figure 45: Template for group discussion on concept cartoons (Lin, 2005)

5. Time for feedback and discussion with the whole group: each group presents his consensus answer. Let learners react on the answers of other groups and have a class discussion.
6. All possible answers are discussed, also answers that were not selected or are wrong. It is important that learners can correctly argue why an answer is wrong.
7. Use questions to help students construct the correct reasoning. For the example:
    a. Answer A: if 2 persons would have the same genes, what would be the consequence? Or, easier, how would they look like?
    b. Answer C: How do genes work? What is their function? Is this the way genes work in human cells or yeast cells?
8. summary of initial problem, enquiry, outcome and what has been learnt from the enquiry.

This concept cartoon can be used best after students have learned about DNA, genes and the relation between genes and proteins.

Using a large sheet of paper helps learners to participate and think as they have to write down their ideas.

Example three: Chemistry

Figure 46: concept cartoon on rusting (chemistry)

Rusting requires the presence of air and liquid water, so wet nails will rust quickly. If they are completely submerged rusting will still occur because water contains dissolved air. However, it will take longer due to the lower concentration of oxygen. Cold conditions will slow down rusting due to the lower concentration of water in cold air. Although rust may look like a disease, it isn't. The presence of other rusty nails does not make rusting more likely. You can let students investigate the situation by setting up various combinations of the different factors (let them first brainstorm to determine these themselves) that might be involved in rusting. Removing air completely is the most difficult part of this. A layer of oil or paint will keep the air out, but it will also prevent moisture getting to the nail. Boiling water for a few minutes to remove the air, then putting a nail in boiled water in a sealed container can provide water but no air as a comparison. Make sure to test one variable at a time and to provide control set-ups.

2) Variations

There are more ways to use concept cartoons in your lessons. Some examples:

- Blank out one or more speech bubbles and let students complete them.
- Create your own concept cartoons by collecting students' ideas.
- Let groups of students create their own cartoons that reflect the range of ideas in their group.
- Creating a concept cartoon can be used as a challenging activity at the end of an unit. Students try to design the best concept cartoon.

Example mathematics

Figure 47: concept cartoon on multiplication of fractions (mathematics)

The best way to use this concept cartoon is to challenge learners to find numerical examples of the statement they agree with (or disagree with). Indeed, if you multiply 10 by 5/2 the number becomes larger. But if you multiply 10 by 2/5, the number becomes smaller. What if you multiply 10 by 5/5, by 0/5 or by 2/5? And what if you multiply a fraction with a fraction?

Activity 26

Are concept cartoons of any use for your teaching?
Place yourself on a continuum between:

- Yes, I will use them often
- No, they aren't of any use

Discuss the pros and contras with the whole group.

3) Tips for using concept cartoons

Many concept cartoons do **not** have a **single 'correct answer'**. In many cases the only reasonable conclusion involves "***It depends on****...*" statements. Even apparently simple situations can have **complicating factors** or exceptional circumstances when they are examined more closely. Similarly, in real science, scientific problems don't have a single right answer. It is an important achievement for students to obtain this insight.

Many teachers find this method of teaching challenging. Their criticism is that the situations in the cartoons should be specified more clearly, so that there is only one right answer. However, it is an important objective of concept cartoons that students learn to express the ideas in the cartoon. It is important to let students argue and discuss about science, rather than quickly giving the 'correct' answers.

Therefore, you need to know what possible answers students may give to anticipate the class discussion.

4) ***Examples from the CBC***

Physics

We have selected 31 cartoons covering a wide range of topics from the CBC (see Appendix P3).

Table 10: Overview of concept cartoon topics for physics

Optics	*Mechanics*	*Heat*	*Electricity*
1. The white cat 2. Sunglasses 3. Shadow screen 4. Shadows at night 5. Two trees 6. The colour of shadow 7. Solar Eclipse 8. Moving shadow 9. Shadow of the Sun (size) 10. Curved mirror 11. Prism 12. Torches 13. Mirror box	14. Bungee jump 15. Falling 16. Wooden bicycle 17. Soccer 18. Fast plane 19. Moon rock	20. Boiling water 21. Coat on ice 22. Teapot 23. Windy day 24. Melting ice 25. When water is boiling 26. Ice cubes	27. Switch 28. Current flow 29. Thicker wires 30. Longer wires 31. Electromagnet

Biology

We selected 9 cartoons covering various topics from the CBC (see Appendix B3).

Plants	*Human Body*	*Evolution & Reproduction*	*Genetics*
1. Growth direction of plans 2. Seeds in the dark 3. Heavy plants 4. Rotten apple	5. Antibiotics	6. Dominance 7. Competition 8. Pond Life	9. Acquired traits

Chemistry

For chemistry we include 8 concept cartoons on various of topics from the CBC (see appendix C3).

Mixtures, compounds, states of matter	*chemical reactions*
1. Liquids 2. Scrambled eggs 3. Muddy waters 4. Condensation 5. Sweet tea (dissolving)	6. Rusty nails 7. Rusty nails (2) 8. Burning Candle

Mathematics

For mathematics we have included 11 concept cartoons (see appendix M3)

Numbers and Operations	*Geometry*	*Data handling and probability*
1. Rumours 2. City temperatures 3. Can can 5. Banana beer 10. In the money	4.Tile it 6.Milk boxes 7.Weedkiller	8.Divide the pie 9. Open to interpretation 11. Play your cards right

Section 6: Computer-Based Measurements

What and why?

The classrooms of the future will be shaped by technology (more ICT, augmented reality, 3D printing, …) ('Classrooms of the Future', 2017) (Figure 47). However, this won't be the only difference. Successful educators will realize that they need to rethink the entire model of education (classes, grades) and redesign it so that it becomes more student-centred. This means adopting new technologies, but it also means giving up old attitudes and increase student involvement and thinking (*4 Changes That Will Shape The Classroom Of The Future*, 2016).

Figure 48: How will the future classroom look like? ('Classrooms of the Future', 2017)

We do not have to wait until the latest technology is available for our classrooms. Even if we only have some standard tools (a laptop, smartphones, …), we can redesign our way of teaching and improve it, so more learners benefit from it.

In this section we will explore the use of computer-based measurements with standard equipment (laptops and smartphones) and with basic external sensors. They will help to improve the experimental and inquiry skills of the learners. Because these tools are becoming more widely available, learners can do the experiments themselves ('learning by doing').

How to use built-in sensors of tablets and smartphones?

Most smartphones and tablets have a lot of built-in sensors. The camera is a light sensor and there is a microphone to measure the sound level. All devices are sensitive to movement to adjust the screen when you are turning the device. Therefore, the acceleration of the device and the direction of the Earth's gravitational field is measured.

Most devices also measure the magnetic field with a Hall sensor and your position on the globe is measured using a Global Positioning System (GPS) sensor. A Hall effect sensor is a device that is used to measure the magnitude of a magnetic field. GPS sensors are receivers with antennas that use a satellite-based navigation system with a network of 24 satellites in orbit around the Earth to provide position, velocity, and timing information.

The amount of data that continuously available on these devices is enormous. There are many apps that use these different sensors. We will focus on the app **phyphox** (*Your smartphone is a mobile lab.*, n.d.), which is freely available and is using all sensors of your smartphone (Figure 48). All experiments are well tested and several small instruction movies are available on how to do the experiments correctly (https://phyphox.org/experiments/).

Figure 49: The phyphox logo (*Your smartphone is a mobile lab.*, n.d.)

Let's look at some examples.

Example 1: Measure the speed of sound with two smartphones

An instructional movie can be found here: https://phyphox.org/news/experiment-speed-of-sound/. You need to install the app on both phones and open the **acoustical chronometer**. This chronometer will start when a loud sound wave is passing by. When you put the two phones a distance d from each other the first person (standing on the left) has to clap with the hands (see Figure 49). This will first start the timer of the smartphone on the left and after the sound wave has travelled the distance d ($\Delta t = d/v$, with v the speed of sound), it will start the second timer on the other smartphone. Now, the person on the right has to clap with the hands too, stopping first their own timer and Δt later the timer from the person on the left.

If you bring both smartphones together, you will notice that the left timer has run $2\Delta t$ longer than the timer on the right. Out of this difference a very accurate measure of the speed of sound can be calculated.

Figure 50: Using two smartphones to measure the speed of sound (phyphox)

Example 2: Measure the speed of a rolling roll

An instructional movie can be found on: https://phyphox.org/experiment/roll/. You need one smartphone, a second device to remotely see the data of the first smartphone, and a cardboard roll to place your smartphone in (see Figure 50).

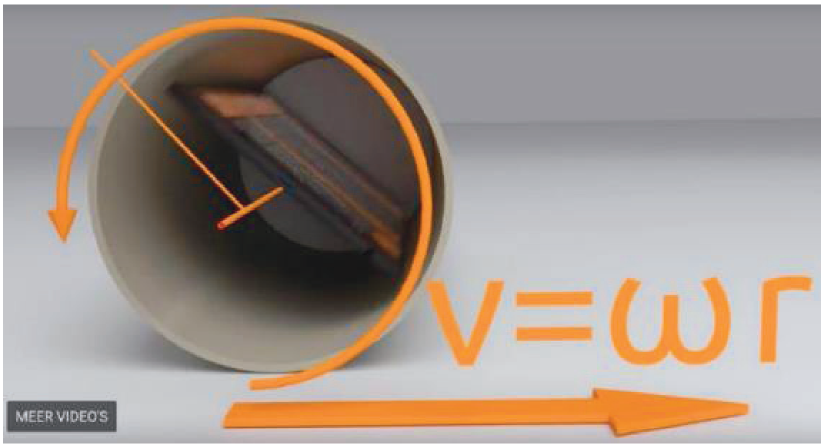


Figure 51: A smartphone in a cardboard roll to measure the speed of the rolling roll (phyphox)

The smartphone measures its angular velocity and if you enter the radius of the roll, you can measure the speed of the roll in real-time.

How to use external sensors: The Pocket Lab

The advantage of using the internal sensors of smartphones is that you do not need any extra equipment. However, several companies provide sensors and software specially designed for didactical applications. The problem is that most of them are quite expensive. One exception is 'The pocket lab' designed by Myriad sensors (*The PocketLab | Wireless sensor for STEM education and makers.*, n.d.). The Pocket Lab contains a well-designed set of sensors (see Figure 51) that is integrated in a small and robust device with many possible applications. These sensors can measure temperature, barometric pressure, humidity and distances (with an infrared rangefinder). These possibilities are not available on smartphones or tablets. Another advantage is that the data of the sensors can easily be captured by smartphones, tablets and laptops.

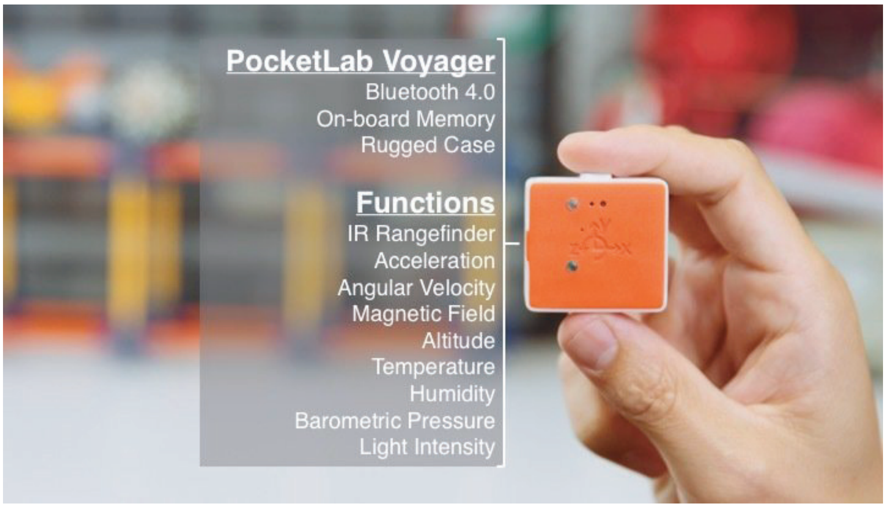
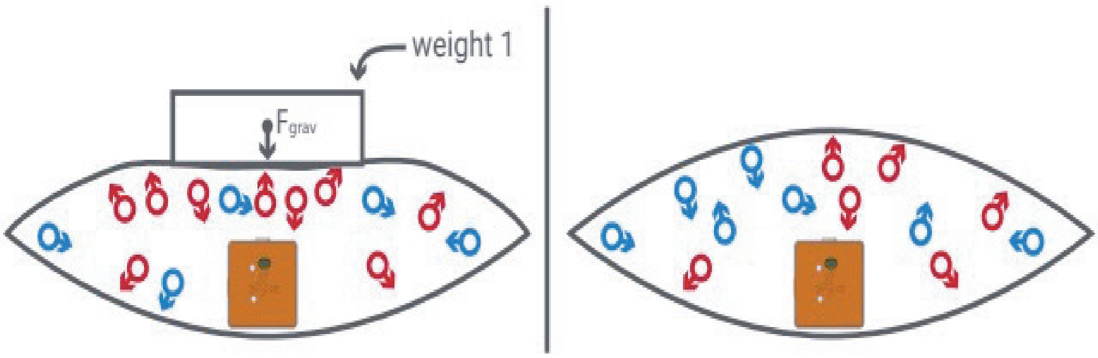


Figure 52: The PocketLab Voyager with a list of available sensors
(The PocketLab | Wireless sensor for STEM education and makers.*, n.d.)*

Installing the device is straightforward. Download the Pocket Lab app on your smartphone or tablet or open the website: www.thepocketlab.com/app on a Google Chrome browser on a laptop or desktop. The connection needs your Bluetooth turned on. Turn on the Pocket Lab and bring it close to your computer or smartphone to make a connection between the Pocket Lab and your computer or smartphone.

A wide variety of applications is available on the PocketLab website (*The PocketLab | Wireless sensor for STEM education and makers.*, n.d.), as well as instructional videos and even lesson materials. We will discuss two examples to give an idea of the possibilities.

Example 1: Use PocketLab to measure the Gas Laws
The PocketLab can measure both pressure and temperature. You can investigate Boyle's Law by putting the PocketLab in sealed plastic bag. When you press the bag or put a weight on it you can immediately see the pressure rise.



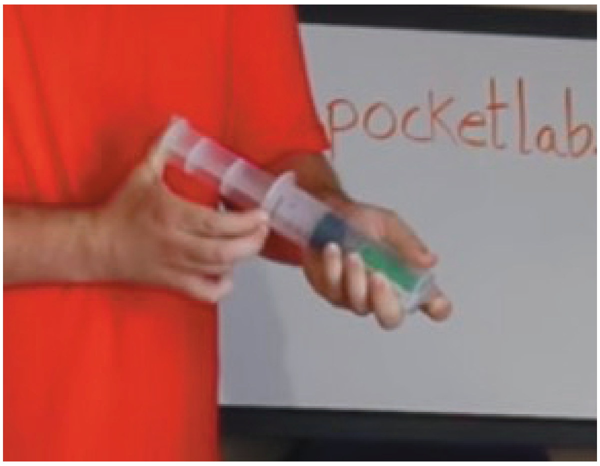


Figure 53: Measuring Boyle's Law using the PocketLab and a sealed plastic bag or a syringe

If you want to measure the volume more accurately, you can use a big syringe and put the PocketLab inside (more info on https://www.thepocketlab.com/educators/lesson/pressure-and-volume-syringe) (Figure 52). You can also heat the gas to measure the Law of Gay-Lussac.

Example 2: Train your learners to interpret and construct time graphs

The infrared (IR) range finder can measure accurately the distance between the sensor and a wall or a table. These data are immediately visualised in a time graph (Figure 53). For many learners interpreting such graphs is not easy. PocketLab is the ideal tool to train them in interpreting these graphs.

Challenge your learners to produce the graphs of Figure 53. Notice that PocketLab can also calculate the speeds as a function of time, but that these speeds are not so accurate as the positions (see also https://www.thepocketlab.com/educators/lesson/linear-motion-match-graph-activity).

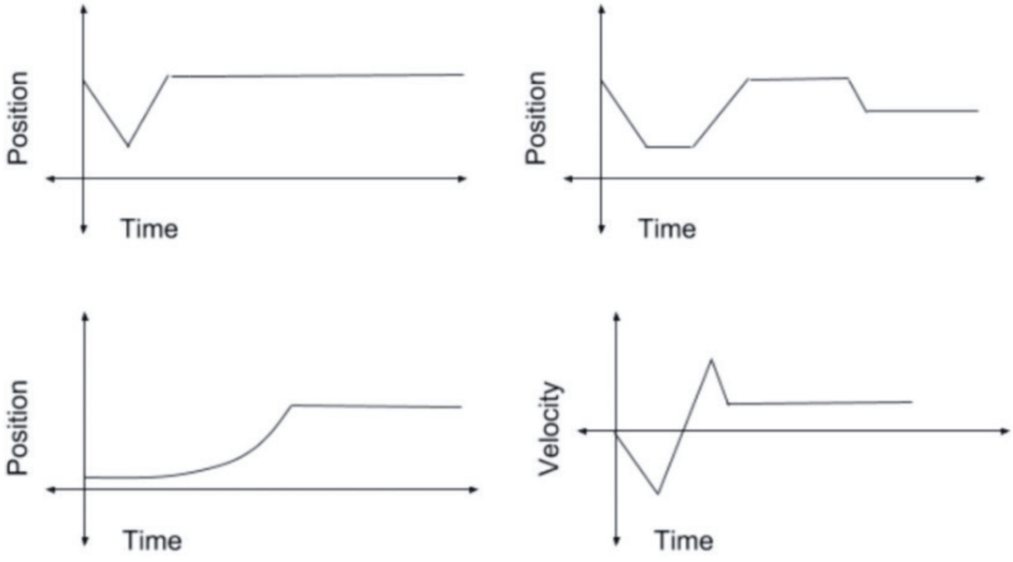


Figure 54: Challenge your learners to produce the graphs above by moving the PocketLab

Section 7: Models, Animations and Simulations

Models

Models are simplified representations of a complex reality (Box & Draper, 1987). This simplification process is essential for understanding a phenomenon, which is often too complex to understand because of its many components and interactions. We therefore reduce it to its essential parts and interactions. A model summarizes our understanding of the phenomenon. For example, scientists will often represent a gas by points, whereas non-scientists may represent it by an empty space.

The use of models has been a part of science, and their use makes it possible for scientists to represent complex phenomena that are not observable in other ways, because they are too fast, too slow, too big or too small (Evagorou et al., 2015).

Scientific models are often developed and used during the Explore phase, and they are a key element of every explanation.

There are two types of models: **conceptual models** (Figure 54) and **mathematical models** (Figure 55). A conceptual model is a representation of a phenomenon, composed of concepts which are used to help people understand a subject that a model represents. Mathematical models encode the phenomenon into mathematical language. Equation-based mathematical models describe the relations between different parameters within a system. These models are always quantitative.

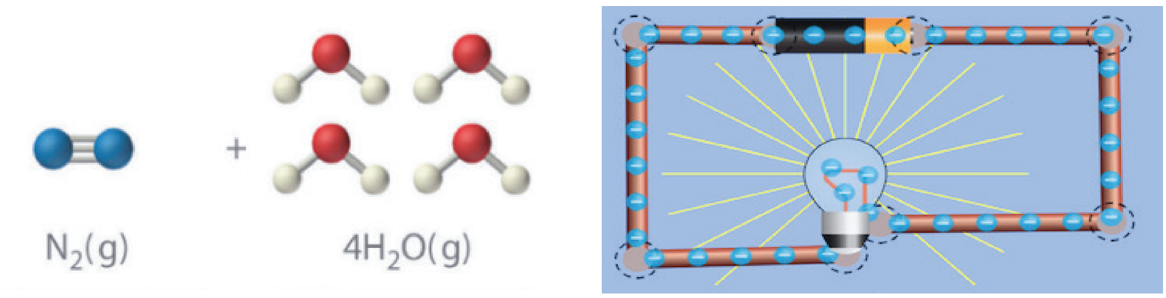


Figure 55: Examples of conceptual models (molecules and electrical circuits) (public domain)

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

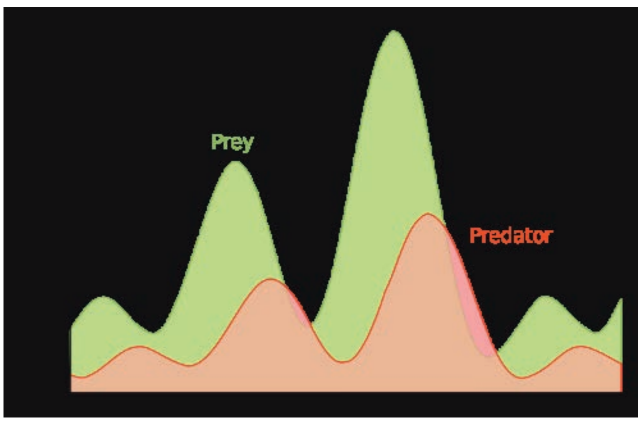


Figure 56: Examples of mathematical models (source: public domain)

Activity 27

Draw a model of:

- a bicycle
- the electric current in a circuit
- a gas
- the square of number a

Discuss each other's representations.

We have all 'mental' models of the world around us. A lot of these models are incomplete or not scientifically correct. Gianluca Gimini asked more than 500 people to draw a bicycle by heart (Rhodes, 2016). Drawing a bicycle from memory is harder than it sounds: out of the 370 people who really tried (Many people go rogue, when they realize their drawings aren't turning out right), about 25 percent managed to accurately sketch a bike.

In his project "Velocipedia" (Designer, n.d.), he created digital renderings of some of the weirdest and most impractical designs that came from the other 75 percent of the test group. "People draw some really crazy stuff when they are trying to be totally non-creative and just follow a task," he says. We collected some drawings and renderings in Figure 56. On the left are drawings, on the right are the digital renderings of these drawings.

Figure 57: Our internal models of bicycles (Rhodes, 2016)

Asking learners to draw a phenomenon is an interesting way to assess their understanding of a phenomenon. A drawing is also a model of the phenomenon. In Figure 57 you will find some models drawn by learners of how an electrical current provided by a battery runs through a light bulb. The naïve ideas about closed circuits are immediately clear.

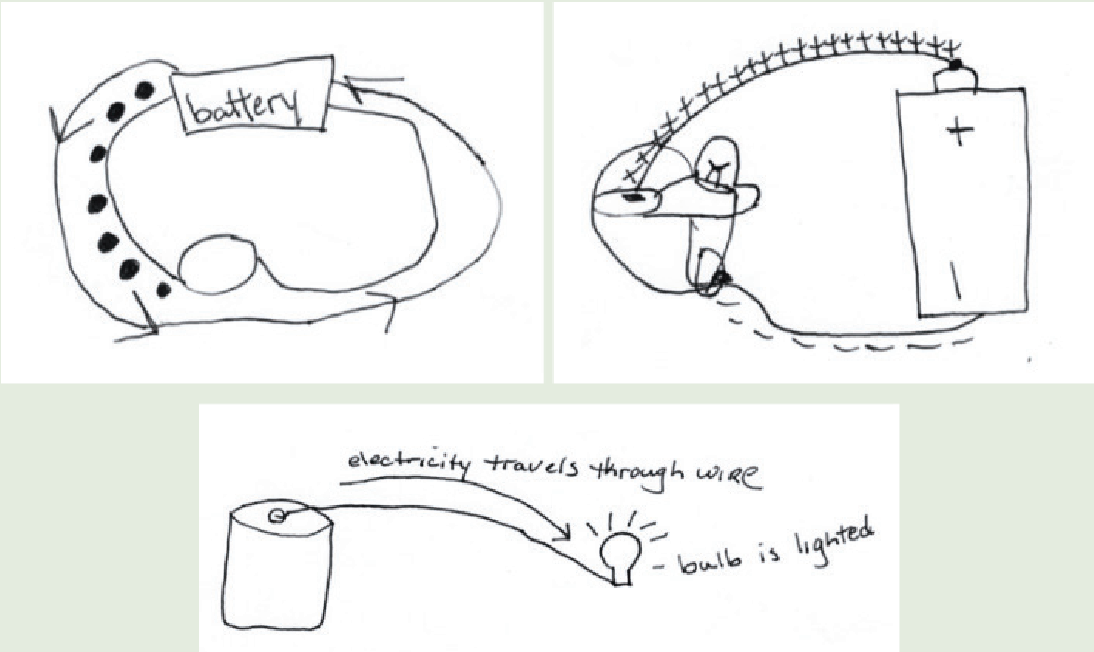
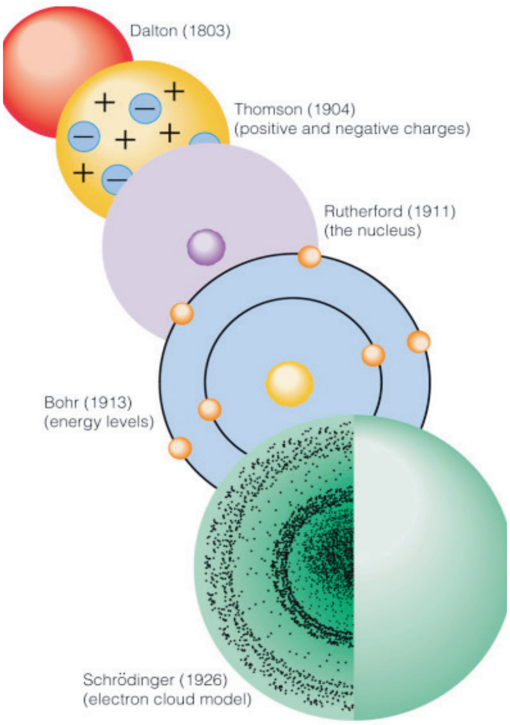


Figure 58: Models drawn by learners of a light bulb charged with a battery

In maths, abstract models are used. The square of can be represented as a2 or as a 2D square with length a.

Models share some characteristics:

- **Equation based models** are used to predict future states of a phenomenon. These predictions are used to validate the model, because these future states must correspond with empirical observations. If the model is invalidated by the data we have to reject the model or modify it ('Scientific modelling', 2018). Refining the model can be done by looking at the original assumptions, the correctness of mathematical manipulations or the properties that are ignored.
- Models have a **limited scope**. For example, Newtonian mechanics was once considered to be a complete model describing moving objects. Now we understand that this model is restricted to moving objects at low speeds. The model of special relativity is the true model describing objects at both low and high speeds. For very small particles, quantum mechanics is used. However, due to its simplicity, the Newtonian model is still used at relatively low speeds.



Models may also **vary over time**. For example, the model of an atom was adapted several times over time because of experimental results that did not fit with the current model at the time (see Figure 58). Although, the historical models aren't used anymore, it is interesting to introduce them to learners. Only this way, learners can understand where the models come from and how you can adept a model. The historical models are often closer to naïve ideas of the learners, so the stories illustrate how scientists themselves have to be very critical for their own models.

Figure 59: Historical development of the atom model (Poblete, n.d.)

How to use models?

After observing 'real' materials or doing experiments, **we remove the non-relevant characteristics from the reality** by comparison and analysis. The observations are processed, and the essential information is shown in a simplified and schematic way through a model.

You can stimulate learners to construct or draw their own models (explore phase), for example: 'How would you represent the force on a ball when you kick it' or 'Make a diagram that illustrates the relationship between animals in a pond'. These models can be compared with scientific models.

Learners can also use existing models to answer the key question during the explain phase. It is best to use various models to understand important conceptual relationships (McClean et al., 2005).

We list the most important visualizations:

- **Visual models:** 2 or 3-dimensional representations of a structure that show how the structure looks like or represent how the structure or phenomenon works. **For example,** 3D-models of molecules or atoms can be used by the teacher to show how they look like. If there are more materials/atomic models available, learners can use them to construct themselves products out of the reagents,

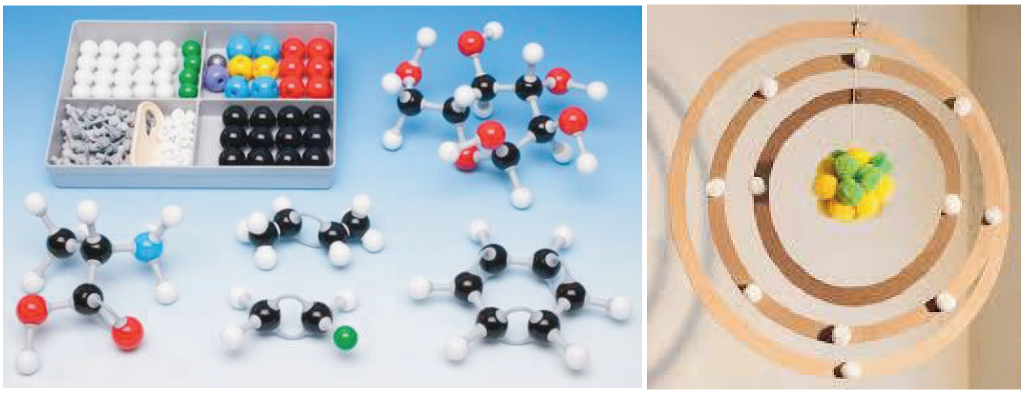


Figure 60: Left: building organic molecules, right: atomic model of Sodium

Figure 61: Learners building atomic models

- **Drawings, photos or diagrams**
- **Animations** illustrate the states of a process in a 'video'. This visualization technique is effective if it can capture the complexity of the individual components and how they interact.
- **Mathematical models** are the most abstract representations of our world.

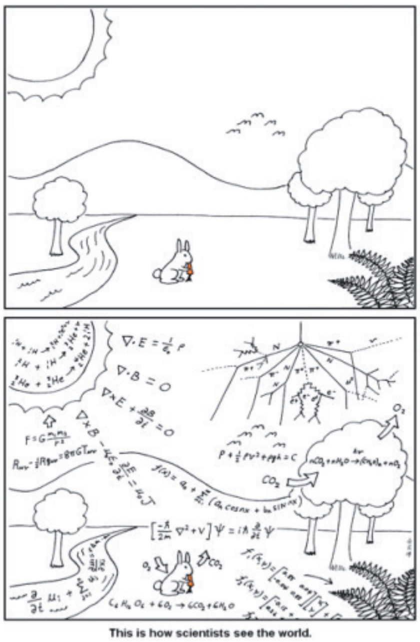


Figure 62: cartoon about how scientists see the world

- **(Online) simulations:** they visually simulate the reality, are based on mathematical models and are therefore valuable as **an interactive tool during the explore/explain phase**. The advantage is that you can change the parameters much more easily than in real experiments.

Animations

Animations are a **sequence of moving images** and are useful to show scientific processes. Examples of online animations for **biology**:

- http://vcell.ndsu.edu/animations/: biology animations and images of molecular and cellular processes.
- https://www.zygotebody.com/: works only with the browser 'Google Chrome'. This website shows a man and a woman on which you can show different layers of the body and different organ systems (digestion, transportation system …).
- https://dynamicecology.wordpress.com/2013/10/08/videos-for-teaching-ecology/: videos about ecology.
- https://english.elpais.com/society/2020-10-28/a-room-a-bar-and-a-class-how-the-coronavirus-is-spread-through-the-air.html: this animation shows how Covid-19 is transmitted in a room, a bar and a classroom. The questions below can be used to guide discussion:
    - What factors affect the infection rate indoors?
    - What measures can you take to limit infection when indoors?

Online animations for **chemistry**:

- https://preparatorychemistry.com/Bishop_animations.htm: different good animations. Most animations are divided in steps that are described next to the animation. That makes it also useful for learners to repeat or learn it by themselves.
- https://www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/simulations.html: a list of links to different websites offering simulations and animations of chemistry.

Online animations for **physics**:

- http://www.animations.physics.unsw.edu.au/
  Animations in physics are more and more replaced by simulations.

Simulations

There are a lot of science simulations available. We will first focus on the PhET interactive simulations, developed by the University of Colorado (*PhET Interactive Simulations*, n.d.).

The name "PhET" was originally an acronym for "Physics Education Technology.", but nowadays, the PhET simulations are **covering all fields of science and mathematics**. The simulations are very visual, based on results from education research, developed by professional programmers and widely tested by experts and in classrooms (see Figure 62). They are also available offline and can be downloaded on a tablet or a smartphone.

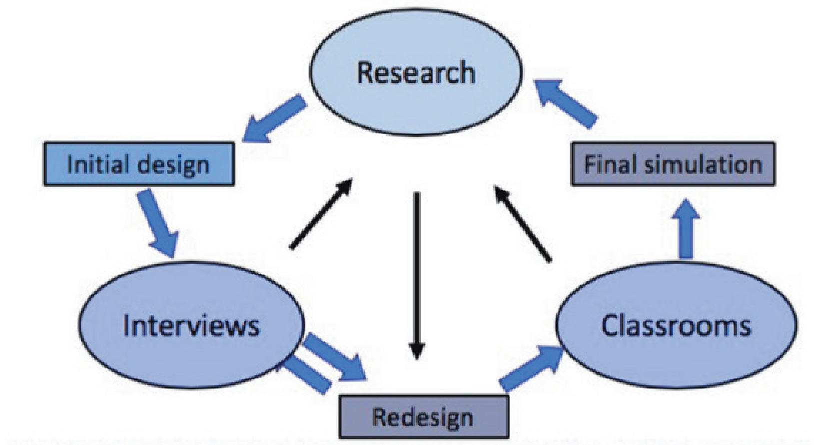


Figure 63: Design process of PhET simulations

You can find all simulations for free on phet.colorado.edu. An overview of its wide variety of possible uses in the classroom is available on: https://phet.colorado.edu/en/teaching-resources/usingPhetInLecture. When they are used during the lessons you need or a computer class for them or a computer and a projector.

It is not necessary to use a simulation in all the phases of a 5 E-lesson. It is **preferable to use real physical demonstrations to simulations, whenever possible**. Only use simulations during the first stages (Excite and Explore), when physical demonstrations are too difficult to organize.

The PhET simulations are most effective if they are **used in an interactive way**. Here are some possibilities for using simulations during **a 5E-lesson:**

1. Simulations simulate reality and are therefore valuable as **an interactive demonstration tool during the explore phase**. Do not use them as a standard demonstration, as they are a perfect tool to work in a learner-centred way. The advantage is that you can change the parameters much more easily than in real experiments. In this way, learners get used to a wide variety of situations and you can let them predict the outcomes of the simulation and try out the various parameters of the simulations. The simulations are often related to naïve ideas (alternative conceptions) and can be combined with peer instruction and other techniques.
2. Because the mathematical model behind the simulation is not directly visible, the simulations can be used **to derive the model behind the phenomenon during the explore phase** (e.g. Ohm's Law, the sodium and potassium channels opened by a neuron, a logarithmic pH scale …).
3. During the **explain phase**, the reasoning to derive the laws from the observations can be repeated in a very visual way.
4. Because the simulations cover a wide variety of situations, they are also perfect tools for the **extend and evaluate phases.**
5. They are also excellent tools for **extra exercises** for the learners. Use them for homework (if they have access to a computer at home or in the school), differentiation (additional exercises for fast learners) or exercises.

When you register as a teacher (for free) you can download extra teacher materials (see Figure 63) containing:

- teacher tips: how to use the simulations effectively;
- a video primer (only for the teacher) about the didactical use of the simulation;
- teacher resources (lesson plans, questions, etc.) about how teachers have used the simulations in their lessons.

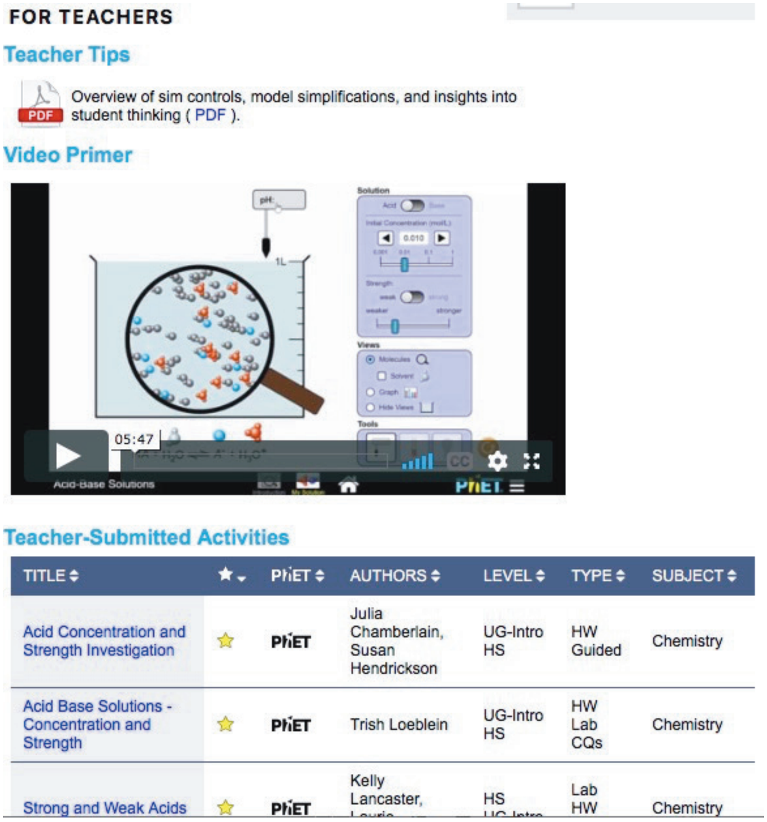


Figure 64: Extra resources for teachers are provided for most simulations

There are many **simulations** that can be used for **exploring mathematical content**. These help to develop conceptual understanding of mathematical formulas and increase motivation. An example for algebra (S2 Unit 2: Polynomials) is to explore how algebraic identities $(a+b)^2$, $(a-b)^2$, (a+b) (a-b) can be represented by the surface area of a square and a rectangle (See Appendix M.5).

You can use simulations during the explore phase for the topic on unit circle & Sine, Cosine and Tangent (S4 Unit 1: Fundamentals of Trigonometry). There are a lot of simulations available online: https://www.mathsisfun.com/algebra/trig-interactive-unit-circle.html and also apps like https://play.google.com/store/apps/details?id=processing.test.trigonometrycircleandroid&hl=en

The video explains unit circle and trigonometric ratios. https://www.khanacademy.org/math/algebra2/x2ec2f6f830c9fb89%3Atrig/x2ec2f6f830c9fb89%3Aunit-circle/v/unit-circle-definition-of-trig-functions-1?modal=1.

You can find a lot of other scientific animations on the internet. Sometimes, they are also available offline or can be downloaded.

Activity 28

Find and open the simulation “Build an atom” (chem/bio) or “area model algebra” (maths/phys).

Find out the charge of an atom that has 6 protons / 5 neutrons/ 6 electrons. Show the full symbol for this atom. Investigate what determines the mass of an atom. Test your ideas and change if needed. Show examples that fit your rule.

Afterwards, discuss:

- What will students be doing in each activity?
- What will students learn in each activity?
- What is the teacher doing?

Activity 29

Based on what you have learned in this section, discuss the following questions:

- Will you use the simulations in your school? Why (not)?
- How will you use them? Give an example.

Section 8: Using Contexts

Context-based learning refers to the use of real- life and fictitious examples in teaching environments in order to learn through the actual, practical experience with a subject rather than just its simple theoretical parts. Everything we learn in science lessons has a link to the world we live in, which we call context. As we teach science or mathematics, this context may not always be clear to learners and they may ask themselves why a certain topic needs to be studied. When we use meaningful contexts or make the connection with contexts explicit, we stimulate a sense of wonder and the involvement of learners in the lesson. Therefore, the use of context is essential in science and mathematics lessons.

We can divide contexts into **3 categories**:

- scientific and social context: for example: the outbreaks of the Ebola and Covid-19 epidemics, global warming, plastic pollution, antibiotics, vaccines, renewable energy, understanding exponential rates of covid-19 transmission …
- context of professions, for example: laboratory assistant/technician, researcher, conservationist, virologist, tourist guide…
- context of daily life, for example: living at home, preparing food, on a farm, sports, school, protecting oneself against viral transmission …

There are two ways to apply contexts in a lesson:

1. *Start from a context and introduce new concepts from within this context*

- Example biology: the outbreak of the Ebola epidemy or Covid-19 pandemic (Biology, Senior 2) can be the start of the lesson about viruses, the multiplication of viruses, the human immunity system, the transmission of infectious diseases … Don't wait until that topic is planned in the curriculum but consider switching lessons to another moment of the year planning if something occurs in daily life that has a link with a topic of that subject area.
- Example physics: How is our electricity produced? How can the burning of gas or coal result in electricity? How is most of our electricity produced?
- Example chemistry: metals aren't found on the Earth in their pure form. They are mined in ores (mineral aggregates containing metals). We search for rocks or sediments that contain sufficient minerals with economically important elements, typically metals and that can be efficiently extracted from the deposit. How can these metals be refined from the ores?
- Example mathematics: based on the update of Covid-19 pandemic, assume 21,783 is the total cases, 20,182 is the total recovered people and 307 is the total number of deaths, (a) how can you compute the percentage of rate of death? (b) express the active cases A, in terms X, Y and Z where possible. (c) Construct the exponential curve of the infection rate?

2. *Learners apply what they have learnt in a different context*

- example biology: How can you avoid a plague of insects, snails, … in the garden? Which ideas from the biology lessons can help us?
- example chemistry: If you can't remove spots of glue with soap, which solution can you use as an alternative?
- example physics: How can you increase your chances to survive a car crash? Which concepts of physics are involved?
- example mathematics: How can you calculate your chances of winning in a dice game? How can you calculate how much fertilizer you will need to treat your field?

UNIT 4: GENDER AND INCLUSIVENESS IN STEM EDUCATION

Introduction

Activity 30

Discuss the following entry question in pairs:

- What do you do in your teaching to make sure that all learners can learn to the best of their abilities?

Rwanda is currently ranked ninth in the world in ensuring equality between men and women[4]. Women hold 61 percent of seats in the Lower House of Rwanda's National Legislature[5]. Even with these accomplishments, many cite a patriarchal social structure and "traditional" beliefs that limit the power of girls and women (USAID, 2018). People with disabilities hold even less power and often miss out on opportunities related to education and employment.

There has been a lot of progress in the Rwandan education system. It has the highest participation rates in East Africa and has achieved gender parity in net and gross enrolment at pre-primary, primary, and secondary levels (USAID, 2018). In fact, girls' enrolment surpasses boys' enrolment at primary and secondary levels, raising concerns on the participation of boys in the education system.

However, dropout rates for both boys and girls, as well as disabled learners, remain a challenge. Boys younger than 13 are more likely to repeat and drop out than girls; and at age 14, the dropout rate for girls surpasses that of boys (MINEDUC, 2018). Among children with disabilities, deaf and hard-of-hearing children of primary school age in Rwanda are the most likely to drop out compared to children with other disabilities.

In national examination results, boys outperformed girls in almost all districts at P6 and S3 levels during the period 2008-2014 (MINEDUC, 2018). This indicates that girls face more challenges inside and outside schools than boys. An analysis of data shows the percentage of children making it from P1 to P6 in the previous six years was only 10% on average; for boys, the percentage was slightly lower than that for girls (NISR, 2015). This shows that, while girls face many challenges related to learning, progression and completion, boys also face challenges that include repeating and dropping out of primary school (NISR, 2015). To eliminate all the obstacles which lead to disparity in education, the Ministry of Education included gender and inclusive education as crosscutting issues in the Competence Based Curriculum framework (Rwanda Education Board, 2015).

4 https://www.weforum.org/reports/gender-gap-2020-report-100-years-pay-equality

5 https://www.weforum.org/agenda/2019/02/chart-of-the-day-these-countries-have-the-most-women-in-parliament/

Learning Outcomes

By the end of this unit, participants should be able to:

- Explain the meaning of gender, inclusive education, differentiation and related concepts;
- Explain the difference between inclusive education and special needs education;
- Have insight in the social construction of gender in society;
- Relate gender and inclusive education to classroom teaching and learning processes;
- Apply a gender responsive pedagogy in the classroom;
- Apply differentiation in STEM lessons;
- Reflect on how to apply gender concepts to teaching and learning STEM;
- Design learning activities that will interest and engage girls and boys in STEM;
- Support fellow teachers in applying gender responsive pedagogy in the classroom;
- Make learning of STEM enjoyable for both girls and boys;
- Make STEM lessons more inclusive
- Address gender stereotypes in STEM instruction;
- Appreciate that boys and girls have equal abilities to achieve proficiency in STEM;
- Commit to working towards equity in their school.

Section 1: What Is Gender?

Many people wrongly think that gender means “women’s issues”. In reality, gender refers to socially determined roles and relations between males and females (Subrahmanian, 2005). Gender is different from sex. Sex refers to purely biological differences between men and women. Gender roles, on the other hand, are created and sustained by the society, which assigns different responsibilities to men and women, e.g., cooking for women and decision-making for men.

Gender roles can therefore be changed and vary over time and from community to community. These gender roles are consciously or unconsciously carried into the classroom dynamics by both teachers and learners. In children’s textbooks, for example, women are often represented as cleaners, caregivers and nurses, and men are drivers, doctors and leaders. These images reinforce gender roles.

In a famous study, thousands of children were asked to draw a scientist (Chambers, 1983). Of the almost 5,000 drawings, just 28 depicted a female scientist, and all of those were drawn by girls. Not a single boy drew a woman. In follow-up studies, the number of learners drawing a woman as a scientist has increased, but is still far from 50% (Miller et al., 2015). It is also notable that even girls, as they grow up, become more likely to draw scientists as men. At age 6, girls draw 70 percent of scientists as women, but this proportion flips around ages 10 to 11 and by 16, they draw around 75 percent of scientists as men (Yong, 2018). Lower secondary school is a critical period in which they’re learning this gender-biased information about what is a scientist (Miller et al., 2015) .

Figure 65: Example of a female scientist, drawn by learners (Yong, 2018)

Activity 31

Are following statements related to sex or gender?

- Women give birth to babies; men do not.
- Girls are gentle; boys are rough.
- Doctors are men; nurses are women.
- Boys don't cry.
- Boys are good at math and science and girls are good at language and history.
- Boys' voices break at puberty; girls' do not.

Activity 32

Can you give examples of how cultural norms and practices have an impact on girls' and boys´ participation in STEM lessons in your school? Has there been any evolution over the years?

Activity 33

Watch the video 'As a Girl" and discuss following questions:

- What stereotypes about boys and girls are addressed in the video?
- Do you encounter these stereotypes in your school? What other stereotypes are there?
- What can you do in your school to remove these stereotypes?

Areas where consistent gender differences have emerged are children's beliefs about their abilities in STEM, beliefs and attitudes of other stakeholders (school leaders, teachers, parents, community leaders) in abilities of boys and girls, learning outcomes in STEM, children's interest in STEM and their perceptions of the importance of STEM for their future.

Researchers have found that girls often have less confidence in their abilities for STEM subjects than males do and that from early adolescence, girls show less interest in mathematics or science careers (Zuze & Lee, 2007). Girls tend to underestimate their abilities in STEM subjects. This is a problem because research shows that children's beliefs about their abilities are crucial to determining their interest and performance in different subjects and the career choices they make (Beilock et al., 2010)their math anxiety carries negative consequences for the math achievement of their female students. Early elementary school teachers in the United States are almost exclusively female (>90%.

This gender difference contrasts with research that males and females generally show similar abilities in STEM, as measured by test scores (Hyde et al., 1990). Male brains are, on average, larger than female brains, but the size is not indicative of cognitive ability. Studies of the brain's anatomy also show that there are structural differences between the brains of women and men, but the variation between individuals is far larger than that between the sexes – in other words, there is no such thing as a "female" or "male" brain (New Scientist, 2018).

Section 2: Key Terms

When discussing gender, we use various terms. In this section, we clarify their meaning.

- **Gender discrimination**: Denying opportunities and rights or giving preferential treatment to individuals on the basis of their sex.

- **Gender equality**: The elimination of all forms of discrimination based on gender so that girls and women, boys and men have equal opportunities and benefits (OECD, 2015).

- **Gender equity**: Fairness in the way boys and girls, women and men are treated. In the provision of education, it refers to ensuring that girls and boys have equal access to enrolment and other educational opportunities (Subrahmanian, 2005)

- **Gender stereotype**: The constant presentation, such as in the media, conversations, jokes or books, of women and men occupying social roles according to a traditional gender role or division of labour (OECD, 2015). However, avoiding gender stereotyping does mean the denial or minimisation of differences between males and females.

- **Gender sensitive**: The ability to perceive gender issues. It is the beginning of gender awareness (UNICEF, 2017). The opposite of gender sensitivity is gender blindness. This is an attitude to ignore gender issues, claiming that they don't exist. For example, a gender-blind teacher may see no problem with boys taking all leadership roles in the class.

- **Gender-based violence** refers to acts of violence inflicted on women because of their gender and sexuality. It includes physical violence in the form of corporal punishment, psychological violence such as verbal abuse, and sexual violence ranging from unwanted sexual talk and indecent touch to rape.

Section 3: Gender Responsive Pedagogy

Observations of classroom practices show that the teaching and learning process is often gender biased (Aikman & Underhalter, 2007; Consuegra, 2015). Many teachers apply teaching methodologies that do not give girls and boys equal opportunities to participate. They also use teaching and learning materials that reinforce gender stereotypes. Consequently, there is an urgent need to introduce a gender responsive pedagogy.

Gender responsive pedagogy refers to **teaching and learning processes that pay attention to the specific learning needs of girls and boys** (Mlama, 2005). Gender responsive pedagogy calls for teachers to take an integrated gender approach in the processes of lesson planning, teaching, classroom management and evaluation.

Gender responsive pedagogy includes **gender neutral language use by the teacher**. Inappropriate language use can transmit negative messages and inhibit learning. A boy or girl whose teacher constantly tells them "you are stupid", will come to believe this to be true. Language can also reinforce gender differences and inequalities and in the classroom often reflects male dominance and reduces females to an inferior position. By contrast, a teacher can enhance students' performance by using encouraging, inclusive language in the classroom.

Teachers may discourage girls from doing mathematics and science by telling them that such subjects are for boys or are too difficult for girls. When a girl is self-confident, she is told to stop behaving like a boy, and when a boy cries, he is urged to stop behaving like a girl.

Much gender insensitive communication is non-verbal. Laughing, an indifferent shrug of the shoulders or rolling of the eyes suggests that the student is too foolish or annoying to deserve attention. Other gestures and body language, such as winking, touching, brushing, grabbing and other moves may be overtly sexual. This type of communication may go unnoticed by others for a long time, but it can be extremely damaging to classroom participation for the one at whom the communication is targeted. It is also difficult for the victim to act to stop it because there is often no tangible evidence. Most sexual harassment occurs and becomes much worse in this way.

Section 4: Making STEM Lessons Gender Responsive

Introduction

In this section, we discuss strategies that teachers can use to promote the involvement and learning of girls in STEM lessons.

What can teachers do to encourage girls in learning STEM? Many techniques that we discussed in this module aim at stimulating thinking and involving all learners. None of these strategies, however, is automatically gender responsive. Often, boys tend to dominate learning processes to maintain their superiority in the presence of girls. Therefore, teachers need to consider the specific gender needs of girls and boys in planning their lessons.

In their lesson plans, teachers should think about how all students can participate in learning activities. They should ensure that there is equal participation in activities such as making presentations, conversations and practical activities. In group activities, ensure that both girls and boys are given leadership positions and roles. Consider how learning materials will be distributed equitably to both girls and boys, especially in cases of shortages.

Activity 34

Think individually about what teaching methods you have used to encourage equal learning of boys and girls in your lessons.

Remember that equal participation is not sufficient for gender equity. What can you do to make sure that learning outcomes are equal as well?

Consider:

- classroom arrangement
- teaching methods
- attitudes and beliefs

Afterwards, discuss your ideas with your neighbour.

Activity 35: Case Study from Groupe Scolaire Saint- Pierre

Students for Groupe Scolaire Saint-Pierre have started an entrepreneurship club, guided by their chemistry teacher. By applying what they have learned about chemistry, they started making soap using locally available materials. Sodium Benzoate is used as a preservative, various colourings are used to give the soaps a nice appearance and aloe vera, grown at the school compound, gives the soap its characteristic fragrance.

The soaps are sold on the local market and profits are used to buy school materials such as lab equipment. The deputy head teacher says that the entrepreneurship club shows how the competency-based curriculum can be put into practice. Boys and girls learn to work together, develop a business and put science into practice.

Activity 36: Case Study: Groupe Scolaire ASPEKA

Watch the video about Groupe Scolaire ASPEKA in Kamonyi. With the support of the environment teacher, learners have started an entrepreneurship club.

Discussion questions:

- How does this initiative promote gender equity?
- How does this initiative promote STEM?
- Could you start a similar initiative in your school? Explain.

You can watch the video via: https://www.youtube.com/watch?v=DPHA81vr6Rw

Making STEM lessons gender equitable

1) **Classroom arrangement**

Consider the typical classroom arrangement – desks arranged in rows facing the teacher. This kind of arrangement has been used in most schools and has certain strengths. A big drawback is that it reinforces traditional gender patterns (Mlama, 2005). Since girls are not brought up to speak out – or rather, are brought up not to speak out – when they sit at the back of the class, they are less likely to participate unless the teacher makes a special effort to involve them. Remember the distinction between equality and equity. Being gender responsive does not means treating all learners equally, but making sure that all learners have equal opportunities to learn.

A different arrangement such as breaking the class into smaller groups may encourage girls to participate more.

2) **Teach students that abilities to learn are expandable and improvable**

To change girls' beliefs about their abilities, teachers should understand and communicate to students that abilities in STEM —like all abilities—can be improved through consistent effort and learning (Dweck, 2006, 2015). Research shows that even students with high ability who view their cognitive skills as fixed are more likely to experience greater discouragement, lower performance and reduce their effort when they encounter difficulties. Such responses may be more likely in the context of STEM, given stereotypes about girls' innate mathematics abilities (Dweck, 2006).

In contrast, students who view their abilities as changeable keep working hard to increase their performance when they are faced with difficulty or frustration. To help girls resist negative reactions to the difficulty of science and maths, it is very important to stress for them to learn that their maths and science abilities can improve over time with continuous effort and engagement.

Check also: https://www.youtube.com/watch?v=fC9da6eqaqg

3) **Expose girls to female role models**

Researchers have found that negative stereotypes can affect performance and have called this phenomenon "stereotype threat."

Studies show that stereotype threat can lead young adolescent girls and women to choose unchallenging problems to solve, lower their performance expectations and devalue mathematics as a career choice. In addition, we suggest that teachers invite women or elder students who can serve as role models in STEM to be guest speakers or tutors. These role models should communicate that becoming good at mathematics and science takes hard work and that self-doubts are a normal part of the process of becoming expert in any field.

Activity 37

In this activity, we will discuss the importance of female role models in STEM. We will watch the video "Joining the ranks of Neurosurgery: My Impossible Dream" on the life of Claire Karekezi.

After 15 years of intense training and studying that has taken her across three continents, Dr Claire Karekezi returns home to Rwanda as the only female neurosurgeon in the country.

Video: https://www.youtube.com/watch?v=96wNdg-8t2o

After watching, discuss the questions below.

Questions for discussion:

1. Do you think that it is important to expose girls to women who achieved a lot in science and maths?
2. What are conditions for someone to act as a role model for girls in STEM?
3. Can you give examples of how female role models have helped to achieve gender equity in your school?

Examples of **role models for STEM in Africa**:

Apps and Girls

Apps & Girls is a Tanzanian registered social enterprise that was founded in July 2013 by Carolyne Ekyarisiima. It seeks to bridge the tech gender gap by providing quality coding training (web programming, mobile app development game development and robotics) and entrepreneurship skills to girls in secondary schools via coding clubs and other initiatives such as mentorships and scholarships. So far, they have created 25 coding clubs in Tanzania and they have trained 269 teachers and 2656 girls. They want to train 1 million girls before 2025.
Link website: http://www.appsandgirls.com/
Link YouTube: https://www.youtube.com/watch?v=yNNrVqUvkjg

Scratch2050

VVOB, REB and Rwanda Coding Academy (RCA) via Rwanda Polytechnic, have been working together with 45 secondary schools in Kayonza to start after-school coding clubs. In these coding clubs, students learn how to code using Scratch, a block-based coding tool. At least 50% of the members of the clubs are girls. Teachers are trained in facilitating the clubs, but also in integrating Scratch in their STEM lessons. With these coding clubs, REB wants to link STEM and ICT teaching with the world of work stimulate boys and girls to consider choosing a STEM career. After the pilot in Kayonza, REB and RP plan to scale up the coding clubs to other districts as well. You can find more information on Scratch via https://scratch.mit.edu/ and on the project via https://rwanda.vvob.org/news/becoming-ict-engineer-tesi%E2%80%99s-dream

Box: Rwandan Association for Women in Science and Engineering

The Rwandan Association for Women in Science and Engineering (RAWISE) is a non-profit organization founded by a group of Engineers and Scientists women from Rwanda. The association aims at increasing the number of girls in science, technology, engineering and mathematics (STEM); provide a platform for engineers and scientist women in Rwanda to meet, discuss and collaborate; and increase female participation in scientific and technology-related professions in Rwanda.

The association aims to increasing women scientists' participation in decision making and development our country Rwanda and provide a hub for Rwandan women scientists where they can meet, network, collaborate and further their research. You can find more information on: https://www.rawise.org.rw/

4) **Create a classroom environment that stimulates curiosity and long-term interest in STEM**

Researchers have found gender differences in students' interests, with boys typically more interested in activities and careers involving scientific, technical, and mechanical pursuits and girls more interested in activities and careers that involve social and artistic pursuits (Beilock et al., 2010).

An important way to cultivate students' long-term interests in STEM is to build upon their curiosity. Once students' interest in a topic or content area is created, teachers can build on that, providing students with opportunities to engage with interesting material with the objective to transform that curiosity into a long-term interest. One strategy is to set STEM problems in interesting real-world contexts.

5) Gender-responsiveness in classroom interactions

Many techniques that we have discussed in this course aim at improving the quality of interactions in STEM lessons, both between teacher and learners and among learners. In managing these interactions, it is important as a STEM teacher that you are aware of potential gender bias and that you can act to address this. In Table 11 we list guidelines to ensure that conversations and group activities are gender responsive.

Activity 38

How can you ensure gender responsiveness in your lessons? What have been your challenges to achieve it?

Table 11: Actions to make lessons more gender responsive

Methodology	Action
Conversations (questions and answers)	▪ Extend positive reinforcement to girls and boys. ▪ Allow sufficient time for students to answer questions, especially girls who may be shy or afraid to speak out. ▪ Assign exercises that encourage students, especially girls, to speak out. ▪ Distribute questions to all the class and ensure that each student participates fairly. ▪ Phrase questions to reflect gender representation – use names of both men and women, use both male and female characters in problems, pictures…
Group activities	▪ Ensure that groups are mixed (both boys and girls). ▪ Ensure that everyone has opportunities to talk and lead discussions. ▪ Ensure that group leaders are both boys and girls. ▪ Encourage both girls and boys to present the results. ▪ Ensure that both girls and boys record the outcomes.

source: Mlama, 2005

Section 5: Inclusive Education

Introduction

All learners are different. Inclusive education is based on the idea that all learners have the capacity to succeed at science and mathematics and the recognition that differences in thinking and learning are valuable. Inclusive education means tailoring teaching to meet the learning needs of each learner. For many STEM teachers, the most difficult issue is how to meet the needs of so many students with large differences in terms of what they currently know, what they can do, their motivation, their personalities… The competence-based curriculum framework identifies special needs as a cross cutting issue in all subjects including science and mathematics. Therefore, teachers are called to identify any students who are struggling and adjust the learning environment to better enable them to learn. Inclusive education is about treating all learners as individuals. It is about making sure that all learners can learn. Therefore, it is much broader than special needs education, which focuses on learners with disabilities.

Activity 39

Describe in one sentence what inclusive education means to you practically in your teaching.

Compare and discuss with your neighbour. Come to an agreement.

Components of Inclusive Education

When we think about inclusive education, often we only think about getting children into school. However, we also need to ensure that children can access teaching and learning materials, are participating in lessons and school life, and that they are achieving learning outcomes and are integrated into the school community.

Therefore, when thinking about inclusive education, we always need to consider **Presence, Participation and Achievement** (Figure 65) (Ainscow, 2005).

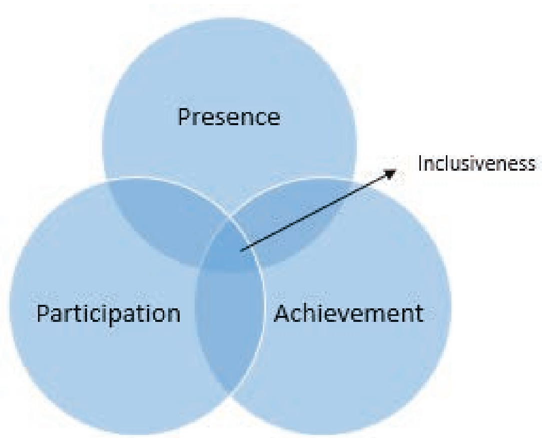


Figure 66: Components of Inclusive Education (Ainscow, 2005)

It is not enough that children attend the lessons; all children should be given opportunities to fully participate and achieve.

Equal presence: Teachers should be instructed to do daily attendance checks of all children. If there is an attendance issue related to sex, disability or other reason, talk with parents through School General Assembly meetings. Invite the concerned parents at school to speak about why all learners should be provided equal learning opportunities and how to support their learning needs.

Equal participation: Teachers should ensure that all learners are participating actively and given chances to lead in classroom activities, classroom discussions, and different clubs. All learners should have opportunities to access learning materials such as books, experiments and ICT.

Equal achievement: Parents, teachers and school leadership should ensure that there are no systematic gaps in achievement and that all learners can achieve according to their potential. You may think it is too difficult to address the needs of a diverse range of children, as there are so many challenges. However, by working as a team within your school, with support from families and local communities, and by making small changes to your teaching methods, you will be able to meet the needs of all children.

Differentiation

Differentiation is a key classroom strategy to make teaching and learning more inclusive. But what does differentiation mean? Is it feasible in classrooms with many learners and how do you go about it?

Activity 40

Discuss whether you **agree or disagree** with the following statements (agree/not agree/depends)

1. Differentiation is the same as effective teaching.
2. Differentiation means grouping students by ability.
3. Differentiation is mostly aimed at students with learning disabilities.
4. Differentiation is about valuing and planning for diversity.
5. Differentiation means that all students do different things.
6. Differentiation is not possible in classes with more than 50 learners.

You can find the solutions in the infographic below (Figure 67)

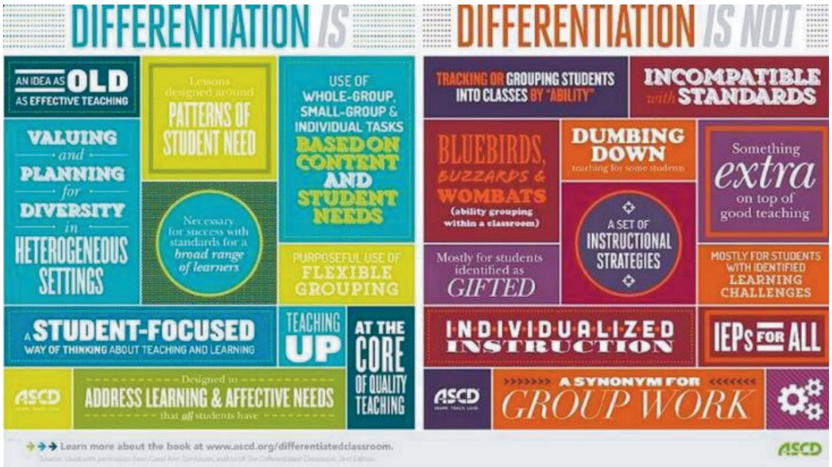


Figure 67: Differentiation is and differentiation is not (ASCD, 2015)

Source : http://www.ascd.org/ASCD/pdf/siteASCD/publications/Differentiation_Is-IsNot_infographic.pdf

Every classroom at every grade level has students with varying ages, abilities, prior knowledge and backgrounds. In Rwanda, many students' mastery of learning is several grade levels below the grade they are in (Rwanda Education Board, 2018). Perhaps the most important work of teachers is to identify students' level of prior knowledge and then plan lessons that support and challenge all students to learn. This will enable teachers to differentiate instruction effectively, considering the large class sizes, providing remediation for struggling learners so they can catch up with their peers and providing challenging content and activities for fast learners.

Activity 41

A maths teacher teaches in grade 7, but notices that some students do not have the required prior knowledge on fractions that they should have learned in grades 5 and 4. What would you do?

Differentiation is not about treating every learner equally. It is about giving all learners the support they need to achieve the learning outcomes. This implies that some learners will need more or different support than others (see Figure 67). In the third image, all three children can see the game without any supports or accommodations because the systemic barriers have been removed. The cause of the inequity was removed.

Figure 68: Equality versus Equity (Save the Children, Mureke Dusome project, 2017)

Differentiation is about giving all learners the support they need to learn

Differentiated instruction versus individualized instruction

Differentiated instruction is often confused with individualized instruction. Individualized instruction is focused on sorting students by ability and give different content or exercises to different students. This can be useful when teaching for mastery of basic numeracy or literacy skills. This approach is teacher-centred, as it is up to the teacher to design suitable tasks for each individual learner. Differentiation takes a **learner-centred approach** by providing students with tasks that will allow all of them to have success. Differentiation stresses problem solving opportunities that enable the entire group to learn with and from each other.

Differentiation is not about having students do different things all the time, nor is it about teachers choosing the learning for them, it is about students doing the same thing in different ways. By sharing our differences, we learn from and with each other.
More information: https://buildingmathematicians.wordpress.com/2017/03/12/the-same-or-different/

How to differentiate

This content is based on a workshop from The Literacy and Numeracy Secretariat to support leadership and instructional effectiveness in Ontario (Canada) schools. The full workshop can be accessed at: http://www.edu.gov.on.ca/eng/literacynumeracy/inspire/research/different_math.pdf

A **first step** in differentiating teaching is taking the knowledge that learners bring to class into account. There is a lot of evidence that learning is improved if teachers pay attention to the prior knowledge and beliefs of learners, use this knowledge as a starting point for instruction and monitor learners' learning (J. A. C. Hattie & Donoghue, 2016). If their initial understanding is not engaged, they may fail to understand the new concepts that are taught.

Secondly, differentiating instruction means engaging all students. All students need sufficient time and a variety of problem-solving contexts to apply concepts, procedures and strategies and to develop and consolidate their understanding. Teachers should consider the different ways that students learn by using a variety of teaching strategies.

Thirdly, differentiating instruction involves continuously assessing your learners and designing tasks and activities that focus both on learners that are at risk of falling behind (remediating instruction) and those that are ready for more challenging problems (advanced instruction).
There are four approaches in implementing differentiation (Figure 68):

Figure 69: Approaches to differentiation

1. Differentiate by quantity

This approach recognizes that stronger learners will work faster, and extra work should be made available by the teacher to help them and keep them motivated. However, 'more work' is unhelpful when this only means 'more of the same'. These learners need to explore ideas in more depth, not merely cover more exercises. The extra work can introduce more advanced content or require higher order thinking skills.

2. Differentiate by task

In this approach, learners are given different problems or activities, according to their learning needs. This approach is difficult to implement well, because it presumes that the teacher can judge the performance of each learner accurately beforehand, and that the teacher has suitable problems or activities at different levels available to the teacher. When you decide in advance that some learners will not be able to cope with some concepts and ideas of the lesson, you deny them the opportunity to engage with these ideas. It is therefore not a good strategy to simplify activities for some learners in advance.

A better approach is to give learners some choice in the activities they undertake. For example, learners can be asked to choose between a straightforward, a moderately difficult and a challenging task. Research showed that few learners will choose the straightforward task and that most prefer a challenge (Swan, 2005). This approach assumes that learners can make a realistic assessment of their own ability to solve the problem. It works less well with less confident learners, as they may choose tasks that are too easy for their level of understanding.

3. Differentiate by level of support

In this approach, all learners are given the same task, but are offered different levels of support, depending on the needs that arise during the activity. This reduces the risk of judging learners beforehand. During group work or individual work activities, the teacher can walk around and help those who need support. For example, you may give carefully chosen elements of support during a group work activity. This is a realistic approach to apply differentiation in Rwanda.

4. Differentiate by the outcome of the activity

Open activities that encourage a variety of possible outcomes offer learners the opportunity to set themselves appropriate challenges. This approach is used in many activities in this guide. For example, some activities invite learners to create their own classifications or their own problems and examples. Teachers may encourage learners to ‘make up questions or problems.

Activity 42
Review the four ways to differentiate teaching. Develop an example for your teaching for each of them.

Which of the four do or would you use the most? Which one the least? Why?

Strategies to implement differentiation in STEM lessons

1) ***Identify and focus on key concepts of the lesson***

Determine for each lesson what the key concepts are that each learner should master at the end of the lesson and what is additional or non-crucial content. The curriculum will provide you with a starting point for what the key concepts are. The key question of the lesson (See section 1: 5 E´s as an instructional model) should help you to determine the key concepts.
It is impossible to differentiate if teachers do not recognize the key concepts. Another critical aspect of differentiation is considering the student’s development in the concept that is taught. It is key to map out a sequence of instruction for students. The Realistic Mathematics Education Group in the Netherlands states that student mathematical growth can be described in terms of being able to move from familiar contexts to more abstract situations (Van Den Heuvel-Panhuizen, 2003). Let’s consider this idea by thinking through another problem and the different ways that students could respond to it.

Tables and Seating Problem

79 parents said they are coming to a meeting in our school tonight. They will sit at large tables that seat 5 people each. How many tables do we need?

A P3 student might be able to solve this problem using repeated addition or repeated subtraction, yet not recognize that this problem is an example of a “sharing problem” situation. A more mathematically advanced student will recognize the more general situation; that is, this problem can be solved for any number of parents using the division operation.

For teachers, it is important to map out the connections among concepts, strategies and models of representation. Also, such a map can be helpful in recognizing how students' thinking and understanding could develop across that cluster.

5) ***Designing Open Tasks***

Suppose a P4 teacher wants to teach the key concept that any subtraction can be thought of in terms of a related addition. P4 students should be able to solve addition and subtraction problems involving multi-digit numbers, using concrete materials and standard algorithms, as well as use estimation to help judge whether a solution is realistic. Some students may not be ready to deal with three-digit numbers, even with the use of concrete materials. A teacher might change the planned task to turn it into an open task (Figure 69). Open tasks are also called "**Low threshold, high ceiling tasks**". The low threshold means that the task can be done by learners who still have a low understanding of the concept. The high ceiling means that the task can still be challenging for learners who have already a good understanding of the concept.

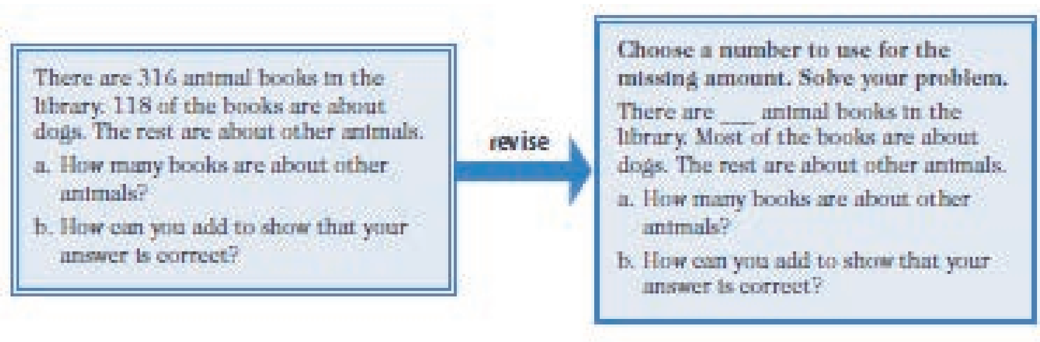


Figure 70: Example of a closed (left) and open Task (right) (Beckmann, 2013)

With the open number task, students have a choice in the numbers they use, choice in the strategies they use and a choice in how they interpret the problem. Students who can only handle numbers below 20 can do so. Students who can handle numbers below 100 in a concrete way can do so too. Students who are ready to work with very large numbers can do so as well. Also, in the revised task, some students will interpret the phrase "most of the books" to mean more than half. Others can simply interpret it as meaning that more books are about dogs than other animals; they might make a list of different animals with a total number of books about each animal, ensuring that the number for dogs is the greatest number on the list. These variations really don't matter. All students will be considering a subtraction situation; all of them are relating it to an addition situation; all of them have an opportunity to understand and solve the problem using their own student-generated strategies and appropriate materials. Whether students are working with large or small numbers, the sharing of their mathematical thinking is valuable for the collective learning of the class.

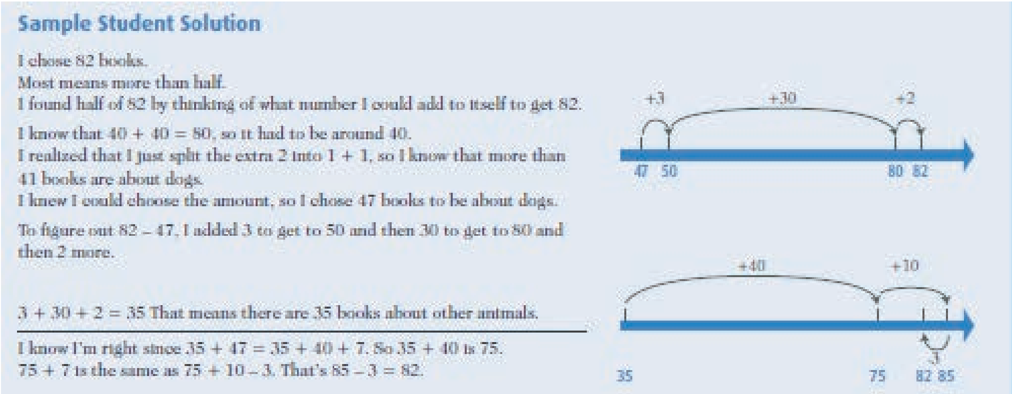


Figure 71: Example Solution for an Open Task (Beckmann, 2013)

In fact, there might be more sophisticated thinking from a student who uses a smaller value than one who simply uses a standard algorithm to subtract 118 from 316. With several differentiated student responses to the problem, it is valuable for students to share their thinking and compare strategies. In this example, the teacher can coordinate a class discussion about the use of different models of representations to show different mathematical thinking.

The use of open tasks contrasts with a more familiar procedure for differentiating mathematics instruction; that is, to break up a task that may be too difficult for some students and ask them to think about little bits of the task at a time. This approach reinforces the notion that some students are not capable of independent mathematical thinking and denies some students opportunities to develop that capacity.

There were _________ children on the playground.
_________ more came to join them.
How many children were on the playground then?

Figure 72: Example of open learning task

In the above example, children can choose various combinations of numbers to solve the problem.

Here is another example for mathematics

Sarah and Mike ran each day this week. Each day Sarah ran 3 kilometres in 30 minutes. Mike ran 6 kilometres in 72 minutes. Here are the answers: 42, 2, 294, 3 ½. What can be the questions for each answer?

Possible responses:

42: How many more minutes did Mike run than Sarah each day?
2: How many more minutes does it take Mike to run a kilometre?
294: How many more minutes did Mike run this week than Sarah?
3,5: How many hours did Sarah run this week?

Activity 43

Develop an example of an open task that you can use in your teaching. Exchange results and provide feedback on each other's work.

6) ***Regularly check all students' understanding***

Structure your lesson in such a way that there are frequent moments for checking learner understanding. Avoid long series of exercises where students may get stuck for a long time. Some struggle is fine for students, and even helps learning and retention, but avoid that they get completely stuck and become demotivated.

Build in moments during the lesson when learners show their learning before they move to the next step. This is part of the process of collecting learner data. The objective is to closely monitor learning progress to make quick remediation possible. For example, learners make a few exercises. When they are finished, they raise their hand for a quick check. If ok, they can proceed with the next exercises. If the same errors keep coming back, you can build in a moment of whole-class instruction. These control moments should be short to limit wait time. The risk of the technique is that learners must wait too long before they get feedback.

More exercises between control moments increase the time difference that learners finish the exercises. This technique allows for accommodating both faster and slower learners.

7) ***Involving learners with learning challenges***

Differentiation does not require the specialized knowledge to deal with specific learning disabilities. However, as a teacher you can take some simple steps to help learners with learning disabilities. Table 12 lists some classroom strategies to help learners with various learning challenges.

Table 12: Learning Challenges and Possible Classroom Strategies

CHALLENGE	CLASSROOM STRATEGY
HEARING	▪ Try to convey information to the child using sign language or informal signs and hand gestures. ▪ Seat the child in the front row. Speak loudly and clearly. ▪ Ensure the child can see your mouth when you speak. ▪ Provide the child with a detailed outline of the lesson/objectives at the start of the lesson. ▪ Use charts, pictures and icons to present information. ▪ Assign the child a learning buddy (other learner in class). ▪ Speak with the child's parents to identify and build on communication techniques used at home. ▪ Refer to child to a doctor for hearing aids.
TALKING	▪ Encourage the child to continue when he/she is trying to communicate. ▪ Be attentive while he/she is talking. ▪ Provide opportunities to use different ways of communication such as role play, gestures, drawing, writing, etc. ▪ Speak with the child's parents to identify and build on communication techniques used at home.
PHYSICAL ACCESS	▪ Ensure the child is physically able to access his/her classroom and seat. ▪ Ensure the child can access learning materials. ▪ Assign a student helper or circle of friends to help the child navigate the classroom. ▪ Shift classroom furniture so that there are clear passageways.
READING	▪ Ask the child to follow along on the page with a finger. ▪ Provide a piece of paper or other material and instruct the child to uncover one sentence at a time while reading. ▪ Provide extra reading practice time in school and at home. ▪ Pair the child with a reading buddy who reads with him/her daily.
SEEING	▪ Ensure that the classroom has good lighting. ▪ Write in large clear letters on the blackboard. ▪ Assign the child a learning buddy. ▪ Seat the child in the front row. ▪ Refer the child for glasses, if possible.

Source: Save the Children, Mureke Dusome project, 2017

Activity 44

Review Table 12 and discuss following questions:

- Which techniques have you used already and what have been your experiences and challenges with them?
- Do you use other strategies to help learners with specific learning challenges learn?

Discuss your experiences and ideas in small groups.

UNIT 5: ASSESSMENT

Introduction

Assessment is an important element in teaching and learning (Hattie, 2009). Quality assessment provides information to students, teachers, school leaders, parents and the education system in effective and useful ways. To be helpful, however, it must be broad ranging, collecting a variety of information using a range of tasks before, during and after a teaching sequence. Assessment is more than the task or method used to measure students' learning. Assessment includes the process of drawing conclusions from the collected data and acting upon those judgements in ways that improve teaching and learning.

There are two types of assessment: formative and summative assessment. However, in this manual, the emphasis is on formative assessment.

Learning Outcomes

At the end of this unit, participants will be able to:

- Explain principles of formative and summative assessment within the competence-based approach;
- Explain the importance of formative assessment in improving learners' performance;
- Conduct formative and summative assessment with the objective to improve learner's performance;
- Support fellow teachers to organise formative and summative assessment activities and use data from the assessment to improve their teaching;
- Appreciate the role of assessment for quality STEM teaching.

Section 1: Formative and Summative Assessment

Formative Assessment

Formative assessment refers to activities that monitor student learning frequently to provide ongoing feedback that can be used by teachers to improve their teaching and by students to improve their learning (Black and Wiliam, 2001). More specifically, formative assessment:

- helps students identify their strengths and weaknesses and target areas that need more work;
- helps teachers identify the concepts students are struggling to understand and address problems immediately;
- enables teachers to build on learners' prior knowledge and match their teaching to the needs of each learner.

Formative assessments are generally low stakes, which means that they have no or a low impact on students' final grades. Examples of formative assessments include asking students to:

- draw a concept map in class to represent their understanding of a topic;
- discuss a concept cartoon
- take a short quiz at the start or end of the lesson;
- vote on a concept test;
- write short notes summarizing the main ideas of the lesson;
- work in groups to make a poster or presentation on a topic.
- use traffic light cards to answer the teacher's questions., etc

Summative Assessment

Bloom, Hastings, & Madaus (1971) defined summative assessment as an evaluation given at the end of a unit of learning and which is designed to judge the extent of students' learning of the material in a course with the purpose of grading, certification, evaluation of progress or even for researching the effectiveness of a curriculum. The goal of summative assessment is to evaluate student learning by comparing it against standards or outcomes (Black and Wiliam, 2001).

It is carried out at intervals when achievement has to be evaluated and reported (Hattie, 2009). Examples of summative assessment include:

- a midterm exam
- P6 national examination
- a final project, etc.

Summative assessments happen too far after the teaching and therefore do not directly inform to make instructional adjustments and interventions during the lesson.
Another distinction between formative and summative assessment is student involvement. If students are not involved in the assessment process, formative assessment is not effective. Students are usually not involved in designing summative assessments.

However, formative and summative assessment are connected (Figure 72). Summative assessment such as tests and exams can also be used for learning by students and teachers. For example, a teacher can use marked exams to change the scheme of work, paying more attention to areas where students did not perform well.

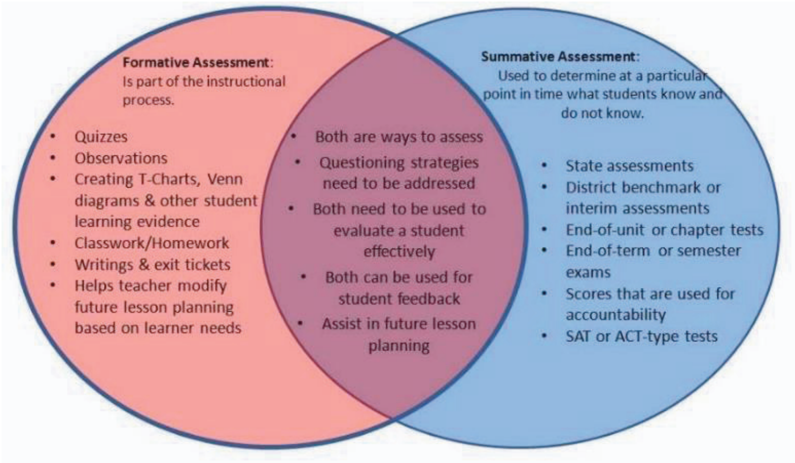


Figure 73: Formative versus Summative Assessment

Source: https://improvingteaching.co.uk/2016/12/11/a-classroom-teachers-guide-to-formative-assessment/

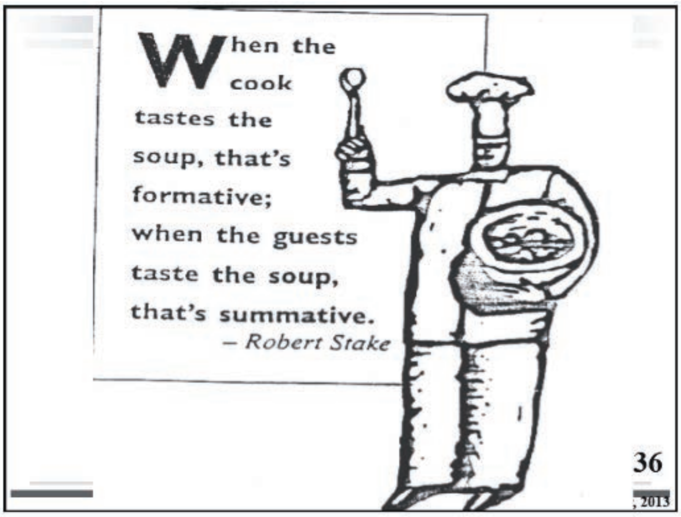


Figure 74: Explaining the difference between formative and summative Assessment

Section 2: Conducting Formative Assessment

Activity 45

Think individually about what you are currently doing on formative assessment in your teaching. Write down two specific examples of formative assessment activities that you have done recently and how they were conducted.

After a few minutes, exchange your ideas with your neighbour.

Techniques to integrate formative assessment in your teaching

1) **Explain learning objectives of the lesson activities to learners**

The teacher knows why the students are engaged in an activity, but the students are not always able to differentiate between the activity and the learning that it is meant to promote. Explicitly sharing the learning objectives will direct students' attention to the learning. The learning intention is expressed in terms of knowledge, understanding and skills, and links directly with the curriculum.

The design of learning intentions starts with the answers to these questions.

- What do I want students to know?
- What do I want students to understand?
- What do I want students to be able to do?

When students know the learning objectives of a lesson, they are helped to focus on the purpose of the activity, rather than simply completing the activity.

The teacher shares these learning objectives with her/his students, either verbally or in writing. Sometimes the learning objectives are written on the board and shared with students at the beginning of a lesson or unit. At other times, it is not mentioned until after the engagement activity.

The learning objectives form a central element in the teaching and learning process (Figure 74):

- Having decided on the learning objectives, teachers plan a series of teaching and learning activities to help students learn the knowledge and/or skills and achieve the understanding described.
- While questioning the students, they keep the learning intention in mind and this provides a focus for the lesson.
- They design an assessment task which will allow students to demonstrate that they have achieved the learning intention and provide students with the success criteria so that they will know what they need to do to show that they have achieved the learning intention.
- They make certain that feedback to students about their performance focuses on the learning intention and success criteria; likewise, when students assess their own performance, they too focus on the learning intention and success criteria.

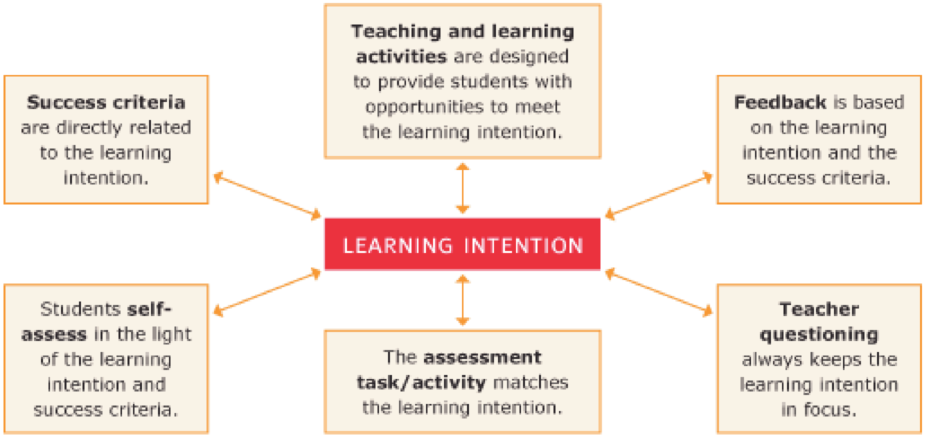


Figure 75: Central Role of learning intentions in teaching and learning (Clarke et al, 2003)

2) **Plan assessment opportunities during lessons, not just at the end**

As teachers, we assess all the time, through questioning, review student work and listening in on the work of learners during group work. These assessments, however, need to be supplemented by systematic and planned assessments. As well as informing teachers, planned assessment should also help learners become more aware of what they still need to learn and how they might go about learning these things.

Research in Rwanda found that there is little or no time to gather, analyse and use assessment information to improve learning and inform planning. This prevents teachers' ability to get to know their learners personally, differentiate appropriately and improve the effectiveness of teaching (REB, 2017). A common feature of bad lessons is the failure of teachers to make regular checks on students' learning and their determination to continue with the planned work even when students clearly do not understand it.

Take your time for the evaluation phase. Use the results at the start of the next lesson. Formative assessment should be present in every phase of 5 E's. Questioning the lesson goals provides information to the teacher. During the engage phase, the teacher collects information about students' prior knowledge and interest. Concept tests and concept cartoons help the teacher to monitor the evolution of students' ideas. Learners formulate explanations during the explain phases. During the elaborate phase, they apply their knowledge to new contexts or situations.

3) **Assess groups as well as individuals**

Given the large class sizes in Rwanda, formative assessment can be very time consuming, particularly when it is focused on providing detailed, formative feedback to individual learners. Group activities allow opportunities to observe, listen, and question groups of learners in ways that provide a lot of formative assessment evidence that may be used to refocus teaching. For example, group work sessions in which learners produce posters are very helpful group assessment opportunities.

4) **Encourage self-assessment and peer-assessment**

Studies on formative assessment point to the value of learners assessing themselves. Through this process learners become aware of what they need to know (what is important), what they know now, and what needs to be done to narrow the gap. One way of achieving this is to give copies of learning objectives to learners, ask them to produce evidence that they can achieve these objectives and, where they cannot, discuss what they need to do next. Over time, it is also possible to foster a collaborative culture in which learners take some responsibility for the learning of their peers. This involves making time for learners to read through each other's work and to comment on how it may be improved. Learners need to develop the skills to assess their own learning.

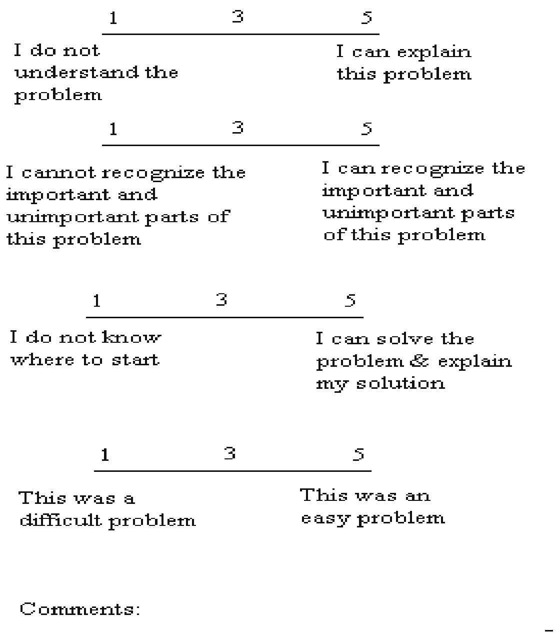


***Figure 76:** Template for self-assessment*

5) **Give feedback that is useful to learners**

Evidence suggests that the only type of feedback that promotes learning is a meaningful comment (not a numerical score) on the quality of the work and constructive advice on how it should be improved (Nicol, 2007). Indeed, grades usually detract learners from paying attention to qualitative advice.

The research evidence (Black & Wiliam, 2001; Nicol, 2007; Hattie & Timperley, 2007) clearly shows that constructive feedback:

- focuses on the task, not on grades;
- is specific rather than general;
- explains why something is right or wrong;
- is related to objectives;
- makes clear what has been achieved and what has not;
- suggests what the learner may do next to achieve the learning outcomes;
- describes strategies for improvement.

This doesn't necessarily mean writing long comments at the bottom of each piece of work. It is helpful to give comments orally and then perhaps ask learners to summarise what has been said in writing.

6) **About marking learners' work**

A mark on a test is often seen by learners as an end-point. You have passed or failed. It is far better for teachers to deliver feedback in the form of specific comments that point to improvement. A mark alone says nothing meaningful about how a learner can change and improve. Even high scorers see a high mark as 'having done enough' and take their foot off the pedal. A score, rather than understanding and improvement, becomes the goal. It promotes the idea that you need to pass the test, not master the subject. Therefore, marks should not play an important role in formative assessment.

Black & Wiliam (1998) argue that we need to focus more on 'formative', rather than 'summative' assessment. They recommend **high quality, small, frequent tests** that require good feedback. It is the feedback on what they don't know, not that which the student got right, that leads to learning (Black & William, 1998).

7) **"My Favourite No" Technique**

Students will answer a question provided by their teacher and then analyse a wrong answer given by a classmate (Lemov, 2015). The purpose of this activity is for the teacher to quickly assess how many students are understanding the concept and for those who are not, what exactly is causing their misunderstanding. It is essentially a formative assessment that works well as a warm-up activity. It is important to foresee enough time for the analysis of the wrong answer. "My Favourite No" is a teacher's strategy that helps students to realize that wrong answers are an important part of the learning process.

Key elements of this technique are:

- Select an error that is commonly made by students or that reflects important misconceptions for the topic.
- Start with what is good in the answer
- Move to what is incorrect in the answer and create a dialogue about the error.

Activity 46
Watch the video: https://www.teachingchannel.org/videos/class-warm-up-routine#

Questions for discussion:

- What criteria does the teacher use to pick her "favourite no"?
- How does the teacher use assessment data to inform her teaching?

8) **"Exit ticket" Technique**

An exit ticket is a brief evaluation that students write and turn in before the end of the class (Lemov, 2015). It should have only 2 or 3 short questions or problems and show what they have remembered from the day's class. This can provide valuable information on who learned what and who needs more help. It can help you respond to individual students' needs and decide on what to focus in the next lesson. It is a kind of formative assessment that informs the teacher, but also the learners about how well they have understood the key outcomes of the lesson.

Good exit tickets:

1. Contain just two or three questions.
2. Contain questions of different types (e.g., one multiple choice, one open-ended question)
3. Answers can be analysed quickly by the teacher.
4. Questions relate to the key objective(s) of the lesson.

Questions that encourage student self-reflection can also be used, possibly in combination with content-oriented questions, can include:

- What did you find the most important idea of the lesson?
- What did you find difficult and would like more exercises or explanation on?
- How does the lesson relate to what you have learned before?
- Write one question you still have

The information helps the teacher to assess whether the learners have achieved the objectives. It provides the teacher with feedback from each learner. It is important that the teacher uses the information from the tickets to review at the start of next lesson or to improve instruction.

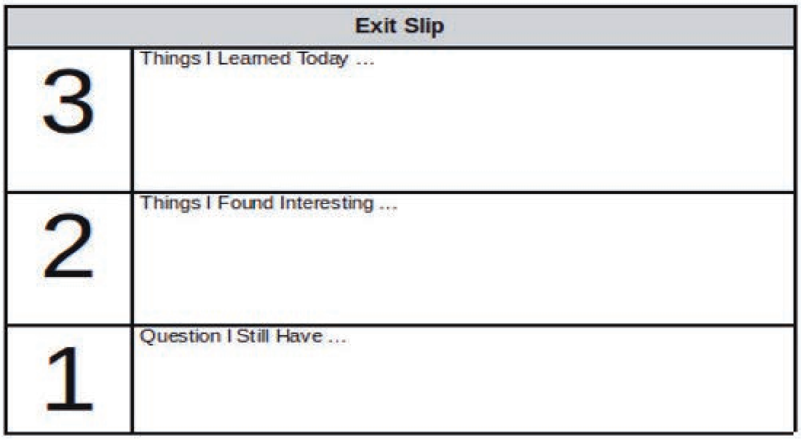


Figure 77: Template for exit tickets

Figure 77 shows a template for an exit ticket. However, you can use any format that you feel comfortable with. The main idea is that it is short and allows to get a quick look on students´ mastery of the key outcomes.

An exit ticket should give you quickly some data about student learning. Maybe you were working on subtracting with regrouping across zeros. Be sure one of the three problems does not have regrouping across zeros, as some students will be so stuck on the procedure they ignore the underlying concept: they will borrow when the subtrahend is bigger than the subtractor or carry a ten when the sum is not bigger than.

It is important that you follow up on the results of the exit ticket. If most students have a problem with the first question, return the tickets look at the kinds of problems students encountered, and model the way to correct the problem (Lemov, 2015). You select some common mistakes for discussion the next day. You may decide to put some students in a separate group for extra instruction or exercises.

More information on exit tickets: https://buildingmathematicians.wordpress.com/2016/07/04/exit-cards-what-do-yours-look-like/

9) "Traffic Light Cards" and "Voting Cards" Techniques

Traffic light cards and voting cards are cards that are used by learners to respond to questions from the teacher (Figure 77).
Traffic light cards are used by learners to communicate their understanding about a topic:

1. Raising a red card means: "I'm stuck, I need some extra help"
2. Raising an orange cards means: "I'm not quite sure, I need a little help"
3. Raising a green card means: "I fully understand, I don't need any help"

A teacher can use the technique at the end of different units within a lesson. A lot of red cards mean that many learners are still struggling. It shows the need for additional instruction or more exercises. A situation with few yellow or red cards shows the teacher that some learners do still have problems. They may be taken apart by the teacher for additional explanation.

If there are some learners with green cards, the teacher may ask them to explain the concept to those with red or yellow cards.

Learners may vote not according to what they think, but what others do. Therefore, it is good to follow up the voting with a few questions like: "Emile, you voted red, what is it that you find difficult?", or, "Emmanuel, you voted green, can you explain the key idea to the others?"

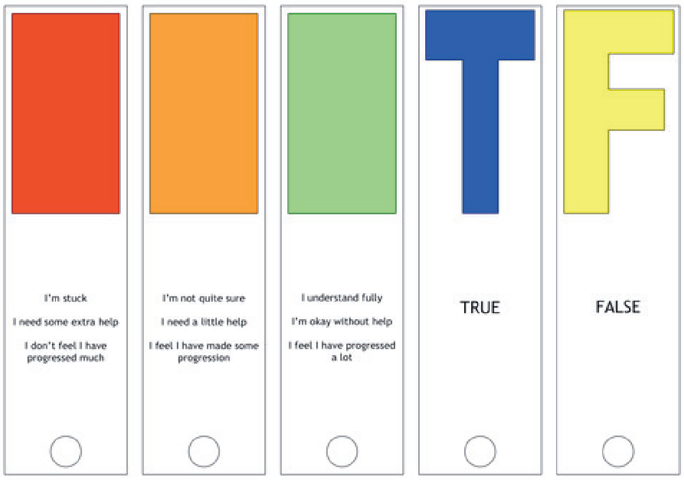


Figure 78: Traffic Light Cards and Voting Cards (TES, 2013)

Voting cards are used by learners to vote for a specific answer on a question by a teacher. This can be a true-false question (Figure 77) or a multiple-choice question (Figure 78).

Figure 79: Voting cards with letters

You can print these cards for your learners. If possible, laminating them is a good idea, because they will keep longer. You can combine colours and letters on the front and back side.

Activity 47

First, think individually about the following questions:

- Have you tried using any of these formative assessment techniques?
- If so, give one benefit and one challenge.
- If not, what stands in the way of your trying it?

Next, discuss your answers with your neighbour.

Section 3: Designing Evaluation Questions

For evaluation two types of questions are used (see also Section 1: Questioning)

- Knowledge questions are asked to reproduce the knowledge learnt in the lesson. They check if learners can remember or reconstruct this knowledge.
- Thinking questions are asked to apply the learnt knowledge in a new context. They check if learners understand the knowledge and can apply it to new contexts.

How do you balance between the two types of questions? You have to evaluate what you have trained learners for during the lesson, so it depends on what type of questions you used most during your lessons. If you have focused a lot on stimulating thinking, then you should have relatively more thinking questions, and vice versa.

Examples

A. Knowledge questions

- Chemical reactions
    - Describe what an endotherm reaction is.
    - Give a daily life example of it.
- List 4 parts of the face that protect the eye.
- Connect each concept with the correct explanation or function. There is only 1 correct answer for each concept.

	Is a consequence of the combination of the images on the retina of both eyes that are combined into 1 image
Accommodation of the lens	An image that lasts longer on the retina
Depth view	Protect the light receptors from glaring light
Pupil reflex	This is the changing of the lens between more and less bold, to make you see sharp close by and far away.
	This is the moving of the lens forward and backward, to make you see sharp close by and far away.

- List the elements of a force.
- State the Pythagoras theorem

B. Thinking questions

- Many types of house plants droop when they have not been watered and quickly “straighten up” after watering. What is the reason that they change shape after watering?
- If you drop an object in the absence of air resistance, it accelerates downward at 9.8 m/s^2. What is its downward acceleration after release if you throw it downward instead?

- A sugar cube is added to a hot cup of tea. What happens to the sugar particles?
    A. They cease to exist.
    B. They spread out through the hot tea.
    C. They melt in the hot tea.
    D. They formed a new and different type of substance with the tea.
- How does the concavity of a quadratic function change in terms of the sign of the coefficient of its quadratic term?
- On seventeen March 2021, the Covid-19 report showed that in Rwanda, the total number of cases (since the start of the pandemic) was 20,551, there were 1,260 active cases, and 284 deaths (since the start of the pandemic). What is the number of recovered people?

Activity 48

1. Design two knowledge questions and two thinking questions about the topic identified by the facilitator. Try to formulate the correct answer yourself. What wrong answers do you expect from learners?

2. Present your questions. Other participants use their voting cards to evaluate the questions.

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