INQUIRY AND ASSESSMENT UNIT

ULTRAVIOLET RADIATION

UV radiation – To tan or not to tan?

Maria Rosberg

ULTRAVIOLET RADIATION

UV RADIATION – TO TAN OR NOT TO TAN?

Overview

KEY CONTENT/CONCEPTS

- Sources of UV radiation
- Detecting UV radiation and exposure levels
- How to reduce UV exposure

LEVEL

- Lower second level

INQUIRY SKILLS ASSESSED

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

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

- Scientific reasoning (drawing conclusions; analysis of data)
- Scientific literacy (critical thinking)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Student devised materials (documentation of inquiry process)
- Presentations

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – ULTRAVIOLET RADIATION

In the **Ultraviolet radiation** SAILS inquiry and assessment unit, four activities are presented for introducing the concept of UV radiation. In particular, this unit addresses sources of UV radiation, potential health and safety considerations and methods of detection of UV radiation. The investigations suggested are carried out using UV reactive beads (UV sensors). These activities are suitable for implementation with lower second level students (aged 12-16 years). The unit activities are presented with *open/guided inquiry* approaches and implementation of the complete unit is expected to take about 3 hours.

Activity A introduces students to the methods of observing UV irradiation, in particular fluorescence, and promotes students' familiarity with the handling of UV beads. In Activity B, the students consider real world impacts of UV rays and how to reduce exposure. The final two activities build on these experiences and encourage students to investigate the intensity of UV rays and UV sources.

This unit can be used for development of many inquiry skills, in particular *planning investigations*. In addition, students can develop their skills in *developing hypotheses* and *forming coherent arguments*, and enhance their *scientific reasoning* and *scientific literacy*. Possible assessment opportunities include teacher observation, student artefacts, use of rubrics and peer- and self-assessment.

This unit was trialled by teachers in Denmark, UK and Germany – producing three case studies of its implementation. The skills of *developing hypotheses* and *planning investigations* were assessed in all case studies and assessment of *working collaboratively* and *scientific reasoning* was also described.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The activities in the **Ultraviolet radiation** SAILS inquiry and assessment unit were based on the article T*o Tan or Not to Tan? Students learn about sunscreens through an inquiry activity based on the learning cycle*.[1] The teaching and learning activities were adapted for the SAILS project by the team at Kristianstad University.

In this unit, four activities are outlined, that are suitable for introducing lower second level students (aged 12-16 years) to the topic of ultraviolet radiation. These activities develop student understanding of the harmful effects of solar radiation and what preventative measures can be taken to reduce the risks associated with exposure to UV sources, e.g. sunlight. During this unit, students use UV beads – polymeric beads that change colours when irradiated with UV light – to investigate how to detect "invisible" light. This unit is very suitable for use with an *open inquiry* approach, as students generally have lots of ideas that they want to test. Students will be stimulated to formulate their own questions (*developing hypotheses*) and design suitable experiments to carry out (*planning investigations*). In addition, students develop their *scientific reasoning* and *scientific literacy* skills through analysing, interpreting and reporting their results.

For this inquiry and assessment unit, it is important to engage the students from the beginning of the lesson, by raising questions such as "What is UV radiation? What can we use UV radiation for? How can we protect ourselves from UV radiation?" The teachers can introduce the concept of UV radiation as a form of light, e.g. "Sometimes we hear the words UV light, what is this?" The term light is often used as a generic term to describe many different sources of light such as incandescent light, fluorescent light, or sunlight. However, not all light waves carry the same energy. Using UV beads (or a different UV sensor), students can discover an "invisible" form of light, namely ultraviolet light or ultraviolet radiation. Just as there are many different colours (wavelengths) in the visible light spectrum (red, yellow, green, blue, etc.), there are also many wavelengths of ultraviolet light. However, all radiation in the ultraviolet region of the electromagnetic spectrum is not visible to the naked eye. Firstly, there is long wave ultraviolet radiation (UVA, 300 to 400 nm), which is commonly identified as "black light," the radiation that is often used to make decorations glow in discos and theatrical productions. Long wave UVA radiation can easily pass through plastic and glass. Short wave ultraviolet radiation (UVB, 100 to 300 nm) is used to kill bacteria, speed up chemical reactions (act as a catalyst), and is also used for the identification of certain fluorescent minerals. Unlike long wave UV (UVA), the short wave UV (UVB) cannot pass through ordinary glass or most plastics. Indeed, the shortest UV wavelengths cannot even travel very far through the air before they are absorbed by oxygen molecules (as they are converted into ozone).

The four activities in the **Ultraviolet radiation** SAILS inquiry and assessment unit are suitable for developing student understanding of the harmful effects of solar radiation and to recognise preventative measures that can be taken to reduce the risks associated with exposure to sunlight. When you expose bare skin to sunlight, your skin will either burn or tan. UV radiation carries enough energy to break chemical bonds in your skin tissue and with prolonged exposure, your skin may wrinkle or skin cancer may appear. These responses by your skin are a signal that the cells under your skin are being assaulted by UV radiation.

The ideas behind the four suggested activities have been informed by different articles on ultraviolet light and sunscreens:

- *To Tan or Not to Tan? Students learn about sunscreens through an inquiry activity based on the learning cycle*.[2]
- *Invisible rays: our extraterrestrial enemies? Detecting UV radiation in our environment*.[3] A practical protocol of using UV sensitive beads is given in this article.
- *What is ultraviolet light?* [4] A resource from the Stanford SOLAR (Solar On-Line Activity Resources) Center, which outlines an inquiry activity and provides supplementary information for grades 2-4, 5-8 and 9-12.[4] This activity outlines the objectives of the topic, main concepts and inquiry skills and details the use of UV sensitive beads. Note that this material is from the USA and may need to be adapted for other curricula.

[1] To Tan or Not to Tan? Students learn about sunscreens through an inquiry activity based on the learning cycle, Linda Keen Rocha, The Science Teacher, 2005, 72, 46-50
http://people.uncw.edu/kubaskod/SEC_406_506/Classes/Class_6_Planning/To_Tan_Not_Tan.pdf [accessed October 2015].

[2] Invisible rays: our extraterrestrial enemies? Detecting UV radiation in our environment, Margarida Gama Carvalho, Joana Desterro, Teresa Carvalho, Célia Carvalho, Patrícia Calado and Noélia Custódio, Biosciences Explained, 2007, 3. http://www.bioscience-explained.org/ENvol3_2/pdf/uvpearlveng.pdf [accessed October 2015].

[3] Stanford SOLAR Center, http://solar-center.stanford.edu/activities/uv.html [accessed October 2015].

[4] As the sun burns. Supplemental science materials for grades 5-8, http://solar-center.stanford.edu/webcast/wcpdf/SunBurns5-8.pdf and As the sun burns. Supplemental science materials for grades 9-12, http://solar-center.stanford.edu/webcast/wcpdf/SunBurns9-12.pdf [accessed October 2015].

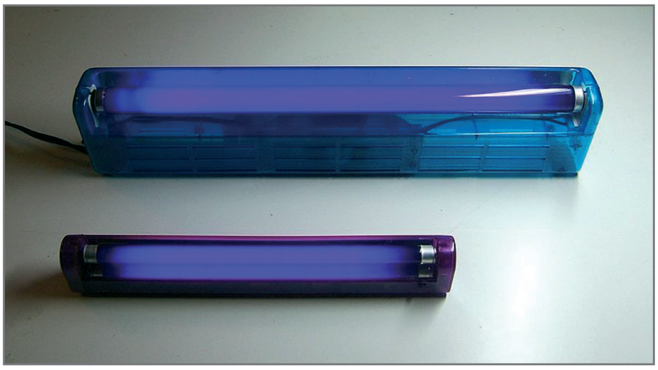

Figure 1: UV lamp, also known as a "black light"

Activity A: How can you detect UV rays?

Concept focus	Introduction to UV radiation Detection of UV radiation and fluorescence
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (forming conclusions)
Assessment methods	Classroom dialogue Teacher observation

Rationale

In this activity, students use a UV lamp ("black light"), and also use the sun as a source of UV radiation. Students will investigate how different materials that "react" to UV irradiation and thus can be used to detect it. The activity starts by using the UV lamp because this mostly emits UV radiation and almost no visible light. During this activity, students observe that many white materials look "luminous" near the lamp, thus introducing the phenomenon fluorescence. A white copy paper fluoresces, and could thus be used for detecting UV radiation.

Suggested lesson sequence

1. Students are provided with a UV lamp (Figure 1) and asked to illuminate a common white copy paper and an off-white recycled paper with UV light. The teacher asks, "Do you see any difference?"
2. The activity is extended to illuminating other items, to see which have similar properties; for example illuminating white clothes or banknotes. The teacher will encourage students to engage with the activity by asking, "Do you have other items that might be interesting to test?" There may be more things that the teacher or students want to test. Many white papers and fabric products are treated with optical brighteners i.e. something that fluoresces under UV radiation. For example, try paper napkins, panty liners, toilet paper, etc.
3. The teacher should pour a glass of tonic water, illuminate the tonic water using UV radiation and observe the effect.
4. The final task suggested is to illuminate some UV beads and observe the resulting colour change.

In the next part of the activity, students decide which of these materials are suitable for use outdoors, to investigate the sun's UV rays. The teacher suggests that students should "bring some of the materials that worked well in the UV light out into the sunlight! Is there UV radiation in the shade?"

5. Examine the same materials using the light from the sun, both through direct sunlight and in the shade.

Students will discover that the UV beads work best outside. They may observe the bluish glow in the tonic water even outside in the sunlight, but for most materials the fluorescence effect can be entirely hidden by the bright light of the sun. They will also see that white paper looks whiter than the recycled paper, even in sunlight. The sunlight is reflected in both types of paper, but the white paper is also affected by the sun's UV rays and fluoresces. Therefore, the white paper looks "dazzling white" when compared to the recycled paper.

Activity B: How can you protect yourself against the sun's UV rays?

Concept focus	Protection from UV radiation Energy of UV radiation
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (forming conclusions) Scientific literacy (real world context)
Assessment methods	Classroom dialogue Student devised materials (experimental plan)

Rationale

In this activity, students are asked to consider different ways to protect against UV rays, i.e. how to prevent them from reaching their bodies. For this investigation, something that detects UV rays, such as UV beads (or a UV detector or UV sensor) is needed, as well as different types of materials that may stop the rays, such as suncreams, umbrella material, t-shirt fabric, etc.

Suggested lesson sequence

1. The teacher introduces the topic and may suggest some materials to investigate:
   a. Try different types of fabrics. Take a thin and a thick fabric, one white and one dark. How about wet fabrics? Try a white t-shirt.
   b. How does the fabric work if it is wet? Try it! Do you notice any difference?
   c. You probably have a broken umbrella at home. Test the umbrella fabric!
   d. Do your sun hat or knit cap protect from UV?
   e. What about UV protection by your sunglasses? Is there a difference between Polaroid glasses and other sunglasses?
   f. Does it help to wear regular glasses? Test!
   g. Is there any difference between glasses made of plastic or glass?
2. Can UV rays go through glass? If the investigation uses a UV lamp, ensure that students are aware that the lamp only emits UVA rays, i.e. those containing the least energy. These rays go through glass – even window glass. To test the hypothesis, "You can not get a tan if you're sitting inside a window" students use sunlight as a source of UV radiation and do the experiment. In this case, the source will contain both UVA and UVB rays. Glass transmits UVA, but not UVB, which means that the risk of getting burned by the sun behind a glass window is small.
3. Students are then challenged to test the effect of sunscreens. In Activity A, students will have found that the best UV detectors for UV rays are the UV beads. Therefore they should now use them to do their investigations. The beads react quickly to UV, but then it takes time for them to recover their white colour. Therefore, it is important that all the beads are kept in the dark, except the ones being used to do the investigation.
4. For the testing of sunscreens to be comparable, it is important that students carry out their investigations in the same way. For example, it is appropriate to have the UV beads in a cup, a can or a box that can be covered with the different materials whose permeability is to be tested.
5. Students should ensure that the beads are not exposed to any sunshine before the planned experiment is carried out. When students inspect the beads for colour, they must be sure to do it while the beads are not exposed to the sun. Note that it is good to use beads of the same colour, as it will be easier to make comparisons between them. It has been observed that the colour shifts are more distinct for the darkest colours – the purple beads.
   a. Go out into the sun (if there is no sun or it is winter, use a UV lamp) with some UV beads (protect them from UV). Take up a bead and let the sun shine directly on it. See how the colour changes! Go into the shade and try a new bead. Does the colour still change?
   b. Now take transparent plastic film (overhead transparency) and put on three different thickness layers of sunscreens. The thinnest layer should to be really thin. Use a film for each type of sunscreen you have. Use a sunscreen with high SPF (25 or higher) and a low SPF. Select a waterproof cream and a non-waterproof version for comparison.
   c. Pick up some beads and put them below the film with the layer of sunscreen. Here it is important to be careful (and fast) so that no sunlight reaches the beads. Hold the beads below the film for a little while and look at them from the side.
   d. If you test both waterproof and non-waterproof suncreams you should definitely rinse off the plastic films with water – i.e. swim – to see how much sunscreen is left!
   e. Investigate if old sunscreen performs differently than new sunscreen.

Note that if students find it difficult to handle the beads and films, while preventing the sun from shining in from the side, then they can place the beads in a cup/mug. Hold the cup and then place the film with sunscreen over the top of the cup. Tilt the cup so that sunlight reaches down to the beads. Ensure that the sunscreen covers the whole opening of the cup. Sunscreen can be rubbed directly on the beads, but it gets terribly messy! The result can also be a bit misleading because the cream does not penetrate into the beads and remains as a white "film" that you can not see through. It is worth noticing that one can distinguish between sunscreens with physical and chemical filters. Physical filters are generally composed of zinc or titanium oxides, which reflect a large part of the UV radiation. Creams with chemical filters block radiation by absorption. Try to get both, and note how these two types of filters react to UV rays.

6. Try different sun blockers (materials), e.g. fabric from a t-shirt. Add some beads to a t-shirt, a pair of jeans or under a cap and note whether the beads change colour.

Activity C: How does UV radiation vary throughout the day?

Concept focus	Intensity of UV radiation
Inquiry skill focus	Developing hypotheses Planning investigations
Scientific reasoning and literacy	Scientific reasoning (forming conclusions) Scientific literacy (real world context)
Assessment methods	Classroom dialogue Student devised materials

Rationale

The goal of this activity is to examine how UV radiation varies throughout the day by collecting data with a UV detector (the detector should measure radiation intensity from the UVA and UVB regions). It is important to record the date, the temperature and whether there is any cloud cover or haze each time the students take a UV measurement. The amount of ultraviolet radiation that reaches the earth's surface on any given day is typically highest around noon. This is because the sun's rays travel the shortest distance to the earth's atmosphere at that time. But other factors such as amount of cloud cover, and the presence of atmospheric haze can also affect how much UV reaches the earth's surface.

Suggested lesson sequence

1. The teacher introduces the topic and asks the students to predict if UV radiation will change throughout the day, as well as what factors can affect this.
2. Students then plan their own investigation on how UV radiation changes throughout the day.

Activity D: Measure UV radiation from different light sources

Concept Focus:	Sources of UV radiation
Inquiry Skill Focus:	Developing hypotheses Planning investigations
Scientific reasoning and literacy	Scientific literacy (real world context)
Assessment methods	Classroom dialogue Student devised materials

Rationale

In this activity, students examine different light sources: incandescent bulb, halogen lamp (with or without filters), fluorescent lamps of different types, overhead lamp, television screen and computer monitor and determine if they emit UV radiation. If possible, they should measure each of these sources at different wavelengths.

Suggested lesson sequence

1. The teacher asks the students to consider if all light sources are sources of UV light.
2. Students plan an investigation to examine the emission of UV radiation from different light sources.

2.2 Assessment of activities for inquiry teaching & learning

When implementing these unit activities, it is important that the assessments are in line with the objectives of the topic and the curriculum. It is also important that students understand how to report their results and how they will be judged, before they carry out the activities. This inquiry and assessment unit recommends that *planning investigations* is a key inquiry skill that can be developed during the unit activities, which can be assessed using a 3-level rubric as shown in Table 1.

Table 1: Criteria for assessing the skills of planning investigations and carrying out an investigation

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

This unit is also suitable for the assessment of *developing hypotheses*, as students are asked to make predictions regarding how UV light can be detected, what materials can provide protection from UV radiation and what are sources of UV radiation. Again, a rubric with a three levels of success criteria may be used for evaluation of the skill of *developing hypotheses* (Table 2).

Table 2: Rubric for the assessment of the skill of developing hypotheses

Inquiry skill	1	2	3
Developing hypotheses	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.

To assess students' *scientific reasoning* competencies and skills in *forming coherent arguments*, a 3-level rubric may be used for assessing students' skills in interpreting results, drawing conclusions, as well as documenting and discussing (Table 3). This rubric can be used by the teacher with in-class observation, or for evaluation of student artefacts after the lesson. The activities in this unit may also be used to assess the students' skills in collecting, documenting and analysing data, again allowing them to demonstrate their *scientific reasoning* capabilities. These activities allow the teacher to assess students' ability to document an investigation in text and with pictures (using graphs, tables and symbols) and to use the documentation in their discussion of results and conclusions. Finally, the assessment of students' observation skills can be achieved, looking at identifying properties, finding similarities and differences, and describing objects in words and drawings.

This unit was based on the article *To Tan or Not to Tan? Students learn about sunscreens through an inquiry activity based on the learning cycle* by Linda Keen Rocha in *The Science Teacher*, which suggests how the assessment of students can take place throughout the learning activity. In summary, this evaluation can be carried out using short quizzes, journal recordings, formal lab reports, portfolios and grading rubrics.

Table 3: Rubric for the assessment of scientific reasoning and forming coherent arguments

Inquiry skill	1	2	3
Interpreting results and drawing conclusions	The student draws conclusions, but only uses a limited amount of the results from the investigation. The student compares the results from the investigation with the hypothesis.	The student draws conclusions, based on the results from the investigation. The student compares the results from the investigation with the hypothesis.	The student draws conclusions, based on the results from the investigation. The student relates the conclusions to scientific concepts (or possible models and theories). The student compares the results from the investigation with the hypothesis. The student reasons about different interpretations of the results.
Documenting and discussing	The student documents the investigation with an everyday language and contextual pictures, drawings, etc. Uses the documentation in discussions around how the investigation was carried out. Discusses the investigation in an everyday language.	The student documents the investigation with text and pictures and supports the documentation with graphs and tables. Uses the documentation in discussions around how the investigation was carried out and the results obtained. Discusses the investigation and results obtained, but combines everyday language with scientific concepts.	The student documents the investigation with text and pictures and supports the documentation with graphs, tables, and appropriate scientific symbols and representations. Uses the documentation in discussions around all parts of the investigation, including the conclusions drawn and how the investigation might be improved. Discusses the investigation and results obtained with the use of scientific terminology.
Observation skills	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 – **CS1 Denmark**, **CS2 United Kingdom** and **CS3 Germany**. Three case studies have been compiled from classroom implementation by three science teachers in a total of four classes. The activities have been carried out with lower second level students; classes were mainly of mixed gender, but in **CS2 United Kingdom** the class consisted of only boys. All of the case studies were implemented by teachers who had some experience of teaching through inquiry, but the students involved had limited experience of inquiry learning.

CS1 Denmark consisted of a class of 24 students, aged 14-16 years, working in groups of 4-5 students, and **CS2 United Kingdom** describes a class of 26 all-male students, aged 14-15 years, who were "top set" performers (high ability). Finally, **CS3 Germany** involved a mixed ability and gender class of 30 students, aged 14-15 years. Activity B: How can you protect yourself from the sun's rays? was implemented in all case studies, while **CS1 Denmark** also implemented activities A and D, and **CS3 Germany** implemented activities A and B.

All case studies describe the assessment of the skills of *developing hypotheses, planning investigations* and *scientific reasoning*, primarily through classroom dialogue and evaluation of student presentations. **CS2 United Kingdom** describes the use of peer-assessment of poster presentations and self-assessment of the skill of *working collaboratively*.

3.1 Teaching approach

Inquiry approach used

The inquiry approach adopted varied in each of the case studies: *open inquiry* was described in **CS1 Denmark**, bounded inquiry in **CS2 United Kingdom** and *guided inquiry* in **CS3 Germany**. In all cases the teacher posed the initial question but there were different approaches to how the students decided to address the question. Students completed the activities working in small groups (see Table 4) and peer discussion was encouraged and facilitated.

Implementation

In each of the case studies, the teachers introduced the real world context of prevention of sunburn to encourage students to explore their prior knowledge of UV radiation. The implementation of the unit and teaching approach adopted varied, depending on the needs of the class and the skills being assessed.

The unit was implemented as an *open inquiry* in **CS1 Denmark**, and the concept of UV radiation was introduced through a whole-class brainstorming exercise and included other concepts within the topic of UV radiation. The class was divided into groups of 4-5 students and were given 10 minutes of research time on the internet to find out more about UV radiation. After this research each group was challenged with three tasks. The task was to find things that could be used as a UV indicator (Activity A). The students were asked to pay specific attention to their planning of such identifications and asked to be aware of different variables. The second task was to investigate UV sources (Activity D). The students again planned their investigations in groups and carried these investigations out in practice. The third task was to investigate how the students could protect themselves from UV radiation (Activity B). Again the groups planned investigations and carried them out. The results from the three investigations were then put into an oral group presentation with special emphasis on the group's hypothesis, planning and conclusions drawn. After each group's presentation there was a discussion among peers on the group's work and their conclusions. A general problem observed was that the students despite being given clear instructions did not discuss their inquiry plans with the teacher and often went from questions to investigations without reflecting on the planning processes. This led to many investigations having very weak or even false conclusions. A positive aspect of these lessons was that the presentations to the whole class often highlighted these weak investigations and the discussions that ensued appeared to promote student understanding of inquiry learning.

In **CS2 United Kingdom**, the unit was implemented as a *bounded inquiry*. The students had previously been learning about the electromagnetic spectrum. The context of the investigation was Activity B: How can we protect ourselves from UV radiation? Some introductory slides were shown to the students with pictures of people sunbathing and some gruesome pictures of skin cancer. The different types of UV radiation (UVA, UVB and UVC) were explained, then the investigation introduced. The structure for the investigation was as follows:

Table 4: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Denmark	Activities A, B, D	One lesson (90 min)	• Two classes combined (24 students in total) • Groups of 4-5 students; mixed ability and gender
CS2 United Kingdom	Activity B	Three lessons (45 min each)	• Groups of 3-4 students (26 students in total) • All male; high ability
CS3 Germany	Activities A-B	One lesson (90 min)	• Small groups • Mixed ability and gender

- **Lesson 1:** The teacher outlined the task; groups were formed and planned what to investigate; groups carried out preliminary experimentation with the equipment. At the end of the lesson, students used a self-assessment guide to identify the three main group skills that they felt they demonstrated (Figure 2). The teacher asked the students to justify why they felt they had shown these skills, which was a useful approach as it added to the reliability of the self-assessment. Student work was collected and teacher feedback was provided based on the planning so far.
- **Lesson 2:** This lesson started with the students identifying three group skills they would like to demonstrate in the lesson. They then carried out their investigations and prepared a poster of their results (all in class). The teacher marked the work and added comments.
- **Lesson 3:** Students carried out peer-assessment at the start of the lesson (without teacher feedback) and reviewed what they had learned from the whole process. The teacher again marked student work using a teacher adapted rubric and provided feedback.

As a starting point in **CS3 Germany**, the teacher showed students a comic that illustrated two people lying on a beach. The first person asks: "Don't you want to come to the shade under the umbrella?" And the second answers: "No, I will have a swim and in the water I can't get sunburnt." Referring to the comic, students reported their experiences with sunburns and their knowledge of UV radiation. The teacher observed different students' opinions about the transmissibility of UV radiation in water. The question of whether water protects against sunburn was the focus for further investigations. The teacher implemented a *guided inquiry* approach, and provided an overview of the different steps in the inquiry process (propose hypotheses, plan an investigation, carry out an investigation, etc.). The teacher then posed the first question of the **Ultraviolet radiation** SAILS inquiry and assessment unit, "How can you detect UV radiation?" (Activity A). To support students' planning the teacher provided a list of materials that could be used for the investigation and distributed short assistance worksheets to support the planning process. In the first step the students had to formulate a hypothesis and then carry out an investigation. After the investigation was completed the teacher posed the second question of the activity, "How can you protect yourself against the sun's ultraviolet rays? (Activity B) referring to the comic at the beginning of the lesson. A second investigation period started. At the end of the lesson students had to document their work in a poster presentation.

3.2 Assessment strategies

Within the three case studies, the inquiry skills of *planning investigations* and *developing hypotheses* were assessed. In addition, *working collaboratively* was assessed in **CS2 United Kingdom** (Table 5). Methods for assessment included teacher observation and feedback in class, evaluation of student artefacts (posters, oral presentations), use of rubrics, peer-assessment and self-assessment.

Individual assessment: **Name:________________**
How you did in the group **Date:________________**

Ring those achieved. Add any that have been missed out. Say if filled out by pupils or teacher. NOTE: this can be done by the pupil as a self-assessment and can then be discussed by the group to see if they agree.

listening positively	**resolve ideas**	**work towards a common goal**	**be friendly**
be supportive	**share tasks**	**allocate tasks**	**collaborate**
empathise	**work with boys/girls/different groups**	**contribute to discussions without dominating**	**peacemaker**
work under pressure	**manage emotions**	**use resources and equipment without taking over**	**democratic leader**
be prepared to defend viewpoint with consideration	**reach agreements**	**take responsibility**	**constructive feedback**
negotiate	**Addition__________**	____________	____________

Figure 2: Self-assessment of group skills

Table 5: Inquiry skills identified by teachers in the case studies

CS1 Denmark	• Developing hypotheses • Planning investigations • Forming coherent arguments • Scientific reasoning (forming conclusions)
CS2 UK	• Developing hypotheses • Planning investigations • Working collaboratively • Scientific reasoning (analysis and conclusions) • Scientific literacy (critical thinking)
CS3 Germany	• Developing hypotheses • Planning an investigation (including implementation) • Scientific reasoning (analysis of data)

In **CS1 Denmark**, before the lesson the teacher referred to the SAILS assessment tool, which details nine skills and competencies, and chose to focus on *developing hypotheses, planning investigations* and *scientific reasoning* (forming conclusions). The assessment during the students work was carried out as oral conversations where the teacher addressed the specific focus points of the activity. The teacher used the assessment rubrics as an inspiration to guide the students in their work and give immediate formative feedback. Even though the teacher had a clear intention of using the developed rubrics for assessing the students' work she found it difficult to keep track of both students' work and the details of the success criteria at the same time. Her usage of the rubrics as assessment tools was therefore limited to them being used as inspiration in her discussions with the students during the lesson. For the next inquiry lesson, the teacher would present the rubrics to the students as self-assessment tools. The rubrics could be a useful tool both for the teachers planning and for the students' work. The students ended the lessons with a presentation and a peer discussion on their hypothesis and their methodology. This gave not only the teacher a clear indication of the students' understanding of controlling variables, but also increased the students' insight of the skills involved in planning and carrying out future investigations.

In **CS2 United Kingdom**, the teacher used a 4-level rubric, shown in Table 6 to assess students' skills of *developing hypotheses* (inquiry questions), *planning investigations* (to test hypotheses), *working collaboratively* (communication) and *scientific reasoning* (analysis and conclusion, evaluation, critical thinking). During the lesson the teacher circulated and tried to assess all of these skills. This was not always easy, but it helped the teacher when marking the students final poster presentation. The hardest skill to mark was their critical thinking, as this was difficult for the students to demonstrate on their poster. The student posters were peer-assessed by another group, who provided feedback on a sticky note on the poster. The groups were instructed to provide constructive feedback that highlighted the positives and possible areas for development on sticky notes. The teacher then marked the posters and reviewed the peer-assessment, which allowed her to ensure that students understood the criteria used for the assessment of these activities. The teamwork skills were self-assessed using a grid of skills, which were introduced at the start of the activity. The teacher ensured that students knew what each skill meant and the importance of these group skills as crucial life skills they will need when they leave school was emphasised. The students then self-assessed their group skills at the end of the planning stage (first lesson) but were restricted to identifying three skills that they believed they had demonstrated. They also had to justify why they felt they had demonstrated that skill. At the start of the second lesson, they returned to their grid and had identified three skills that they would work on in the lesson. This was again reviewed at the end of the lesson. Feedback to the students was provided in the following ways:

- Oral feedback through questioning during the lessons
- Written feedback in the form of brief questions after the planning lesson
- Peer-assessment of the final poster
- Self-assessment of group skills at the end of lesson 1 and 2
- Teacher marking of the final work and a competency level assigned.

In **CS3 Germany** *developing hypotheses* proved difficult for some of the students at the beginning of the first lesson. In the second investigation period (How can you protect yourself against the sun's ultraviolet rays?) the teacher reported that students could more easily formulate hypotheses or presumptions and carry out investigations. The difference in quality of planning and carrying out investigations were mainly observed in the grading of students' reports. Most groups worked in an explorative way. Only some students connected the steps of formulating hypotheses and examination in an appropriate way. A final assessment was made based on poster presentations, which encompassed the hypotheses and experimental approaches of each student group. Before the class, the teacher reviewed the provided rubrics and became familiar with the levels of performance. However, the teacher was unable to use the rubrics because she had no time to assess the students during the experimental process. The teacher's conclusion was that the rubrics could be used in a team teaching situation (two teachers) or should be adapted as a self-assessment tool. The teacher focused on the assessment of the skill of *planning investigations* (and carrying out an investigation). These skills were assessed by observation, progress reports written during the investigation and evaluation of the students' poster presentations.

Table 6: Teacher rubric for the assessment of inquiry skills in CS2 United Kingdom

Inquiry skill	Emerging	Developing	Consolidating	Extending
Asking inquiry questions **Developing hypotheses**	Discusses some testable questions and agrees on one that they feel is feasible.	Raises a testable question with reasoning from previous scientific knowledge or experiences.	Raises a testable question and forms a hypothesis, which is explained with clear reasoning.	Raises a testable question that forms a hypothesis and explains what results to look for to prove or disprove their theory. Their reasoning is backed up by scientific ideas.
Planning investigations **Testing hypotheses**	The method involves changing one factor and measuring the outcome but little attention has been paid to controlling variables.	The method changes only one factor and measures the effect. Controlled variables are identified but some are not present or detail of how they were controlled is not given.	The method changes one variable and identifies the major controlled variables. Some detail of how the variables are controlled is provided (but there are better methods available or all the methods aren't workable).	All possible controlled variables are identified and are carefully controlled or monitored to ensure a fair test. Takes steps to ensure that the results are as accurate as possible. The method is clear and rigorous. Uses a control to compare their results to.
Communication	Describes what they did to test their ideas.	Describes what they set out to test and presents their results.	Explains and presents their results and how they tried to be rigorous.	Explains what they set out to test, presents their results and discusses their confidence in the results and suggests possible improvements.
Analysis and Conclusion	States the results and suggests a pattern (or lack of pattern).	Presents the results, identifies a pattern (or lack of) and attempts an explanation.	Presents the results clearly, correctly identifies a pattern (or lack of) and explains it using sound reasoning. Attempts to comment on the quality of the results (whether it is a clear pattern or less clear).	Attempts to quantify the outcome so that it is less subjective. Presents the results clearly and states the strength of pattern in the results clearly. Forms a conclusion and fully explains it using scientific understanding. Does not overstate results and patterns (e.g. emphasising patterns that are barely there).
Evaluation	Comments on the accuracy of the results or suggests vague errors (e.g. human error).	Identifies at least one source of error and how this could be improved in the future. Possibly considers the number of repeats.	Makes a valid comment on the reliability and accuracy of the experiment, with reference to the results. Identifies any anomalies. Identifies more than one source of error and suggests improvements.	Critically assesses the reliability of the results. Comments on the subjective nature of the outcome and suggests improvements to make it more objective. Identifies almost all of the flaws in the method and suggests improvements that will have a positive effect.
Critical thinking		When one idea is not successful, the group come up with another idea without analysing why the first has failed.	The group look critically at their ideas and consider how to improve their design, sometimes with significant changes.	The group look for ways of improving the design by refinement or by comparing with a different approach. They think critically about what will and will not work. They evaluate their experiences to inform changes.