INQUIRY AND ASSESSMENT UNIT

LIGHT

Reflection and refraction. What do I see in a mirror?

Eilish McLoughlin

LIGHT

REFLECTION AND REFRACTION. WHAT DO I SEE IN A MIRROR?

Overview

KEY CONTENT/CONCEPTS

- Sources of light
- Representation of how light travels
- Shadows, and what determines the size of the shadow on a screen
- Composition of white light, primary colours and the effect of filters
- Reflection and image formation in plane mirrors
- Refraction and image formation in lenses

LEVEL

- Lower second level
- Upper second level

INQUIRY SKILLS ASSESSED

- Planning investigations
- Developing hypotheses
- Forming coherent arguments
- Working collaboratively

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

- Scientific reasoning (making reasoned decisions)
- Scientific literacy (explaining concepts scientifically)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Self-assessment
- Worksheets

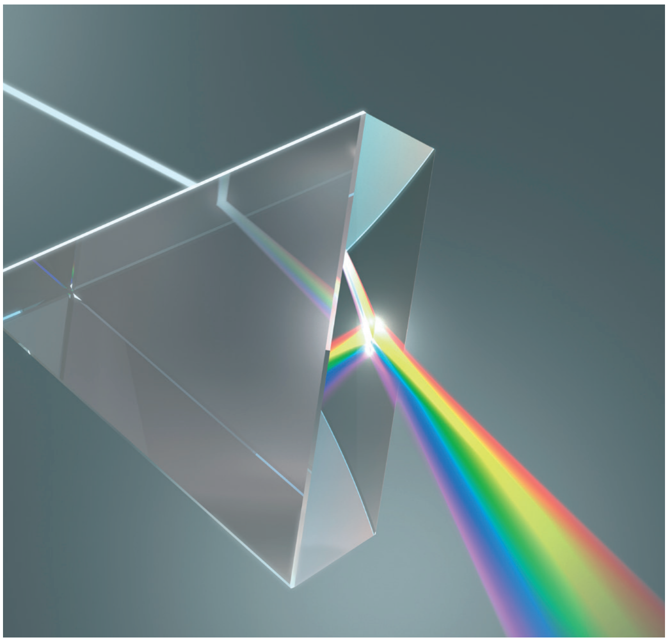
Classroom materials for this Inquiry and Assessment Unit are available at WWW.SAILS-PROJECT.EU

INQUIRY AND ASSESSMENT UNIT OUTLINE – LIGHT

In the Light **SAILS** inquiry and assessment unit, students examine the physical properties of light and its interaction with materials in a predominately qualitative fashion. A series of eight activities are described that aim to develop students' understanding of the concept of light and its characteristics. Students are facilitated to identify that sources of light have specific physical characteristics and these can determine the properties of light, such as its colour and intensity. Students can investigate the interaction of light with matter and explore phenomena such as reflection and refraction. The unit activities are presented as a guided inquiry-based approach and an individual student worksheet is provided for each activity.

This unit presents several opportunities for the assessment of different inquiry skills, and in particular, *planning investigations, developing hypotheses, forming coherent arguments* and *working collaboratively*. In addition, students can develop their *scientific reasoning* and *scientific literacy* skills. The assessment methods used across the activities of the unit include teacher observation, classroom dialogue, student worksheets and self-assessment.

This unit was trialled by teachers in three countries – Ireland, Greece and Germany – as described in the four case studies (students aged 12-18; mixed ability and gender). The teaching approach adopted was *guided inquiry* in all cases. The assessment of *forming coherent arguments* is described in all of the case studies, and in addition *planning investigations, developing hypotheses* and *working collaboratively* were assessed in some classes. Two of the teachers assessed *scientific literacy* (explaining concepts scientifically) and one teacher assessed the student's *scientific reasoning* (making reasoned decisions)



2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The teaching and learning activities described in the **Light** SAILS inquiry and assessment unit were developed by the FP7 ESTABLISH project[1] and adapted for use in the SAILS project by the team in Dublin City University. The unit presents eight activities (activities A-H), in which students are firstly introduced to the fundamental concepts of light, such as classification of objects by optical characteristics, physical properties of light (e.g. colour, intensity), shadows and light that cannot be seen by the naked eye. This knowledge is used for students to develop a conceptual understanding of light waves and the representation of how light travels using ray diagrams. Students examine the properties of white light, its constituent colours and primary colours. Students consider the effect of filters on the light intensity and colours. Finally, students investigate the interaction of light with mirrors and lenses (reflection and refraction) and how light images are formed.

Activity A: What are sources of light?

Concept focus	Sources of light
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific literacy (reviewing prior knowledge, understanding the properties of light)
Assessment methods	Classroom dialogue Worksheets

Rationale

Students are introduced to sources of light and are required to differentiate between objects that are sources of light and those that are not. The learning aims identified are (1) increasing students' interest in the topic of light, (2) differentiating between objects that are sources of light and those that are not, (3) understanding that sources of light have different properties, and (4) understanding that light may not necessarily be visible to the human eye. Students are challenged to recognise that it is easy to identify that "light sources emit light" but that it is difficult to find a unifying principle that distinguishes light sources from other objects. This approach provides the teacher with information on student's prior knowledge and highlights any preconceptions students may have: for example, that light sources need to be electrical in nature or that all objects are sources of visible light because we can see them.

Suggested lesson sequence

Materials: *candle, torch, infrared TV remote control, overhead projector/acetate or whiteboard/marker, mobile phone (with camera)*

1. The students are asked to consider what objects they can see in the classroom, and to make a (brief) list of their choices in their worksheet (Figure 1). A whole class discussion can then be held on whether these objects are "sources of light."
2. The students should attempt to describe the differences between two different sources of light, a candle and a torch, on the basis of physical characteristics (i.e. is the intensity of light constant, what colour does the source produce, is the source hot, does the source require a battery, etc.).
3. The list of criteria identified for these first two sources can then be expanded to a number of other light sources. the students can then discuss (small or whole class) whether objects that are sources of light have similar properties to those that are not.
4. Finally, an IR remote control can be introduced. The students are asked to determine whether this is a source of light or not. Students can use the camera from a mobile phone to record an image of the remote control's LED while the teacher presses a button. The sensors used in the camera of mobile phones are typically sensitive to the IR light produced and although this light is invisible to the naked eye, it can be captured by the camera.

Possible teacher questions

- Which of the light sources are also hot? Are all light sources hot?
- Which of the light sources are solids, liquids, or gases?
- Which of the light sources involve chemical reactions?
- If we can see walls, tables, and chairs, are they also sources of light? If not, why can we see them?
- Is there a single physical characteristic that explains why some objects are sources of light and some are not? Does energy play a role in some way?

Activity B: How does light travel?

Concept focus	Light is a wave
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific literacy (understand that light is a wave, that light reflects from walls, and that how light can be modelled using rays)
Assessment methods	Classroom dialogue Worksheets

[1] Establish Light unit, http://www.establish-fp7.eu/resources/units/light [accessed October 2015]

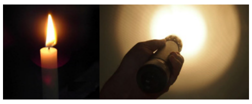
Worksheet 1 What are sources of light?

Light is all around us. It allows us to see, but where does light come from?

1. Have a look around your classroom and list five objects that you can see:

2. Are any of these five objects a source of light?

3. Are a candle and torch sources of light? Explain.



4. What are the differences between the candle and torch in terms of their physical properties?

5. In science we attempt to characterise objects in our universe and group them together according to common properties. In the table below, write down four properties you think light sources have and then list five light sources.

Source of light	Property 1 ________	Property 2 ________	Property 3 ________	Property 4 ________
1.				
2.				
3.				
4.				
5.				

6. Does each source of light have the same properties?

7. Do the properties you have listed only apply to sources of light or do they apply to objects that are not sources of light as well?

8. Why can you see objects that are not sources of light?

Figure 1: Worksheet for Activity A: What are sources of light?

Rationale

The aim of this activity is to develop the students' conceptual understanding that light is a wave, that light exists in the space around them; that light reflects from surfaces, and that how light travels can be modelled using rays. These concepts are addressed through the questions posed in the students' worksheets (Figure 2).

Suggested lesson sequence

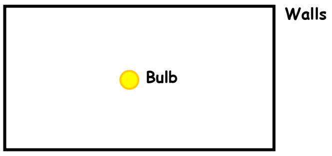
Materials: *cardboard box with a hole cut in one side, incandescent light bulb (~40 W), overhead projector/acetate or whiteboard/marker*

1. An incandescent bulb is placed in the centre of a darkened classroom and switched on. The students gather close to the bulb and asked to raise their hands if they can see light from the bulb.
2. The students are then asked to take up positions around the walls of the classroom, with a large space between each of them. The teacher should then ask the students whether they would be able to see light from the bulb if they stood in the gaps that were left (deliberately) between each of them.
3. Finally, the students should face the wall of the classroom and asked to raise their hands if they can still see light from the bulb, when they are not facing it. The bulb should be turned off for a moment, and then turned back on, and the students asked if they wish to reconsider whether they can see light from the bulb when they are not facing it.
4. Using the acetate and overhead projector, the bulb is represented by a dot in the centre of the acetate and the relative positions of the students and their direction of view marked on the acetate with arrows for the three cases above (steps 1-3). This forms (approximately) concentric rings of different diameters.
5. The students should then discuss how they think the light reached them in each case. The teacher should facilitate this discussion towards conclusions that involve light "spreading out" from the bulb. This can be directly compared to sound waves.
6. Students should then discuss how they think light reached their eyes when facing the wall and consider the direction that the light travelled from the bulb to each observer. The teacher can guide the discussion towards conclusions involving straight-line paths or "rays" from the bulb.
7. As an additional component, the students could be asked to consider where they would need to stand in order to see the light from the bulb after a box (with a small hole in the side) is placed over it. They can then test their ideas by performing a similar "hands-up" experiment to that at the beginning of this activity, and students can then map the positions from which they can see the light from the bulb. This can be used to show the validity of the "ray" model in predicting how light travels and where the students need to stand in order to see the light that exits the box.

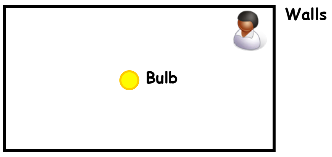
Worksheet 2 How does light travel?

A light bulb is set in the middle of a classroom and turned on.

1. In the diagram below, the rectangle represents the walls of the room and the circle represents the position of the bulb. Where in the room would it be possible to detect light from the bulb? Mark this/these position(s) in the diagram.



2. Consider a person standing in the corner of the classroom.



Does light from the bulb travel as far as this person? How do you know?

....

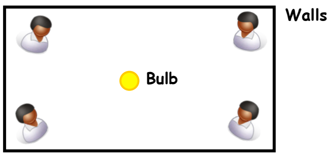
On the diagram, draw in the path that light takes from the bulb to the person.

How does this path change if the person closes their eyes?

....

....

3. Now consider that four people are facing the bulb.



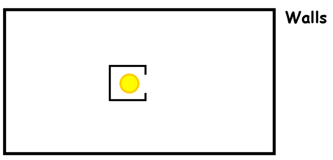
Draw in the path that light takes from the bulb to each person.

4. Suppose the four people above faced the wall instead. Would they still see light from the bulb? Explain.

....

....

5. A box with a small hole in the side is placed over the bulb.



Draw in the diagram where you would need to stand in order to see light from the bulb. Is there only one position? Explain.

....

....

Figure 2: Worksheet for Activity B: How does light travel?

Possible teacher questions

- If you changed the size of the hole in the box, would this change where in the room you could see the bulb?
- What happens to the light that doesn't come out (exit) the hole in the box?

Activity C: Understanding shadows

Concept focus	Shadows are the absence of light
Inquiry skill focus	Planning investigations Forming coherent arguments
Scientific reasoning and literacy	Scientific literacy (understanding shadows and what determines the size of a shadow on a screen)
Assessment methods	Classroom dialogue Worksheets

Rationale

Students are encouraged to consider the formation of shadows. They investigate parameters that affect the formation of shadows, and develop an understanding of shadows and the factors that affect their size/formation on a screen. Students are challenged to interpret their observations and discuss these in relation to their knowledge of the properties of light.

Suggested lesson sequence

Materials: *small torches or small incandescent bulbs, small cardboard squares that are a few cm on each side (to cast the shadow), retort stands to hold the torch, white sheet to use as a screen*

1. The students begin by drawing in their worksheets how the given apparatus should be set up so that they would be able to observe a shadow on a screen (Figure 3).
2. Students then qualitatively investigate the formation of shadows in order to determine what variables affect the size, location and other properties of the shadow. The teacher supports student learning by challenging them to provide answers to the following questions:
   a. If the projection screen and torch are fixed in place, how does the size of the shadow change as the cardboard square is moved towards or away from the torch?
   b. If the torch and cardboard square are fixed in place, how does the size of the shadow change as the projection screen is moved towards or away from the cardboard square?
   c. If the screen and cardboard square are fixed in place, how would the size of the shadow change as the torch is moved towards or away from the cardboard square?
3. The challenge for the students is for them to try and explain their observations based on what they know about the properties of light and its propagation.

Worksheet 3 Understanding shadows

1. In the space below, draw a diagram of how you would set up a bulb, cardboard square, and paper screen in order to show a shadow.

2. Now set up the apparatus as you've drawn in the diagram. When you turn on the bulb, do you see a shadow of the cardboard piece on the paper? Why do you think the shadow is formed?

3. Adjust the set up to make the shadow larger on the screen. Explain what modification you needed to make.

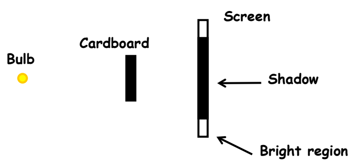
4. Is there another way of the making the shadow larger? (Hint: What did you move in order to answer Question 3? Is this the only part of your set up you can change?)

5. In this investigation there are 3 'variables' that can be changed to alter the size of the shadow. What are these 3 variables?

6. Choose one variable you have not already examined. Predict how you should adjust that variable in order to make the shadow smaller. What alteration to your set up will you make?

   Now adjust the variable in your experimental set up. Does the experimental result match your prediction? Explain.

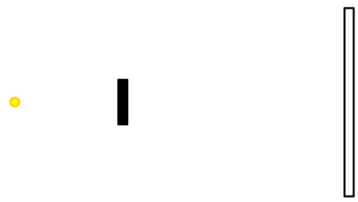
7. The diagram below shows the relative positions of the bulb, cardboard piece, and paper screen.



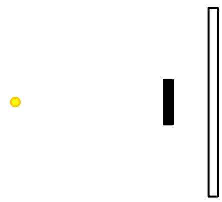
(i) Draw in the path that light travels from the bulb to the cardboard piece. Does this light reach the screen? Explain.

(ii) Draw in the path that light travels from the bulb to the screen. Does light reach all parts of the screen? Explain.

8. Draw the shadow you'd expect to see in each of the following cases:



(i)



(ii)

(iii)

Figure 3: Worksheet for Activity C: Understanding shadows

Possible teacher questions

- If I place a green bottle in front of a bulb, I see a green "silhouette" cast on the wall. This grows in size and decreases in size depending on the bottle's location between the wall and bulb. Is this also a shadow?

Activity D: Exploring white light and filters

Concept focus	White light as a mixture of colours Use of filters
Inquiry skill focus	Developing hypotheses Forming coherent arguments
Scientific reasoning and literacy	Scientific literacy (understanding how concepts relate to real world context)
Assessment methods	Classroom dialogue Worksheets

Rationale

This activity explores the concept that white light is composed of many different colours. To demonstrate this phenomenon, students investigate the effects of filters. They observe that a filter only allows certain colours to pass through, thus they can use this knowledge to recognise that white light is made up of many colours. Students are encouraged to consider the everyday experience of rainbow formation and relate this phenomenon to their laboratory investigations and thus develop skills in *scientific literacy*.

Suggested lesson sequence

Materials: *torches with a narrow cardboard slit attached, glass prisms, good quality (theatre quality) red, green, or blue transmission filters, coloured cardboard "screens"*

1. Each student is given a worksheet and should then project light from the narrow cardboard slit on their torch through a prism and onto a white sheet of paper (Figure 4). They will see the familiar colours of the rainbow – red, orange, yellow, green, blue, indigo and violet. The students are then presented with two alternative explanations for this phenomenon: either (1) the prism converts white light into coloured light or (2) white light is a mixture of colours that are subsequently separated by the prism through different angles.
2. Although students may already know the correct interpretation, they cannot distinguish between these alternatives solely on the basis of their observations. They should then be asked to suggest an experiment that could distinguish this, e.g. the use of two prisms to show that the spectrum of colours can be recombined to reform white light. This can be done as a demonstration although it does not resolve the challenge presented – even with two prisms it is still not clear whether the spectrum of colours is present in the white light before the interaction with the prisms.
3. The students should then investigate the use of coloured filters. By placing a red, green, or blue transmission filter between the prism and screen they will observe that only the corresponding colour is transmitted. If they now place this filter between the torch and prism, they will observe that red light is transmitted through the filter, passes through the prism, and arrives at the screen. The students can repeat this process with different filters, hence proving that white light is a mixture of different colours and these are spatially dispersed by the prism.
4. The key to this experiment is the quality of the filters. If this poses a problem in terms of quantity, then the activity could be run as an interactive demonstration with students invited to place filters in the appropriate positions and record the results.
5. A suitable online resource for this activity is freezeray.com[2], which gives an interactive applet to investigate the effect of different coloured filters.

Possible teacher questions

- If the sun produces white light, then what happens to the light to make leaves appear green in summer?
- In autumn, why do leaves appear red and orange?
- How are rainbows formed?

Activity E: Exploring primary colours

Concept focus	White light as a mixture of colours – primary colours
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific literacy (understanding properties of light; understanding real world applications of concepts)
Assessment methods	Classroom dialogue Worksheets

Rationale

This activity builds on the concept of white light as a mixture of colours. Students will be familiar with the seven colours observed when light is passed through a prism, or when a rainbow is formed. This activity seeks to explore primary colours, leading to an understanding that mixing red, green and blue light can produce white light. The concept of primary colours can be demonstrated effectively through examining pixels of a screen (phone or computer) using a magnifying glass or microscope.

Suggested lesson sequence

Materials: *overhead projector, sheet of card ~300 x 300 mm with three identical holes approximately 15 x 30 mm in dimension, red, green and blue filters, 3 small plane mirrors, neutral density filters with low optical density, magnifying glass/microscope*

1. Tape the red, green and blue filters over each of the holes in the sheet of card and position this on the overhead projector to produce three distinct beams of coloured light. Invite

[2] Freezeray.com Physics resources, www.freezeray.com/physics.htm [accessed October 2015]

Worksheet 4 Exploring white light and filters

In this experiment you will investigate what happens to white light when it passes through a prism.

Take the torch and ensure that the narrow cardboard slit is securely fastened. Shine the torch through one side of the prism and try to align the prism and torch so that light leaving the prism will arrive on a white sheet of paper and form a 'spectrum' of colours.

1. Describe what you observe and draw a diagram of the relative positions of the torch, prism, and screen. Show in the diagram the relative position of red light and violet light on the screen.

2. There are two possible explanations for the colours you have observed on the screen. These are:

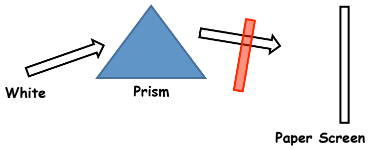
   (a) The prism changes white light into different colours

   (b) White light is a mixture of different colours to begin with and the prism separates them

   Which of these explanations is correct? How do you know based on your observations?

   Can you suggest an experiment that might be able to resolve which of the two possibilities is correct?

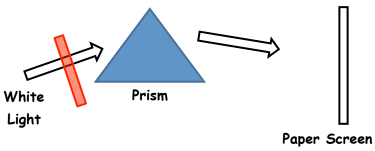
3. Take a coloured filter and place it in the path of the light leaving the prism.



   What colour is the light arriving on the screen?...

   Explain how you think the filter affects the light.

4. Take a coloured filter and place it in the path of the light entering the prism.



   What colour is the light arriving on the screen?...

   What colour is the light after passing through the filter? ....

5. Which of the two possibilities in Question 2 is supported by your observations? Explain.

Worksheet 5 Exploring primary colours

1. What is observed when you mix the different colours of light?

2. What is observed when you mix different colours that aren't the same intensity?

Figure 4: Worksheets for Activity D: Exploring white light and filters and for Activity E: Exploring primary colours

students to intercept each primary colour with a mirror, deflect it onto the ceiling or whiteboard and hence observe and note in their worksheets the colour that results when any two beams are mixed and when all three are mixed (Figure 4).

2. Next, the students should be asked to consider what would happen if the red, green, or blue beam was not as intense as the others – for example, if red was weaker than green, what colour would be produced by mixing them? The students can then test their ideas by placing the neutral density filters on top of each of the coloured filters and mixing the light.
3. Finally, the students should discuss whether any devices they know of produce different colours by mixing just red, green, and blue light of different intensities. They can verify that a TV, laptop or mobile phone screen does exactly this by examining the pixels with a magnifying glass.

Additional investigation:

4. Using a single red, green, or blue filter and an overhead projector, project a small coloured spot onto a screen and have the students stare at it for at least 1 minute. Once the filter is removed (and the projector left on), the students will see a small spot that persists for a moment in their vision that is a different colour to the spot that was projected – most people see red where it was green and vice versa. The reason for this is that the human retina contains cone cells that are sensitive to red, green and blue primary colours. Staring at a red spot breaks down the pigment in the red-sensitive cone cells and when the filter is removed these "bleached" cells will be less sensitive than the green- and blue-sensitive cones, subsequently leading to the persistence of a spot of different colour. This can be used as a demonstration that the eye is sensitive to primary colours and that our perception of colour is due to red, green, and blue mixing.

Possible teacher questions

- Is it possible to create white light without using the seven colours of the rainbow?
- If you can create all visible colours by mixing red, green, and blue, then can you detect all colours by just measuring how much red, green, and blue arrives at a sensor? Is this how the eye sees colour?

Activity F: Exploring plane mirrors

Concept focus	Light rays travel in straight lines Plane mirrors reflect light Angle of incidence equals the angle of reflection
Inquiry skill focus	Developing hypotheses Forming coherent arguments
Scientific reasoning and literacy	Scientific literacy (understanding the real world context of this topic)
Assessment methods	Classroom dialogue Worksheets

Rationale

In this activity, students are asked to consider the reflection of light. They explore the use of plane mirrors, allowing them to consolidate their understanding that plane mirrors reflect light. Building upon this concept, they identify the relationship that "the angle of incidence equals the angle of reflection."

Suggested lesson sequence

Materials: *white sheets of paper, plane mirrors, retort stands, straight drinking straws, pencils, protractors, rulers*

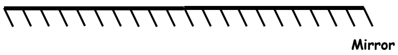
1. The activity begins with students being posed a question, such as, "If you look through a straw at an object, what direction must the light travel from the object to your eye in order for you to see it?"
2. The students are then asked to consider the same question but for two straws forming a V-shape. What might one use to get light to alter its direction so that light passing into the first straw could be seen through the second straw? The teacher should guide the discussion towards the notion of reflection from a mirror.
3. The students can then use their worksheet as a guide (Figure 5) and clamp a mirror at one edge so it is held vertically by a retort stand. The bottom edge of the mirror should be in contact with the mark on the paper. They can then position a drinking straw at some random angle in front of the mirror and attempt to position a second straw so that when they look through it, they will see the reflected light that passed through the first straw.
4. The students should then be asked how they would need to alter the setup if they changed the angle of one of the straws, or the angle of the mirror.

Possible teacher questions

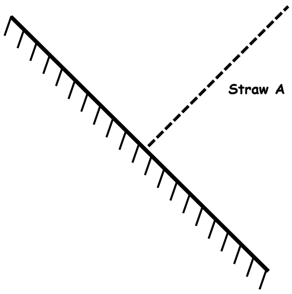
- Do you notice anything about the angles at which the straws have to be in order for light to pass from one to the other?
- Does this relationship hold when the mirror is angled?
- What would happen to light at different points on the mirror if the surface of the mirror was curved inwards or outwards?

Worksheet 6 **Exploring plane mirrors**

1. Position a mirror on the indicated line (held vertically) and two drinking straws in such a way that light passing through one straw (straw A) is reflected from the mirror and can be seen through the second straw (straw B). Mark in the positions of each straw on the diagram and the direction light travels through the straws to your eye. You should do this for three different orientations of straw A.



2. Suppose the mirror is rotated by 45 degrees as below. If straw A is positioned on the dotted line, where should straw B be placed?



3. A submarine captain uses a periscope to see what is on the surface of the water. The arrows indicate the direction light must travel through the periscope to reach his eyes. How would you position mirrors to achieve this?

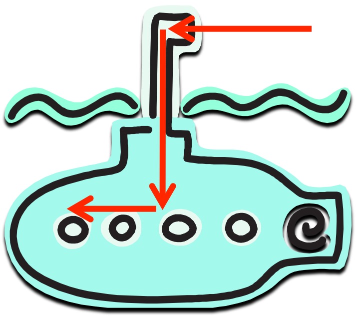


Figure 5: Worksheet for Activity F: Exploring plane mirrors

Activity G: Exploring refraction

Concept focus	Understanding refraction Understanding that light can be reflected from and transmitted through an interface
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific literacy (understanding properties of light – refraction)
Assessment methods	Classroom dialogue Worksheets

Rationale

In this activity students are introduced to a further property of light, that of refraction. Through experimentation they can explore refraction, and observe what occurs when light travels from one medium to another.

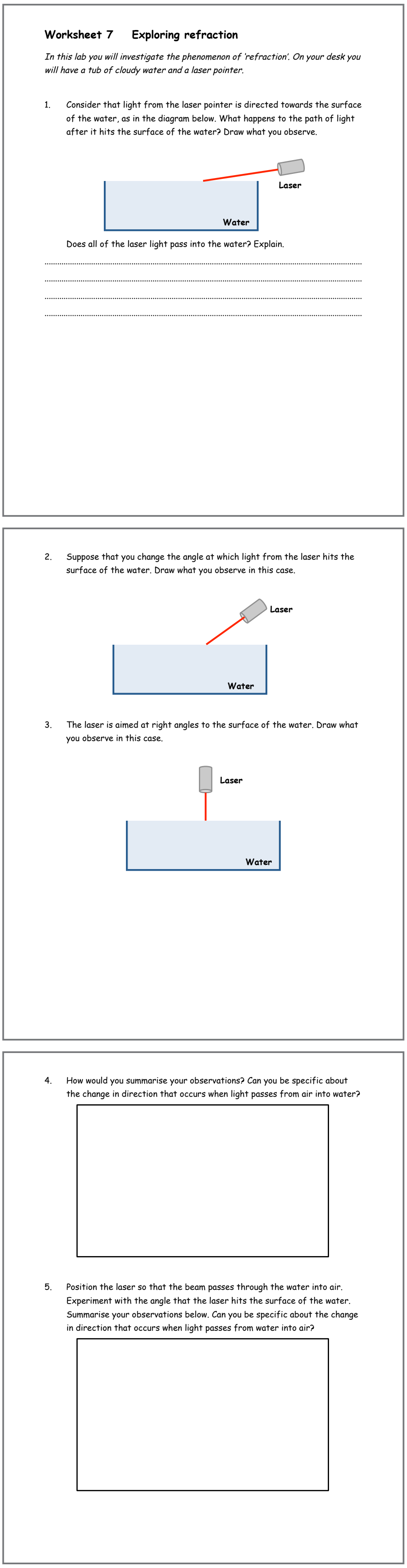
Suggested lesson sequence

Materials: *laser pointers (red, low wattage), large plastic lunch boxes with transparent/semi-transparent walls, salt or milk, water, plastic sheets (e.g. bin bags), plastic spoons, green or blue laser pointer*

1. The plastic sheets are placed on the desks in case of spillage. Students fill a plastic lunch box with water and add salt or milk until the water appears cloudy. Plastic spoons can be used in the case of salt to agitate the water during the investigations. The lunch box should be positioned close to the edge of the desk to allow for a wide range of possible angles.
2. The students begin by shining the laser pointers from air into the water and investigating how the path of light alters as they change the angle. They should draw a diagram in their worksheets to illustrate what they observe (Figure 6).
3. Next they investigate how the path of light changes if they shine the laser pointer through the side of the lunch box, through the water, and into the air. Again, they should draw a diagram to illustrate what they observe.
4. The teacher should then use the green or blue pointer side-by-side with a red pointer to illustrate that light of different colours will refract by different amounts.

Possible teacher questions

- How does the direction of light change when it travels from air into water?
- How does the direction of light change when it travels from water into air?
- Is it possible to pick an angle so that light travelling from water into air is reflected from the interface between the media?
- Why is not possible to see the beam of laser light passing through the air when it can be seen passing through the water?
- Why does a prism disperse white light into its constituent colours?



Worksheet 7 Exploring refraction

In this lab you will investigate the phenomenon of 'refraction'. On your desk you will have a tub of cloudy water and a laser pointer.

1. Consider that light from the laser pointer is directed towards the surface of the water, as in the diagram below. What happens to the path of light after it hits the surface of the water? Draw what you observe.

Laser
Water

Does all of the laser light pass into the water? Explain.

2. Suppose that you change the angle at which light from the laser hits the surface of the water. Draw what you observe in this case.

Laser
Water

3. The laser is aimed at right angles to the surface of the water. Draw what you observe in this case.

Laser
Water

4. How would you summarise your observations? Can you be specific about the change in direction that occurs when light passes from air into water?

5. Position the laser so that the beam passes through the water into air. Experiment with the angle that the laser hits the surface of the water. Summarise your observations below. Can you be specific about the change in direction that occurs when light passes from water into air?

Figure 6: Worksheet for Activity G: Exploring refraction

Activity H: Exploring lenses

Concept focus	Lenses produce images Lenses do not necessarily magnify objects
Inquiry skill focus	Developing hypotheses Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (image formation) Scientific literacy (understanding properties of light – image formation)
Assessment methods	Classroom dialogue Worksheets

Rationale

Students carry out experiments using lenses to investigate how they produce images on a screen. Students are asked to consider the size of the image formed, and what factors influence this. Students build upon their prior knowledge of how light travels, and what occurs as it passes from one material to another. Students also consider the formation of images when using a magnifying glass, in particular the distances that both the eye and lens need to be positioned in order to see the magnified image. This information is then discussed in the context of using lenses to correct for long- and short-sightedness.

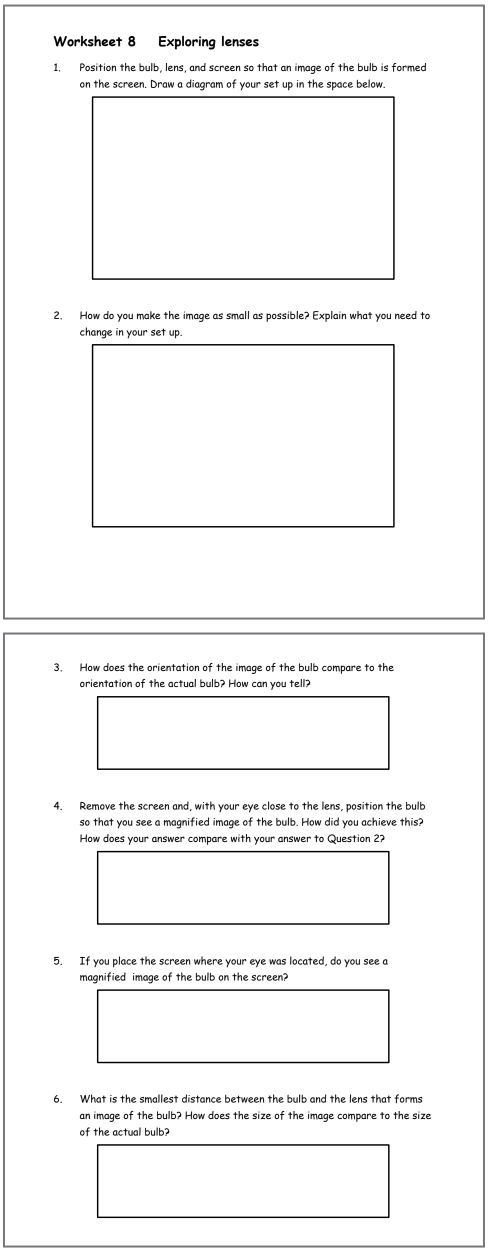
Suggested lesson sequence

Materials: *incandescent bulbs, short focal-length bi-convex lenses, paper screens*

1. The students should take a bi-convex lens and attempt to form an image of their bulb on their paper screens. This should take the form of a challenge to see how small they can make their image by changing the relative positions of the bulb and screen.
2. The students should then be asked to describe what they needed to do to minimise the size of their images and whether the lens magnifies the object. They should record their explanations in their worksheets (Figure 7).
3. Next the students should consider what must happen to the direction of light when it passes through the lens if the image is smaller than the object.
4. The students remove the screen and look through the lens in an attempt to "magnify" the bulb (i.e. in a magnifying glass configuration when the object is inside the focal length). They should be asked to describe where their eye and the bi-convex lens need to be positioned to produce this magnified image. If they now place a screen where their eye was, is an image formed?
5. The students should consider what must happen to the direction of the light through the lens in order to produce this magnified image. A suitable online resource for this activity is an interactive applet provided by freezeray.com to investigate the effect of different types of lenses[3].
6. This activity can lead on to discussing how the human eye works and how we can correct for long- and short-sightedness. Again freezeray.com gives an interactive applet to investigate the effect of different types of lenses on the human eye[3].

Possible teacher questions

- Why is the image upside-down when it is small? Does this fact change the conclusion as to what happens to the direction of light when it passes through the lens?
- Why is no image formed on the sheet of paper when your eyes can see a magnified image?
- What is the purpose of wearing glasses?


Worksheet 8 Exploring lenses

1. Position the bulb, lens, and screen so that an image of the bulb is formed on the screen. Draw a diagram of your set up in the space below.
2. How do you make the image as small as possible? Explain what you need to change in your set up.
3. How does the orientation of the image of the bulb compare to the orientation of the actual bulb? How can you tell?
4. Remove the screen and, with your eye close to the lens, position the bulb so that you see a magnified image of the bulb. How did you achieve this? How does your answer compare with your answer to Question 2?
5. If you place the screen where your eye was located, do you see a magnified image of the bulb on the screen?
6. What is the smallest distance between the bulb and the lens that forms an image of the bulb? How does the size of the image compare to the size of the actual bulb?

Figure 7: Worksheet for Activity H: Exploring lenses

[3] Freezeray.com Physics resources, www.freezeray.com/physics.htm [accessed October 2015]

2.2 Assessment of activities for inquiry teaching & learning

There are several opportunities presented throughout this unit for the development and assessment of inquiry skills. Evidence of both content knowledge and skill development can be collected by using the dedicated guided worksheets for each activity, and through teacher observation and self-assessment. While some assessment tools (3-level rubrics) are suggested within this unit, the teachers are free to devise and implement their own assessment instruments. Suggested skills to be assessed during implementation of this unit include *developing hypotheses, planning investigations*, and *scientific literacy*. In particular, suggested criteria for making judgements on six inquiry skills that are developed in these activities are included in this unit.

Asking questions

The skill of forming and asking questions is an integral aspect of IBSE. A 3-level rubric for the assessment of asking inquiry questions is shown in Table 1.

Teacher questions to guide the students include:

- Which questions would you like to pose about this?
- What would you like to know about this?
- How could you pose this question, so that you may find an answer to the question?

Table 1: Teacher rubric for the assessment of asking inquiry questions

Inquiry skill	Level 1	Level 2	Level 3
Asking inquiry questions	The student poses a number of questions, but does not make a distinction between questions possible to investigate and questions not possible to investigate.	The student, with the support of others, revises questions, so that they become possible to investigate.	The student revises own or others' questions, so that they become possible to investigate systematically.

Developing hypotheses

This skill is about collecting information and ideas about a question, so that a hypothesis can be formulated. The teacher can assess students on *developing hypotheses* through teacher observation or by assessing student artefacts during or after the lesson. A rubric for the assessment of this skill is provided in Table 2.

Teacher questions to aid students in developing their hypotheses include:

- What do you think will happen?
- Why do you think this it happen?
- Can you explain by using your scientific knowledge?

Table 2: Teacher rubric for the assessment of developing hypotheses

Inquiry skill	Level 1	Level 2	Level 3
Developing hypotheses	The student formulates a prediction about what will happen, but does not explain why.	The student formulates a prediction about what will happen and explains why. The explanation builds on own (or others') experiences.	The student formulates a hypothesis, that is, makes a prediction that is scientifically well-founded.

Planning investigations

This skill is about planning an investigation in order to test a hypothesis. Planning involves both identifying appropriate equipment and a functional design. The teacher can assess students on *planning investigations* through teacher observation or by assessing student artefacts. A rubric for the assessment of this skill is provided in Table 3.

Teacher questions to aid students in *planning investigations* include:

- How could you investigate this?
- What kind of equipment would you need?
- What would you look for?
- What can you do in order to get as trustworthy results as possible?

Table 3: Teacher rubric for the assessment of planning investigations

Inquiry skill	Level 1	Level 2	Level 3
Planning investigations	The student suggests how an investigation might be designed, but not in detail.	The student suggests how an investigation might be designed, but the design is incomplete in some respect. The design can, with some revisions, be used for systematic investigation	The student plans an investigation, where the design includes... ...which variables to change and which to be held constant, ...in which order to perform different parts of the investigation, ...which equipment is to be used.

Carrying out an investigation

This skill is about carrying out an investigation previously planned, in order to collect data. In this aspect, the appropriate use of equipment is also included. The teacher can assess students through teacher observation or evaluation of student artefacts. A rubric for the assessment of this skill is provided in Table 4.

Teacher questions to aid students in planning and carrying out an investigation include:

- What do you have to keep in mind when using this equipment?
- What could you do in order to make the results as accurate as possible?
- How can you document your results?

Table 4: Teacher rubric for the assessment of carrying out an investigation

Inquiry skill	Level 1	Level 2	Level 3
Carrying out an investigation	The student… …carries out an investigation from the beginning to the end, but is in need of constant support by the teacher, peers, or detailed instructions. …uses equipment, but may handle the equipment in a way that is not always safe. …sporadically documents the investigation in writing and with pictures.	The student… …carries out an investigation from the beginning to the end, but is sometimes in need of support by the teacher, peers, or detailed instructions. …uses equipment safely. …documents the investigation in writing and with pictures, but the documentation may be incomplete or lack in accuracy.	The student… …carries out an investigation from the beginning to the end, either alone or as an active participant in a group. …uses equipment safely and appropriately. …accurately documents the investigation in writing and with pictures.

Interpreting results and drawing conclusions (scientific reasoning)

This skill is about identifying patterns, making interpretations, and drawing conclusions from the results. The teacher can assess students through teacher observation or evaluation of student artefacts. A rubric for the assessment of this skill is provided in Table 5.

Teacher questions to aid students in interpreting their results and forming conclusions:

- Which patterns do you see?
- How do these results agree with your predictions?
- Can these results be interpreted differently?

Table 5: Teacher rubric for the assessment of scientific reasoning (interpretation and conclusions)

Inquiry skill	Level 1	Level 2	Level 3
Scientific reasoning (interpretation of results; forming conclusions)	The student… …draws conclusions, but only uses a limited amount of the results from the investigation. …compares the results from the investigation with the hypothesis.	The student… …draws conclusions based on the results from the investigation. …compares the results from the investigation with the hypothesis.	The student… …draws conclusions based on the results from the investigation. …relates the conclusions to scientific concepts (or possibly models and theories). …compares the results from the investigation with the hypothesis. …reasons about different interpretation of the results.

Observations (scientific reasoning)

This skill is about, through the use of observations, identifying properties, finding similarities and differences, and describing objects in words and in drawings. The teacher can assess students through teacher observation or evaluation of student artefacts. A rubric for the assessment of this skill is provided in Table 6.

Teacher questions to aid students in developing their observation skills include:

- Which properties do these objects have?
- Are there any other properties that may not be as easily discovered?
- Are there any similarities (or differences)?
- How would you describe your observation?

Table 6: Teacher rubric for the assessment of scientific reasoning (observations)

Inquiry skill	Level 1	Level 2	Level 3
Scientific reasoning (observations)	The student… …identifies easily observable properties among the objects studied.	The student… …identifies easily observable properties among the objects studied, as well as less obvious properties. …uses several different properties to describe an object.	The student… …identifies easily observable properties among the objects studied, as well as less obvious properties. …uses several different and relevant properties to describe an object. …makes use of more than one of the senses, and also makes use of appropriate technological aids, when observing objects.

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in three countries, producing four case studies of its implementation (**CS1 Ireland**, **CS2 Ireland**, **CS3 Greece** and **CS4 Slovakia**). All the case studies were implemented by teachers whom had some experience of teaching through inquiry but generally the students involved had no previous experience of learning through inquiry.

CS1 Ireland, **CS2 Ireland** and **CS3 Greece** involved lower second level students: **CS1 Ireland** was a class of 22 girls working in groups of three, **CS2 Ireland** was a class of 22 boys aged working in pairs and **CS3 Greece** involved a mixed gender class of 24 students working in groups of three or four. These case studies describe double lesson periods, approximately 80 minutes each in **CS1** and **CS2** (both **Ireland**), and 120 minutes in **CS3 Greece**. The students in **CS4 Slovakia** were a class of 28 mixed ability and mixed gender upper second level students aged 17-18 years, working in groups of two or three, and the case study describes a single 45 minute lesson.

Through the four case studies, details of the assessment are provided for the four key SAILS inquiry skills, namely *developing hypotheses*, *planning investigations*, *forming coherent arguments* and *working collaboratively*. Some teachers also found this unit useful for the assessment of *scientific literacy*, looking at students' ability to explain the concepts of light using scientific terminology. The main methods of assessment were classroom dialogue, where the teacher could provide formative feedback on-the-fly, and evaluation of students' worksheets, often using rubrics to distinguish performance levels.

3.1 Teaching approach

Inquiry approach used

The inquiry approach adopted by the teachers was a *guided inquiry* approach, with students completing the activities guided by the questions in the worksheet and the teacher's questions. All students completed the activities working in small groups (see Table 7) and peer discussion was encouraged and facilitated. The teachers observed that the worksheet questions encouraged interactive discussion among students. The teachers circulated between groups probing student conceptual understanding through directed questions to individuals/groups.

Implementation

A total of eight activities were proposed in the unit and each teacher selected 2-3 activities to complete with their students, based on the school curricula and time available. All teachers used the materials provided in the activities for inquiry teaching & learning section of the unit, with the students working in small groups to complete the activities and to facilitate peer discussion. Each student individually completed the associated worksheet in **CS1 Ireland**, **CS3 Greece** and **CS4 Slovakia**, and completed the worksheet in pairs in **CS2 Ireland**. Groups were formed by the teacher for carrying out these activities and in the case of **CS4 Slovakia** these groups were constant for a school term.

Adaptations of the unit

The teacher in **CS3 Greece** started with Activity D: Exploring white light and filters, and at the end of this activity asked students to plan an investigation to determine the correct

Table 7: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Ireland	Activities A-B	One lesson (80 min)	• Groups of 2-3 students (22 students in total) • Teacher assigned; all girls
CS2 Ireland	Activities A-D	One lesson (80 min)	• Groups of 2 students (22 students in total) • Teacher assigned; all boys
CS3 Greece	Activities D-E	One lesson (120 min)	• Groups of 3-4 students (24 students in total) • Teacher assigned; mixed genders
CS4 Slovakia	Activities B, C, G	One lesson (45 min)	• Groups of 2-3 students (28 students, divided into two sub groups) • Teacher assigned; mixed genders

explanation for the phenomenon of the dispersion of white light. The teacher posed probing questions to the students as they were recording their plans. Before carrying out Activity E: Exploring primary colours, the teacher showed the students some online applets that allowed them to investigate the effect of different coloured filters. Again at the start of Activity E, the teacher asked students to plan an investigation to create white light without using the seven colours of the rainbow. The teacher finished this activity by introducing the students to a game that explored the difference between mixing colours of light and mixing colours of paint. Finally, the teacher asked from students to examine the pixels of their mobile phone screen using a magnifying glass in order to verify the usage of red, green and blue light mixing and students were really impressed at what they observed.

The teacher in **CS3 Greece** used the 3-level assessment criteria described in the unit for "Interpreting results and drawing conclusions" to make judgements on the student's skill in *forming coherent arguments*. However, the teacher in **CS1 Ireland** described and used a different 3-level instrument outlining criteria for making judgements on the skill of *forming coherent arguments* and did this both for written responses on worksheet as well as making judgements on verbal responses (Table 8).

In **CS4 Slovakia**, the students at upper second level were required to submit their lab worksheets and the teacher then evaluated these. In the next lesson the teacher discussed the activities with the students and gave feedback given to each individual student, and in particular highlighted possible improvements. Students were then required to revise their worksheets based on the teacher recommendations. The final version of the worksheet was collected and included in the student's personal portfolio as part of their school living exams (matura).

3.2 Assessment strategies

Within the four case studies, the inquiry skills of *planning investigations, forming coherent arguments, developing hypotheses* and *working collaboratively* were assessed in different ways, with some teachers using the rubrics proposed in the assessment of activities for inquiry teaching & learning section of the unit. Additionally the content knowledge and evidence of *scientific reasoning* and *scientific literacy* were assessed through the student worksheets and verbal responses.

Forming coherent arguments

CS1 Ireland presented a rubric with 3-level criteria for making judgements of the skill of *forming coherent arguments* (Table 8) and applied these criteria to both student verbal and written responses to questions 5-7 posed in Activity A: Sources of light. The teacher noted the dialogue between the teacher and 11 students (out of the class of 22 students), arising from specific questions posed by the teacher during class time. The teacher critiqued all 22 students' written responses to worksheet questions to make judgement on this skill after the lesson.

CS4 Slovakia highlights opportunities for assessing this skill in three of the unit activities – Activity B: How does light travel, Activity C: Understanding shadows and Activity G: Exploring refraction. Throughout these activities the students are introduced to the skill of *forming coherent arguments* and in other activities are required to discuss the relevance of their arguments (in case where they are not sure, they ask the teacher for help). At the end of each activity each group is required to present their own solution with argumentation. This case study highlights that argumentation is implicitly included – at the beginning students only say what they think about the problem, but not why. During IBSE activities they are encouraged to use arguments for each of their decisions and not just for the final statement. The teacher can review students' answers in the worksheets and write down comments for improvement of their argumentation skills. However, the teacher did not provide any criteria or collect any evidence of students developing this skill.

The teacher in **CS3 Greece** used the 3-level assessment criteria described in the unit for "Interpreting results and drawing conclusions" to make judgements on the students' ability to form coherent arguments. This case study also presents students artefacts and gives an account of the judgements made by the teacher on student responses in Activity D: Exploring white light and filters, questions 2-5.

Table 8: Teacher rubric for the assessment of forming coherent arguments in CS1 Ireland

Inquiry skill	1 point	2 points	3 points
Forming coherent arguments	The student does not provide and/or does not explain the arguments in his/her own words (construction); key arguments are not properly developed.	The student presents and explains his/her arguments, explaining the key arguments but not completely. In case of verbal communication, this level includes complete answers obtained only after prompting by the teacher.	The student presents and explains his/her arguments in his/her own words (construction), properly developing the key arguments.

Working collaboratively

CS4 Slovakia reports on assessing this skill when groups of two or three students work together with one equipment set, solving problems and fulfilling worksheets together, with only a little help from the teacher in cases where they ask. The teacher made observations about each student's involvement in solving the problem in the activity. Peer discussion was stimulated by the teacher in a way, as the teachers required the students to "explain your opinion within group and use arguments for it." The teacher reports on observation of groups *working collaboratively* and trying to improve collaboration within groups, especially involvement of weak students.

Developing hypotheses

CS1 Ireland used the criteria from the 3-level rubric proposed in the assessment of teaching and learning section of the unit for making judgements on the skill of *developing hypotheses* (Table 2), based on written responses to questions 7 and 8 in Activity C: Understanding shadows. The case study includes examples of student worksheets, and a brief critique of students' ability to form hypotheses.

Planning investigations

CS3 Greece used the 3-level rubric proposed in the unit for making judgements on the skill of *planning investigations* (Table 3). The assessment was based on students' recorded plans for an investigation (1) to determine the correct explanation of the phenomena of the dispersion of white light and (2) to create white light without using the seven colours of the rainbow, as required at the start of Activity D and Activity E, respectively.

Scientific reasoning

The teacher in **CS3 Greece** observed how well students could explain in their own words the concepts of the topic. Their ability to reason was assessed as part of the inquiry skill *forming coherent arguments*, which combined the skills of forming conclusions, making comparisons and interpreting data.

CS4 Slovakia observes that step by step reasoning of scientific background is created and students are focused on conceptual understanding of the problems, not only on memorising of knowledge. This approach supports the development of *scientific reasoning* very well. The teacher identifies reasoning to be related to conceptual understanding of the problems and it could be "measured" by concept test questions.

Scientific literacy

CS4 Slovakia comments that in completing these activities students use a combination of different skills, knowledge and attitudes. In situations where students are doing IBSE activities they are in acting like scientists at the school level. The teacher can observe the "level" of scientific approach within the classroom, i.e. the student interest in the problem, focus of discussions, active communication with the teacher and correct interpretation of the problem.