Notes for teachers

on module 01:

Say it with Light

For more than two thousand years, humans have used light to send and receive information over long distances. Today, most of us are far more dependent on optical telecommunication than we imagine. The internet as we know it would not exist without optical fibres on the oceans seafloors, optical fibres connecting cities and even private houses. And there are good reasons for the use of light in communications - which are directly connected to the basic properties of light.

In this module, the application of light in communication is used as framework to introduce your students to the properties of light, the law of reflection and the method of engineering.

Summary: While students develop a communication system for an imaginary community in the Andes, they get to know the basic properties of light. Confronted with the question of how to send light signals around an obstacle, they discuss mirrors and reflection. After they have been introduced to the process of light guiding by total internal reflection, they apply their knowledge in a game, in which they build an optical fibre-based telecommunication system.

The module is structured in 2 chapters:

- Valley Talk and Properties of light (see page 2); and
- Optical Fibre Communication (see page 5).

Designed for: Lower secondary level (age ca. 12 to 15)

Duration: The first chapter is designed for two lessons, the second chapter for one lesson. Each lesson is estimated to take approximately 40 minutes.

What students should already know:

- No previous knowledge is required.

What students will learn:

Facts

- That light goes fast and straight;
- To differentiate between absorbing, scattering, reflecting and transparent materials;
- Reflection; and
- How optical fibres guide light.

Skills

- Teamwork; and
- Working as engineers: Developing technical solutions, which meet given specifications.

This module includes:

- 3 worksheets; and
- 1 fact sheet.

Chapter 1 | Valley talk

Suggested lesson outline

While students develop a communication system for an imaginary community in the Andes, they get to know the basic properties of light.

Timing in minutes	Activity	Material
First lesson		
0 – 25	Group work: developing a communication system Discussion on the advantages of optical communication developed by the student groups	WS01.1
25 – 40	Discussion on the properties of light and related experiments: - Light is 'seen' by the eye; and - Light goes fast and straight.	LED modules *Not included in the kit:* Larger mirror (> DIN A4)
Homework	Preparing to continue this discussion	
Second lesson		
0 – 20	Continued discussion on the properties of light: - Light is coloured, and - Light acts differently on different objects.	WS02.2, LED modules, mirrors *Not included in the kit:* Objects with different surfaces
20 – 35	Around an obstacle: reflection	LED modules, mirrors
35 – 40	'Many mirrors problem'	LED modules, mirrors

Description of suggested lesson

Developing a communication system

Please let your students know that their task in this lesson is to develop a communication system – but one without any electricity involved. Then tell them the following story as background for the group work:

In a remote valley of the Andes in South America, the people have decided to live without electricity. Some years ago the government wanted to flood the valley to build a hydroelectric power plant. When the people protested, the government argued that the people in the valley used electric power too. In response, all the inhabitants of the three villages in the valley together swore that they would never use any form of electricity again, whereupon the power plant was built somewhere else.

It has to be said though, that the people of the valley are not at all against technology. In their will to show the government that they can live without electricity at least as well – if not better – than the people in the capital, they created numerous technical masterpieces like water mills for all kinds of complex machinery, or extremely precise mechanical clocks, to name but a few.

The elders of the three villages then came together and decided that they wanted a fast communication system to connect the three villages – a first attempt with birds had utterly failed (they were attacked by condors). Long messages could be sent by letters, which took half a day, but important issues had to be communicated reliably, within a few minutes, at any time of the day. It was also determined that the system should not disturb anyone, e.g. by making noises or harming the environment. Since the elders could not agree on one system, they wrote a list of the criteria the system should fulfil and asked everyone in the valley to take part in a competition. The winning system would be implemented and the name of the inventor carved in the gable of the House of the Council of Elders, which is the highest honour in the valley.

Ask your students to form groups and to establish a solution for the valley people. Before they start working, give them a fixed time frame, e.g. 15 minutes for developing their solution and 2 minutes to present it to the class. Then hand each group a copy of the "Valley Talk" worksheet (WS01.1).

Please let your students know that there is not one single 'right' solution. However, the scenario simulates a typical situation they will later encounter at work: In a limited time, they have to come up with a solution that fulfils a given criteria and can compete with other solutions for the endorsement of the customer or boss.

After each group has presented its solution, let your students discuss the advantages and disadvantages of each system. Which would be the best to present to the village elders? Or would it be even better to combine two or more approaches into one solution?

Properties of light

Most probably, your students came up with one or more solutions that directly or indirectly use light to transmit the message, e.g. flags, light or smoke signals from a fire or reflected sunlight from mirrors. With questions like "with what do you receive the signal?" (usually the human eye) you can guide the students to the understanding that the signal is actually transmitted by light. Ask your students to explain why they would employ light in their proposed communication systems, then use their answers to bring together what your students already know about light.

In each class, this discussion could take another course and the important aspects of light might be named in another order. Please summarize the results of this discussion on the blackboard in the form of short statements (e.g. "Light travels in straight lines"). Ask your students to provide evidence to support each of these statements – ideally based on an experiment. Please note the examples of evidence down in keywords next to the respective statement.

Most likely, the discussion will not be completed within the remaining 15 minutes of the lesson. Ask your students to copy the statements together with the related evidence from on the blackboard. As homework, they could think of additional properties and experiments to prove them.

In the following, some important aspects of light are mentioned, along with guiding questions and suggested experiments.

Light is 'seen' by the human eye

Relevance to the villages' communication task: The detection of light signals is very simple and fast, even without electrical devices.

Ask your students whether humans see because the light comes from objects and enters the eye or because of light emitted by the eye to the objects. Can they give evidence to support their statement?

It is a common misconception among students that vision is based on rays emitted by the eye. Therefore, please keep in mind that they should always follow the light from the source (or illuminated object) to the eye when illustrating the light path (e.g. in the experiments below).

You could ask your students to look into each other's eye. Why is the eye's pupil black like a dark room? You could explain to your students that, just as no light comes from a dark room, so no light comes from the eye. Light that hits the back of the eyeball is transformed into tiny electrical signals, which means that it ceases to exist. The electric signals are sent to our brain, where they are processed, then giving us the impression that we can see a meaningful picture.

Light goes in straight lines

Relevance to the villages' communication task: The direct line between the villages should not be blocked by obstacles like mountains or forests.

Ask your students what path the light takes – does it follow an arc, like a ball thrown in the air, or does it go straight? Then ask your students how they could prove their answer, ideally with an experiment. If your students do not find a suitable experiment, you might suggest the following one (but only then):

One student holds the LED module and sends light signals, while another observes the light source from a few meters away. You can then ask a third student to cover the light source with one hand and slowly move the hand towards the observer, so that the light source remains occluded. The other students observe the trajectory of the hand and see that it follows a straight line between the light source and the eye of the observer.

Figure 1.1: Experiment to illustrate that light goes straight

For each experiment, ask your students to describe what they observe, making a clear distinction between observation and interpretation. What can be proven with this experiment and what might speak against a certain interpretation? For instance, would it be correct to conclude from the previous experiment that light has no mass (and therefore does not experience weight)?

Another way of demonstrating that light rays travel in straight lines is to cover a table lamp in a darkened room, such that light can only pass through a hole of about half a centimetre across. The light ray can be made visible with a bit of water spray (from a sprayer, e.g. one used for gardening or cleaning purposes). This experiment also illustrates that light is only visible if it hits our eye directly or is redirected from another object into our eyes. In the case of the water spray, the light from the lamp hits the water droplets, from where it is scattered and reflected in all directions, so that a part of the light also enters into the eyes of the observers.

Light travels fast

Relevance to the villages' communication task: Since nothing is faster than light, light can be used for the fastest communication systems.

One of the most important reasons your students use light in their suggested communication system is probably speed – which is precisely why the international telecommunication networks are based on light today.

To give your students an idea about the speed of light, place a mirror at one end of the room and ask two or three students to stand at the other, so that they can see themselves in the mirror. Then give them each an RGB-LED module from the kit and ask them to estimate the time which elapses between the moment a button is pressed on the module and the moment they see in the mirror that the light went on. This is a rather simple repetition of Galileo's experiment to measure the speed of light. But it gives you the opportunity to clarify the basic aspects of the propagation and perception of light. Ask your students for step-by-step explanations of what happens in this experiment by guiding them with questions to the following observations:

1) the student presses a button;
2) the light goes on;
3) the light travels in all directions (otherwise students observing from the side couldn't see that the light is on) unless it is blocked by an obstacle;
4) a part of the light reaches the mirror and bounces back, which, in technical terms, is called a 'reflection' (but this time it does not bounce back in all directions, otherwise the students observing the experiments from the side of the room would be able to see the light in the mirror);
5) some of the reflected light reaches the students' eyes, where the light causes a sensation which stimulates the brain and in turn makes the students 'see the light'.

The students participating in the experiment will (most probably) agree that the light travelled so fast to the mirror and back to their eyes that they could not measure the time it took.

To illustrate the speed of light, you could compare it to the speed of sound: Only special airplanes can fly faster than the speed of sound. Ask your students if they already noticed that in a thunderstorm one does not see the lightning and hear the thunder at the same time. They will most probably agree that they first see the lightning and then hear the thunder, which you can use to prove that light is much (about 874 000 times) faster than sound.

Another effective illustration is that if light were to travel along the earth's surface around the globe, it could go 7.48 times around the earth in just one second.

Light is coloured

Relevance to the villages' communication task: The colour, e.g. on a flag, can carry additional information and make their communications more effective.

How would light without a colour look? Some students might answer 'black'. You could then explain that an object appears black to us if no light comes from it to our eye.

Your students might come up with questions and ideas about colours that might not fit into the timeframe of the discussion. Please note them down for yourself and let your students know that you will discuss them later in a lesson dedicated to colours.

Light acts differently on different objects

Relevance to the villages' communication task: Optical communication can be hindered by obstacles or fog.

A drawback of optical communication is that any obstacle in the direct line between sender and receiver will hinder the light from reaching its destination. But how does light behave if it hits such an object? Point out different objects in the class room like the wall, a window, a shiny plastic surface, a black object or a white piece of paper, and ask what light does when it hits these surfaces.

Then hand out the worksheet "Light hits matter" (WS01.2). Point 1) in this worksheet is designed to let students themselves discover what happens to light when it encounters different surfaces. Please give your students sufficient time to work (and play) freely, encouraging them to note down their observations from the three viewing directions.

Probably, your students will need your help to classify different surfaces into categories (Point 2). Please give them time to develop their own categories and guide them with questions. One possible system of surface categories would be:

- Absorbing;
- Scattering;
- Reflecting; and
- Transparent/Translucent.

Around an obstacle

Point 3) of the worksheet "Light hits matter" (WS01.2) is designed to make the transition from discussions about the properties of light to reflection. If necessary, please help your students to conclude from their research (with the worksheet) that reflective surfaces can be used to direct light around obstacles.

Going back to the initial task of developing a communication system for the 'Valle de la Lumbre', you could ask your students how they could send light signals around a big rock which is hindering the direct view between two villages. Most probably they will suggest the use of a mirror to 'see around the rock'. Then ask them what they would reply to the Council of Elders in the valley, if they were asked where to place that mirror and how to orient it.

Mirrors

To study this question, place two objects, representing the villages, at two edges of your table and an obstacle, e.g. your bag, between them. The objects should be positioned so that *later on* two students can easily look at the table height from one 'village' to the other to check if the mirror is installed correctly.

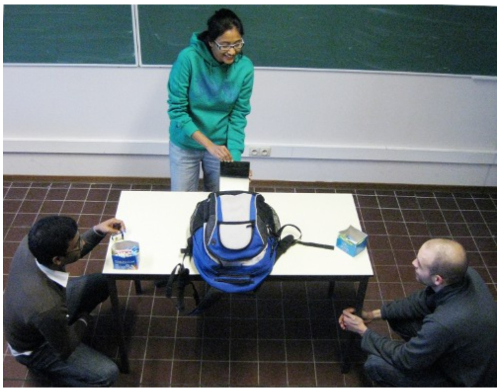

Figure 2.1 Setup on the teachers table for the mirror challenge

Let your students know that you expect them to give you clear instructions on how to place a mirror on the table, such that light signals can be sent between the two 'villages'. This instruction should make it possible to solve the problem from the overhead viewpoint, and be a generic rule that would also give a correct position and orientation for the mirror if the objects were placed differently on the table. Empirical solutions like "turn the mirror until one can see the other village" are not allowed. As a hint, you may ask your students what requirements the position the mirror has to fulfil (= the mirror has to be visible from both 'villages').

Then let the students establish groups and hand out the mirrors so they can experiment freely. Suggest the use of drawings to help solve the problem. They can also use the worksheet "Light hits matter" to find out more about the behaviour of reflection – and may thus discover the law of reflection by themselves. Walk around between the different groups, and try not to stay longer than a few minutes with the same group.

If a group thinks that it has found a solution, let them demonstrate it by sending two group members to the teacher's table. While you position the mirror in accordance with the students' instructions, try to orient the mirror so that it does *not* allow light signals to be sent from one 'village' to the other – in case their instructions are not yet correct or specific enough. Then let one student (try to) send signals with the LED module from the object that represents one village, while the other student observes, at table height, with one eye close to the object, which represents the second village (see picture above).

If the students succeed in formulating a suitable instruction, let them try to send light signals in both directions between the two villages. Ask the students if it is a general rule that light paths are reversible.

Although it is relatively easy to find the correct position of the mirror empirically, it might take your students some time to formulate a generally applicable instruction on how to place the mirror. One possible instruction (your students might as well come up with better solutions) would be to use table edges:

1) Find the part of a table edge that is visible from both 'villages'.

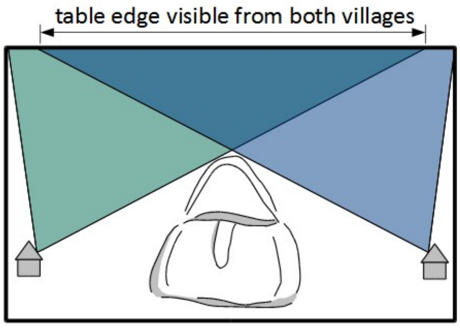

Figure 2.2 The triangles illustrate the 'view' from the villages.
The mirror should be placed where it is visible from both villages.

2) Duplicate the distance between one of the villages and this edge and mark this point (e.g. by holding a pencil there). Then estimate the direct line of this point to the second village. Hold the mirror against the table edge where this imaginary line crosses the table edge.

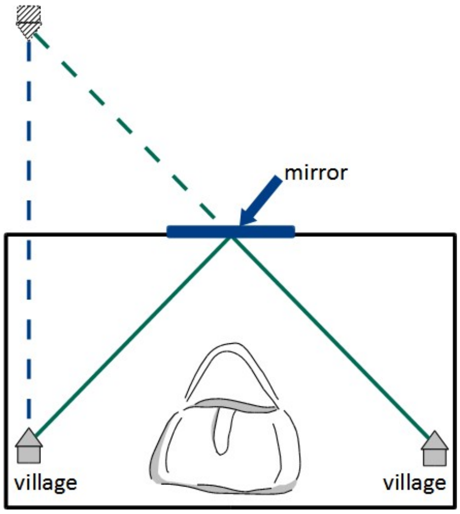

Figure 2.3 One possible solution for the mirror challenge

Law of reflection

If the time allows, you could introduce your students to the formal definition of the law of reflection. Some of your students might already have found (parts of) it themselves. They should then share their observations with their class mates. All groups could then test these observations of their classmates with the worksheet "Light hits matter": if the students turn the mirror around the centre of the half circle, they will observe that the angle of reflection equals the angle of incidence.

If you introduce the formal definition of the law of reflection, please remember to let your students note it on the factsheet (FS01.1), which would be handed out at the end of the next lesson.

'Many mirrors problem'

After your students have applied the law of reflection to one mirror, please ask them to reflect light signals using two and then three mirrors. One student group sends light signals to the neighbouring table. From there it is reflected by 90 degrees to the next table, and so on. After how many mirrors can your students still detect the signal?

Your students will soon see that, with an increasing number of mirrors, the task becomes more and more challenging. Let them know that in the next lesson you will show them a trick about how to send light around as many corners as you like.

Background information

Different forms of optical communication

The sense of vision and optical communication are closely linked. Optical communication is therefore not limited to humans, but is commonly used by animals with vision. Typical forms of non-verbal communication are the use of colours (e.g. for a beetle to indicate that it is toxic, or in the case of humans, e.g. black clothing to indicate mourning), gestures and facial expressions.

Humans have developed many different forms of optical techniques to communicate over long distances. Examples are beacon fires, smoke signals, flags, heliographs, and semaphore lines.

Heliographs use a mirror to reflect sunlight to an observer at a 50 km distance or more. By blocking the light or moving the mirror, it is possible to generate light flashes and send a message, e.g. using Morse code.

Semaphores are large, widely visible installations with flags or paddles. The positions of the flags or paddles encode the signal. Semaphore lines refer to a chain of several relay stations where the signal from another semaphore was read and reproduced so that the next station in the line would receive the signal.

Today, optical communication is usually based on light-guiding technologies like optical fibres, which can transport light signals over hundreds of kilometres.

Students might ask

Why use the LED module if it uses electricity?

Electricity was banned for the communication system to encourage students to determine optical solutions to the communication problem. However, in the class room experiments are much safer and it is more convenient to use the LED module as a light source than, e.g. candles.

What is the weight of light?

Light does not have a mass, but it can behave as if it weighed something. However, this is not a direct property of light, but rather a consequence of the physical effects that Einstein described with his theory of relativity. Large masses, such as the sun, can deform the space around them so that light (going straight through the deformed space) bends. During a solar eclipse, it is therefore possible to see stars which are actually behind the sun.

What about invisibility cloaks?

Before answering the question, you may ask your students what actually makes an object visible: Light from a source like the sun, lamps or light reflected as another surface hits the object and is reflected or scattered by the object. If a part of this light reaches our eye, or if light from behind the objects – which we would expect to reach our eye – is blocked by the object, we see its presence.

Invisibility cloaks are commonly used by heroes in fairy tales and science fiction. Scientists have made some progress in developing this effect in laboratories. Light hits their invisibility cloaks, is bent around the object and continues beyond it, (almost) as if no obstacle was in the way. However, the object would only be invisible for an observer whose eyes are limited to seeing one particular wavelength (colour) with a particular polarization (the observer is therefore kindly asked not to tilt his or her head).

An interesting question (which will also reveal your students understanding of vision) is "what one would see from inside the cloak?" Since all the light is bent around the cloak, it would be completely dark inside and nothing could be seen – an inconvenience that is expected to limit the commercial success of such cloaks in the consumer market.

Chapter 2 | Optical fibre communication

Suggested lesson outline

Students learn how total internal reflection is used to guide light in an optical fibre. Embedded in a game, they then develop their own light signal code and use it, together with an optical fibre, to send messages.

Timing in minutes	**Activity**	**Material**
0 – 10	Total internal reflections Light guiding in optical fibres	Laser Polymer optical fibre *Not included in the kit:* glass, water, milk
10 – 35	Game on optical fibre communications	Polymer optical fibre LED modules
35 – 40	Reflection on the lesson	FS01.1

Description of suggested lesson

Preparations

Please have a look at the text and pictures under the subtitle "Total internal reflection". To prepare these experiments, it might be good if you conducted some tests before the lesson to see how much milk to put in the water for the best visual effect.

Think of at least two common words consisting of 10 letters and note them down. You could seek inspiration from websites that help to find solutions for crossword puzzles.

Total internal reflection

Please remind your students of the difficulties they had in sending light around several corners. In this lesson, you will show them a trick that will enable them to send light signals over hundreds of kilometres.

Take a glass with long, straight sides or something similar and fill it with water. Mix a very small amount (ca. one drop) of milk into the water, and direct the laser beam into the glass, as shown in the picture:

Figure 3.1 Illustration of total internal reflection

Please explain that the water surface is another kind of mirror, which only works if the light hits the surface under a large angle of incidence (the smaller the angle of incidence, the more the light gets lost through the surface). In order to demonstrate that this reflection obeys the same law as the reflection on a metal mirror, please increase the angle of incidence and show that it is the same as the angle of reflection.

Ask your students what will happen if you direct the beam into the glass as shown in figure 3.2. Then demonstrate the effect:

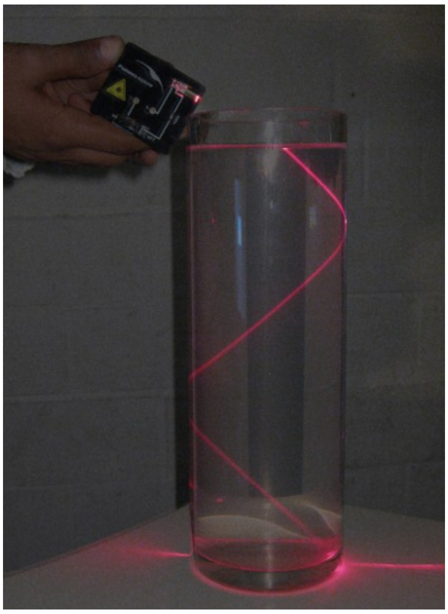

Figure 3.2 Multiple internal reflections

If possible, show your students the laser beam being reflected several times inside the glass. Ask them where the light would go if the glass was very long (e.g. two meters). Help them to conclude that the beam would not leave the glass until it hits the bottom. If the students observe that the light beam becomes weaker and weaker, commend them for their good observations and explain that you could reduce this problem by having no milk in the water. However, without milk it would be much harder to see the beam. In order to make the light beam visible, some of the light has to be scattered by the milk droplet, what makes the beam weaker. Some light is also lost in reflections, if the angle of incidence is not large enough.

You could ask your students how this effect could be used to send light signals and let them shortly discuss the technical problems that would go along with it. Show them the polymer optical fibre from the kit. Explain that the effect is exactly the same as in the water glass, only that the fibre is very long and thin and made out of plastic, which makes it flexible. Ask them what they expect to happen if light is sent into one end of the fibre and then let them try it: give two students sitting at opposite ends of the classroom an end of the fibre and give one of them an LED module.

In order to make it easier for your students to picture how this fibre guides the light, you could make a simple drawing like the following:

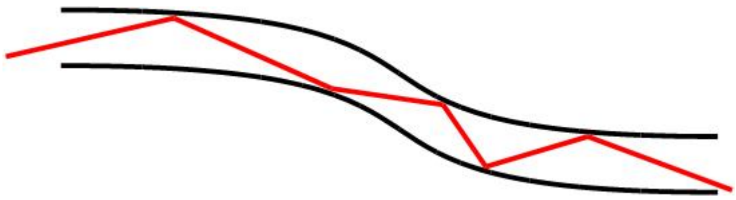

Figure 3.3 Light guiding in an optical fibre, based on total internal reflection

Optical fibre communication

Once your students are familiar with sending light through the optical fibre, you can introduce them to their final task in this module: to develop their own code for sending a message through the optical fibre.

It is recommended to let your class build two competing teams. The goal is to communicate a 10 letter word, as fast as possible, through the fibre. To this end, each of the two teams has to develop its own code.

1. When the two teams are formed, hand each of them a copy of the rules of the game (WS01.2) and two LED modules. Let them know that they have only 15 minutes to develop the code and to write two copies of it: one for the sender, and one for the receiver.
2. Prepare two sheets of paper, each with one 10 letter word, which will be the messages. Fold the paper so that the word cannot be seen.
3. After 15 minutes, collect the codes. The students in each team need to decide who will be part of the sender group and who will be part of the receiver group.
4. The team that plays first separates its sender and receiver groups as far as the 5m length of the fibre allows. The second team sits in the middle, between the sender and receiver, and ensures that the other team plays fair.
5. Return the codes to the sender and receiver groups, respectively.
6. Give the sender team one of the papers with the 10 letter word to be sent, but ask the students not to unfold it until you start the game.
7. Prepare a stopwatch and a hold a paperclip up. Wait for silence. Then let the paperclip fall, and only if you can clearly hear it hitting the ground, start the game and time it.
8. During this part of the game, there should be absolute silence.
9. Go to the receiver group and stop the clock when they hand you a paper with the correctly written word.
10. If the message is incorrectly received, let the students know and give them a reasonable amount of time to correct it.
11. Then let the second team play under the same conditions (points 4 to 10).

Reflection on the lesson and factsheet

After the game, let the students discuss whether or not their codes worked and if one approach was better than the other. What aspects of the code made a difference and what other factors influenced the final result? What would they do differently if they played the game again? Did they enjoy the lesson?

Explain to your students that they were just working like engineers: A customer – here the village elders – asks for a solution (could be a product or service) to a problem. The customer defines the conditions and specifications which a potential solution has to fulfil – e.g. a telecommunication system that operates without electricity. Within a fixed period of time, the engineering team has to find a solution that fulfils these conditions. Often, there are several competing solutions from different teams (companies). In order to convince the customer, the solution has to meet the customer's needs and expectations as closely as possible, with regards to cost, reliability, environmental sustainability, etc..

Very often, the development of new technical solutions requires engineers to 'play' (freely experiment) with physical effects, and to then determine and understand the laws of nature that govern these effects. If applicable, you could remind your students how they discovered the law of reflection. Finally, a good engineering solution usually combines many different fields, as in the case of the optical fibre communication a) the physics of total internal reflection, b) the chemistry to make flexible optical fibres, and c) the information technology to encode, send and later decode a message in a way that makes optimal use of the physical equipment.

Before you finish the lesson, hand out the factsheet and explain to your students how the technology they just developed, namely telecommunication based on optical fibres, has changed their world (see factsheet FS01.1).

Students might ask

How are optical fibres made?

Optical fibres are very often made out of extremely clean glass. Today, fibres are also made from other materials, like polymers or special glass mixtures. However, the basic technology to make these extremely thin and therefore flexible threads of glass (or polymer) has remained the same since the 18th century, when such glass fibres where used for decoration: The material is heated up until it becomes just liquid enough for a drop to build and fall. This drop is connected to the rest of the material with a thin thread. By drawing on that thread, one can determine the width of the thread which then becomes the fibre. This process is carried out today by machines that continually measure the width of the fibre and control the speed of a drum at the bottom, on which the fibre is coiled up, accordingly. To protect the fibre, a plastic coating is usually put on the fibre.

A simple experiment to illustrate this technique is to take a spoonful of honey and let a small drop fall from it. By rotating the spoon or by lifting it up, you can control the thickness of the honey 'fibre' that connects the drop and the honey on the spoon.