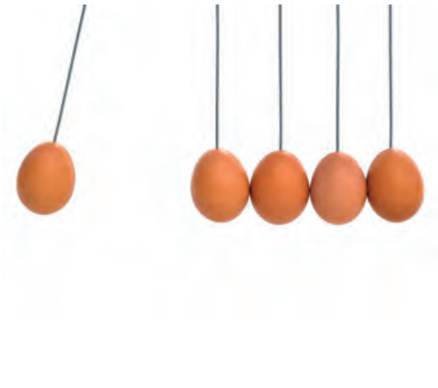
SAILS

Strategies for Assessment of Inquiry Learning in Science



SAILS INQUIRY AND ASSESSMENT UNITS

VOLUME TWO

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SAILS Inquiry and Assessment Units

Volume 2

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ABOUT SAILS

The SAILS project is a European project funded by the European Seventh Framework Programme (FP7) involving fourteen partner organisations, including universities, SMEs and a multi-national organisation, from across twelve European countries (Belgium, Denmark, Germany, Greece, Hungary, Ireland, Poland, Portugal, Slovakia, Sweden, Turkey and the UK). The strength of this consortium lies in its vast experience and expertise in the areas of science education, teacher education and development of resources for teaching, learning and assessment. The overall aim of the SAILS project was to promote and facilitate the use of inquiry based approaches in the teaching, learning and assessment of science across Europe with second level students.

Through the collaborative efforts of the partners, the SAILS project (2012-2015) has:

- Enhanced and developed IBSE teaching and learning materials by incorporating inquiry assessment strategies and frameworks;
- Partnered with teachers to identify and implement assessment strategies and frameworks to evaluate key IBSE skills and competences in the classroom;
- Provided teacher education programmes on inquiry and assessment of inquiry for pre-service and in-service teachers in IBSE;
- Supported teachers to share experiences and practice of inquiry approaches to teaching, learning and assessment – by supporting a community of practice;
- Promoted the use and dissemination of inquiry approaches to teaching, learning and assessment with national and international stakeholders.

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Malmö University, Sweden

Kristianstad University, Sweden

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SAILS APPROACH TO INQUIRY AND ASSESSMENT

This collection of ***SAILS Inquiry and Assessment Units*** showcases the benefits of adopting inquiry approaches in classroom practice, exemplifies how assessment practices are embedded in inquiry lessons and illustrates the variety of assessment opportunities/processes available to science teachers. In particular, the units provide clear examples for teachers of how inquiry skills can be assessed, alongside content knowledge, scientific literacy and scientific reasoning and illustrate the benefits of various types of assessments. More specifically, the units presented show how evidence of student learning can be collected and evaluated through a variety of methods, e.g. classroom dialogue, teacher observation, presentations, peer-assessment, self-assessment, student artefacts, use of assessment rubrics, etc. These SAILS Units are presented so as to be informative for teachers, relevant to classroom practice and include illustrative examples of assessment items and criteria used to evaluate student learning.

The Strategies for Assessment of Inquiry Learning in Science (SAILS) project was funded under the EU Framework Seven programme (2012-2015) to support teachers in adopting inquiry based science education (IBSE) and assessment of inquiry skills and competencies in science at second level across Europe. The SAILS team have successfully developed and provided professional development programmes for second level science teachers, both in-service and pre-service, that support teachers in understanding how inquiry approaches can be encouraged and facilitated in the classroom. In particular the SAILS teacher education programmes supported teachers in using assessment strategies to make judgments and give feedback to their students on how to improve their learning. In this way, the SAILS project has prepared science teachers from across Europe, not only to be able to teach through IBSE, but also to be confident and competent in the assessment of their students' learning in an inquiry classroom.

Inquiry skills are what learners use to make sense of the world around them. Inquiry provides both the impetus and experience that helps students acquire problem solving and lifelong learning skills. These skills are important both to create citizens that make informed decisions and to develop scientific reasoning for those students whose career choices require the logical approach that science encourages. An inquiry approach can also help students develop deeper conceptual understanding and encourages students' motivation and engagement with science.

In carrying out this project, SAILS focussed on supporting the development of six scientific/inquiry skills and competencies: developing hypotheses; working collaboratively; forming coherent arguments; planning investigations; scientific reasoning and scientific literacy. The SAILS team identified and selected inquiry activities that promoted these skills and competences and developed assessment strategies appropriate for each skill and/or competency highlighted in these activities. In this way, the inquiry approach, development of the skill and its assessment were combined and presented as draft (inquiry and assessment) units that could be used by teachers for trialling in the second level science classroom.

Following evaluation with science teachers experienced with inquiry in each country, draft units were selected (based on a range of inquiry skills, subject areas and assessment methods) for further development and trialling in classrooms. These draft units were trialled in over 100 second level classrooms, each unit across at least three different countries and the feedback from teachers was collected in the form of case study reports. The outcomes of this dynamic collaboration between SAILS partners and teachers has led to the presentation of nineteen ***SAILS Inquiry and Assessment Units*** that describe the inquiry approach used to develop and assess a particular skill/competence in classroom practice. In addition, the ***SAILS Framework for Inquiry and Assessment*** has been developed to describe each of the inquiry skills and competencies focussed on, and to present the assessment strategies used for the assessment of that skill/competence, along with illustrative examples from across the disciplines of science and classroom-based assessment practices.

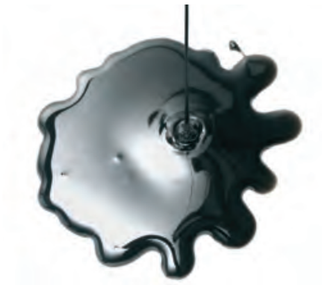
The ***SAILS Inquiry and Assessment Units*** show that a range of assessment methods can be used to assess inquiry skills. As demonstrated in the case studies, the SAILS units can be adapted to focus on other skills that the teacher may wish to develop. The assessment criteria used can also be modified to suit the student age and their experience level with inquiry. The assessment criteria might also be shared with the students so that they develop their experience with self-assessment or peer assessment. Within each unit, the key content/concepts covered are outlined as well as the main inquiry skills and assessment strategies. The first section in each unit provides the unit outline in terms of content and concepts covered. The second section gives ideas on how the activities can be implemented and how the skill/competency involved can be assessed. The third section provides a synthesis of the case studies of the implementation of the unit across at least three countries, in terms of the teaching approach and the assessment strategies. It is clear from the case study syntheses that teachers have adapted and adopted many different assessment strategies to assess the same skill. The case studies themselves provide a narrative of how the teachers approached inquiry within the unit, how feasible the lesson was with the chosen class and how they assessed the success of their learners. It also highlights any issues encountered, relating to cultural perspectives and other equity issues, such as gender.

The collection of nineteen ***SAILS Inquiry and Assessment Units*** has been published in two volumes by the SAILS partners and electronic versions of these units, case study reports and relevant classroom materials are available for download from the project website: www.sails-project.eu. These units and other related project outcomes are freely provided to disseminate to teachers and educators how inquiry approaches can be implemented and assessed in the second level science classroom. These units provide evidence that each inquiry skill and competence focussed on in the SAILS project can be readily assessed.

When using these units, teachers are encouraged to adapt the activities to suit their own particular classroom context. In particular, key advice for classroom implementation, as evidenced through the case studies from teachers, are that:

- Teachers should select which skill/competence to focus on, 2-3 at most, within an inquiry lesson.
- Multiple sources of evidence should be used to map student learning and progress
- The use of indicators of progress is invaluable for students as well as teachers in assessing learning progression of a skill/ competence.

Through the collaborative efforts of the partners, the SAILS project (2012-2015) has showcased how inquiry approaches can be used for teaching a range of science topics, and has supported science teachers becoming confident and competent in the assessment of their students' learning through inquiry. More than 2500 science teachers in 12 countries have participated in SAILS teacher education programmes. These teachers have strengthened their inquiry pedagogy and assessment practices by developing their understanding of the role of assessment.



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Eilish McLoughlin, Dublin City University (DCU), Ireland

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Morten Rask Peterson, University of Southern Denmark (SDU), Denmark

POLYMERS
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Mária Ganajová, Univerzita Pavla Jozefa Safárika v Kosiciach (UPJS), Slovakia

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Gábor Veres, Csaba Csíkos, University of Szeged (US), Hungary

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How to live on the International Space Station?

Vanessa de Andrade, Mónica Baptista, Cláudia Faria, Cláudia Gonçalves, Cecília Galvão, Instituto de Educação da Universidade de Lisboa (IEUL), Portugal

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Mats Lundström, Malmö University (MaH), Sweden

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Christine Harrison, King's College London (KCL), United Kingdom

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Katarína Kimáková, Univerzita Pavla Jozefa Safárika v Kosiciach (UPJS), Slovakia

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Odilla Finlayson, Dublin City University (DCU), Ireland

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INQUIRY AND ASSESSMENT UNIT

BLACK TIDE – OIL IN THE WATER

Oil in our waters – cleaning up our mess!

Cláudia Faria, Cláudia Gonçalves, Cecília Galvão

BLACK TIDE – OIL IN THE WATER

OIL IN OUR WATERS – CLEANING UP OUR MESS!

Overview

KEY CONTENT/CONCEPTS
- The effects of an oil spill on our coast
- Chemical mixtures (behaviour of oil in water)
- Equilibrium of ecosystems

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 (defining variables)

ASSESSMENT METHODS
- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials (investigation plan, photographs of investigations)
- Presentations

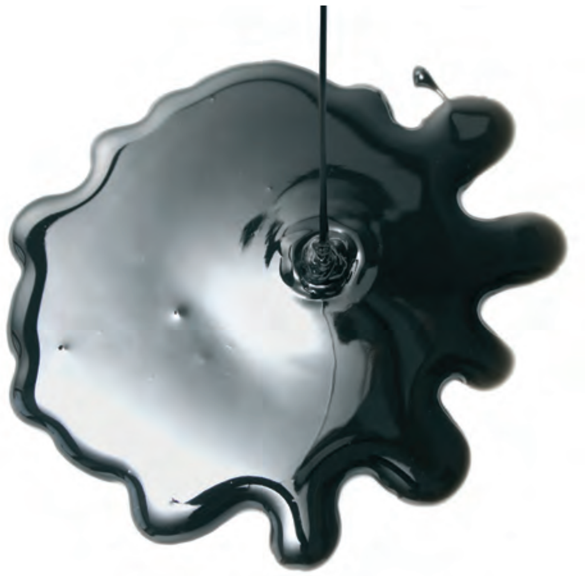
Classroom materials for this Inquiry and Assessment Unit are available at WWW.SAILS-PROJECT.EU

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – BLACK TIDE – OIL IN THE WATER

The **Black tide – oil in the water** SAILS inquiry and assessment unit focuses on the study of the effects of an oil spill on our coast. Students investigate an oil spill using a model system to simulate the behaviour of oil in water and identify factors that influence the spread of oil. Students can consider the ecological impact of an oil spill, and the challenges that they pose to scientists and society. This unit is recommended for implementation at lower second level, as a *bounded* or *guided inquiry*.

This unit can be used for development of many inquiry skills, in particular *planning investigations, developing hypotheses* and *working collaboratively*. In addition, students can develop their *scientific reasoning* skills through collecting data and drawing conclusions, and enrich their *scientific literacy* by critically evaluating their investigations. Proposed assessment methods include teacher observation, student artefacts and peer- and self-assessment.

This unit was trialled in Portugal, Hungary, Germany and Greece – producing five case studies of its implementation. Four case studies describe the experiences of teachers with lower second level students, while one Hungarian implementation was with upper second level students. Students in the case studies were aged 12-16 years and of mixed ability and gender. *Planning investigations* was assessed in four of the case studies, while *developing hypotheses* and *working collaboratively* were also assessed in some cases.



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 **Black tide – oil in the water** SAILS inquiry and assessment unit were adapted from the iLit project [1], developed by Cláudia Faria at the Instituto de Educação da Universidade de Lisboa (IEUL) and adapted for the SAILS project.

Concept focus	The effects of an oil spill on our coast Chemical mixtures (behaviour of oil in water) Equilibrium of ecosystems
Inquiry skill focus	Developing hypotheses Planning investigations Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (identification of variables) Scientific literacy (identifying the consequences of oil spills on ecosystems)
Assessment methods	Teacher observation Worksheets Student devised materials (experimental plans)

Rationale

Since the 1970s, oil spills in the ocean have been frequently in the news. The Amoco Cadiz accident, which occurred in the French administrative region of Brittany in March 1978, is one of the most well-known. This disaster spilled 1.635 million barrels of oil, equivalent to about 220 tons. The Exxon Valdez accident, discussed in this unit, spilled 260 thousand barrels, or about 35 tons. The consequences of such spills for living species (including human beings) and ecosystems are dramatic. This activity aims to explore some of these consequences, allowing students to increase their *scientific literacy* while developing their inquiry skills. This activity aims to contribute to:

- Development of an ecological consciousness,
- Understanding the ecological impact of oil spills,
- Understanding of inquiry processes, in particular *planning investigations*
- Promotion of thinking skills, attitudes and values that enable students to take an active role in decision-making about socio and environmental concerns.

Skills which can be developed during this activity include *planning investigations, developing hypotheses* (identifying scientific questions and putting forward hypotheses), carrying out experiments, *forming coherent arguments* (drawing conclusions using reasoned arguments and evidence), *scientific reasoning* (consideration of the influence of various factors) and *working collaboratively* (collaboration and cooperation), all of which enrich students' *scientific literacy*.

Suggested learning sequence

The **Black tide – oil in the water** SAILS inquiry and assessment unit is recommended to be implemented as a *bounded or guided inquiry*, and suggested student worksheets are detailed. The task should be investigated by groups of 3-4 students, with mixed abilities and genders where possible. In this way, the groups can benefit from multiple perspectives and each student should be able to carry out a comprehensive reflection on their skill of *working collaboratively*. The teacher should take care to guide students through questioning, providing suggestions to guide their progress, but not to give definitive answers during the period in which the students are working in groups. Whole-class discussions can be useful, where the teacher can assist with any problems that arise. In this situation, it is preferable to first give students the opportunity to speak, thus each group can present its contribution to the general discussion.

This unit develops over four phases; first, the students engage in discussion about the topic of the lesson – how does oil behave when spilled in the ocean? Next, the students plan an experimental activity to investigate this question, which they implement once the teacher has approved the method. This allows for formative assessment of the work plan, and an opportunity to identify any problems or misconceptions that may arise. For the third phase, students can relate their experimental simulations to a real-world context, i.e. the factors that affected the spread of oil following the Exxon Valdez oil spill. The final phase seeks to further students' knowledge of the impact of an oil spill on the environment, and the associated social and economic effects.

There are several underlying objectives to the set of questions outlined on the student worksheets, such as discussion of topics related to the immiscibility of two liquids, but also the promotion of students' familiarity with scientific procedures:

1. To begin the inquiry, students are introduced to the topic by reading an introductory text (Figure 1). The students can engage in a brief discussion about the topic, prompted by the question, "What happens to the oil spill in the ocean?" This gives them an opportunity to engage with the topic and review their prior knowledge. They can begin to develop research questions.
2. Next, the students are asked to plan an experiment to investigate the research question. They can be given a worksheet, which provides guidance through a list of materials and some suggested parameters for investigation (Figure 2).

[1] Between tide marks: Integrating Literacy's (iLIT), funded by the Portuguese Foundation for Science and Technology (FCT), https://www.fct.pt/apoios/projectos/consulta/vglobal_projecto.phtml.en?idProjecto=117923&idElemConcurso=4231 [accessed October 2015]

Black Tide – Oil in the Water

Student's document

Introduction: Since the mid-nineteenth century, when we learned to distil oil and separate it into various components such as gasoline, diesel, kerosene (fuel used in airplanes) and oil tar, demand for oil worldwide has been increasing. Since it is a natural resource that is not evenly distributed across the planet, it is necessary to transport it from the countries of production to where it is consumed. One of the main ways to transport oil is by sea. For this, large ships equipped with big reservoirs, known as tankers, are used, which can reach over 400 m in length with a capacity exceeding 500 000 tons of oil.

The oil is a viscous black liquid and when a tanker has an accident, the oil may be spilled at sea and its removal is very difficult. Recently, scientists have been working to find ways to remove spilled oil from water, but have not had much success. What happens to the oil spill in the ocean?

How does oil behave when spilled into the ocean? To answer to this question, you have to plan and carry out experiment(s) to investigate the behaviour of oil when poured into a mass of water.

1. Think, with your colleagues, of possible answers to the previous question.

Figure 1: Student worksheet, page 1 – introductory text

2. Now **plan**, **in groups**, **an experiment** that helps you to find an answer to the previous question. On the laboratory bench, you will find some materials and equipment, listed below, that can be used in your planning. You must take into account the different natural factors that interfere with the ocean's activity – currents, waves, winds – and consider them in your planning.

Materials: *Glass or plastic bowls, spoon, water, oil (such as vegetable oil or "simulated oil," prepared by mixing 12 tablespoons of vegetable oil and 8 tablespoons of cocoa powder).*

If you need other materials that are not in the list above, please request these from your teacher.

When planning the experiment don't forget to identify the different variables:

- the independent variable (what you change during the investigation),
- the dependent variable (what you will measure or observe), and
- the controlled variables (what you are you going to keep constant).

2.1. **Discuss** your group's experimental plan with the teacher, before you carry out the experiment.

2.2. **Write down what you predict will happen** as a result of the experiment that you have planned. **Present a justification** for this prediction.

2.3. In your group, **carry out the experiment**.

2.4. **Record** the results.

2.5. **Compare** the prediction presented in question 2.2 with the obtained results. Do you need to re-evaluate your initial prediction?

2.6. **Explain** the results registered in question 2.4. If needed, you may consult literature or websites that help you build an explanation.

2.7. **Answer** the initial question: ***How does oil behave when spilled into the ocean?***

Figure 2: Student worksheet, page 2, Question 2

Question 2 consists of seven sub-questions, which guide the students through the planning and implementation process. The teacher should ensure that students understand the role of the materials used in the simulation, and allow them to identify some limitations of the model. Students should be aware of the key aspects involved in an experimental activity, in particular careful recording of data throughout the process, isolation of variables that are being tested (presence/absence of oil) and use of a control system. For example, as a control when investigating the effect of currents, waves or wind, students should repeat the entire procedure with undisturbed oil in the water.

3. Question 2.1 allows the teacher to analyse the students' plans and assess the feasibility and adequacy of the experimental protocol (Figure 2). Two distinct types of problems may arise: (1) the experimental plan does not answer the research question, or (2) the plan contains procedures that are difficult or impossible to implement. In both situations, the teacher should ask questions and give clues to help/allow the students to be able to solve the question.

4. Question 2.2 asks the students to make predictions and to justify their predictions (Figure 2). This is an opportunity for the teacher to assess students' skills in *developing hypotheses* and *forming coherent arguments*. The hypothesis (prediction) should be related to the experimental plan, and the investigation carried out (Question 2.3) and the results obtained (Question 2.4) should be used to test the hypothesis (Question 2.5).

5. It is recommended that students can approach their experimental work as a way of testing the falseness of a hypothesis, instead of focusing only on verifying that a hypothesis is true. While students often focus on getting the "right answer," it is equally valid to disprove an incorrect hypothesis and this is an opportunity to introduce this concept to the students.

6. In Question 2.6, students are asked to explain their results, which can be supported using references to literature or websites (Figure 2). This activity offers an opportunity for the assessment of students' skill in *forming coherent arguments*, and can also allow for evaluating students' ability to search for information.

7. In the final part of Question 2, the students draw conclusions (Figure 2). They should use their results to support their conclusions and relate the conclusions to the original prediction from Question 2.2.

8. Once the experimental process is complete, students should consider Question 3 (Figure 3) and Question 4 (Figure 4). These questions allow the students to go further in exploring the problems related to oil spills in the ocean. This time, however, the teacher can choose to emphasise other procedural aspects of science, in particular the interpretation and use of third party data, the use of technological tools to search and the establishment of relations between science, technology and society

9. Using the *Exxon Valdez* case as a real-life example of an oil spill, in Question 3 students are shown a map of the area affected by the oil spill (Figure 3). The map units are presented in the imperial system, so the teacher can ask the students to convert these units to metric. There

3. In the following figure you can observe the area affected by the oil spill released from the *Exxon Valdez* tanker during an accident that occurred on March 24, 1989 near Valdez town, Alaska. The sea regions demarcated in blue (or light grey) denote the area affected over the 56 days following the accident.

(Exxon Valdez Oil Spill Trustee Council - http://www.evostc.state.ak.us/)

This map shows the distances in imperial units (miles). For a better understanding of the scale of this disaster it is useful to convert these values to kilometres, since you're more familiar with this length unit. Knowing that 1 mile = 1.61 km, convert and register the values in the map. Convert the value of the affected area indicated in the map legend to km^2. Confirm the results with your teacher.

3.1. Based on the conclusions you made from your investigations, explain the expansion of the oil spill from the Exxon Valdez.

3.2. Find a justification for the statement from the text: "In recent years, scientists have been working to find ways to remove the spilled oil from the water, but have not had much success."

3.3 To get a better idea of the extent of the spill, use Google Maps to find the location of the spill and make an image similar to that shown in the figure.

Figure 3: Student worksheet, page 3, Question 3

4. As you can imagine, the *Exxon Valdez* oil spill had not only an environmental impact, but also economic and social effects. Search for information on the implications of this accident on marine life and human populations in the affected coastal areas. Write a story for a newspaper telling what happened, the adverse consequences of the accident and the effect it had on the establishment of new rules for the transport of oil at sea.

Image of the Exxon Valdez (Wikimedia Commons)

Figure 4: Student worksheet, page 4, Question 4

are two possibilities for this conversion: (1) calculate the extension using the scale and (2) ask the students to find the conversion ratio and use it in calculations. The teacher's decision should take into account the contexts where the task will be applied and the time that will be devoted to it. Question 3 consists of three sub-questions. Question 3.1 seeks to allow students to transfer the knowledge gained in their experimental tasks to a real-world context. In addition, they can learn more about the challenges faced by scientists during the clean-up activities where the oil spill occurred, and gain a greater understanding of the far-reaching effects of such an accident.

10. Finally, in Question 4 (Figure 4), students are encouraged to consider the economic and social impact of an oil spill. This can increase their understanding of the role of science in society, and offers an opportunity for students to develop coherent arguments and to search for further information.

2.2 Assessment of activities for inquiry teaching & learning

As detailed in the suggested lesson sequence, this unit offers opportunities for the assessment of all SAILS inquiry skills (*planning investigations, developing hypotheses, forming coherent arguments, working collaboratively*) and key competencies (*scientific reasoning, scientific literacy*). The teacher may carry out the assessment in class through observation and classroom dialogue, or utilise the student worksheets for evaluation. The assessment should be based on aspects such as understanding the terms and concepts involved, full development of the experiment (planning and implementing), correct handling of materials and equipment, accuracy in recording data and adequacy of the proposed experimental protocol (variables tested experimentally and answers to questions).

In addition to developing students' inquiry skills, students can gain substantive and procedural knowledge. After carrying out the tasks in this unit, students should be able to explain the behaviour of oil in water, plan experiments and record data appropriately. Through development of their reasoning capabilities, students should be able to interpret data and make inferences. In addition, they should be able to communicate scientifically, using appropriate language and presenting data and ideas in different ways. This inquiry should encourage students to be curious and creative and to pursue their investigations with rigour and perseverance.

Even though this activity presents many assessment opportunities, a teacher's guide was devised that focused on assessment of two inquiry skills – *planning investigations* and carrying out an investigation. This assessment tool was built with teachers' cooperation, using the following guidelines:

Purpose: During this activity, it is intended that students will learn the scientific content associated with the behaviour of oil in water and the effect of oil spills on ecosystems, as outlined in the unit. This unit allows students to develop several inquiry skills; however, for the data collection about the assessment process it will be focused on *planning investigations* (and carrying out an investigation).

Teacher actions

1. Before class
   a. Build an assessment instrument for the inquiry skill(s) to be assessed. For example, Table 1 details a rubric for use where the main focus is the assessment of students' skills in *planning investigations* and carrying out an investigation.
   b. Adapt the task for your students and for the context.

Table 1: Assessment tool for planning investigations

Actions	1	2	3
Define goals	Does not define coherent goals according to the proposed problem.	Defines some coherent goals according to the proposed problem.	Defines coherent goals according to the proposed problem.
	Does not operationally define the variables.	Defines, with some difficulty, the variables of study.	Operationally defines the variables of study.
Define strategies and procedures	Does not define the necessary strategies and procedures to achieve the goal.	Defines, with some difficulty, the necessary strategies and procedures to achieve the goals.	Defines the necessary strategies and procedures to achieve the goals.
	Unclear planning requiring reformulation.	Planning well presented but requiring reformulation.	Clear, concise and complete planning.
Choice and use of resources	Does not select adequate resources according to the goals and strategies.	Selects some resources that are adequate for the goals and strategies.	Selects the resources that are adequate for the goals and strategies.

2. In class
   a. At the beginning of the process, clarify the assessment criteria (in particular those relating to the chosen inquiry skills).
   b. At the end of the process, apply a semantic differential to students for identification of their perceptions related to the assessment process.
3. After class
   a. Assess students' artefacts (worksheets, experimental plans), having regard to the assessment tool developed and produce written formative feedback,
   b. Reflect on the assessment process.

Note: Evidence collected can include student artefacts, classroom video recording (optional) or other evidence.

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in four countries, producing five case studies of its implementation – **CS1 Portugal**, **CS2 Hungary**, **CS3 Hungary**, **CS4 Germany** and **CS5 Greece**. All the case studies were implemented by teachers who had some experience of teaching through inquiry and most of the students had prior experience of inquiry activities. However, in **CS1 Portugal** and **CS5 Greece**, the students had no prior experience with inquiry.

The case studies detail implementation at lower second level, except in **CS3 Hungary**, which features a 9th grade class (upper second level). The students involved in the case studies were 12-16 years old and of mixed ability and mixed gender. In **CS1 Portugal**, the student group represented a very good performance level in school achievement.

CS2 Hungary and **CS4 Germany** describe two lesson periods of 45 minutes each. **CS3 Hungary** describes one lesson of 45 minutes, plus a double lesson period of 90 minutes. **CS1 Portugal** describes four 90-minute lesson periods, while **CS3 Greece** was implemented over three 45-minute lessons.

The key skill assessed was *planning investigations*, but the teachers in the case studies also selected additional skills to develop. The assessment methods described include classroom dialogue, teacher observation, evaluation of student artefacts and peer-assessment.

3.1 Teaching approach

Inquiry approach used

The inquiry approach used in all the case studies was that of *bounded inquiry*, i.e. it was guided in the sense that the teacher posed the initial question but there were open inquiry opportunities in that students had freedom in addressing the question. For example, the unit activities start with the introduction of an environmental problem, and the students are asked to plan an experiment related to this problem. This can be totally open (students propose a full experimental plan and implement their plans) or can *be guided* (students propose and discuss an experiment, but follow a given protocol for implementation).

Implementation

This activity aims to contribute to the understanding of inquiry processes, such as experimentation and argumentation, and to the promotion of thinking skills, attitudes and values required for students to take an active role in decision-making about socio and environmental concerns. The activities of this unit can be used to integrate different curricular subjects (physics, chemistry, biology, geography, mathematics, environmental education).

The students in all the case studies worked in groups throughout the lessons, although group composition varied (Table 2). In **CS3 Hungary**, the students were from an upper second level grade, however for the other cases the students were all lower second level, as recommended in the unit. Most classes and groups were reported to be of mixed ability and gender. In particular in **CS3 Hungary** the teacher describes the support required for some students with emotional and behavioural difficulties and with special educational needs. In **CS3 Hungary**, the unit was implemented in the context of the formation and use of sedimentary rocks, their mining and the environmental effects of transportation in geography.

Most case studies implemented the unit without significant alterations. In all case studies, except in **CS4 Germany**, a worksheet was provided to the students. This was quite unstructured, similar to the one provided in the activities for inquiry teaching & learning section of this unit. Implementation in **CS4 Germany** was part of a special science course – "Science Experiments" – which is taught in parallel to regular science classes. In this case study, the teacher mentions using the "marketplace method" for group discussions, where the groups showcase their ideas and plans for experiments, and students can go from group to group to look at the plans.

Adaptations of the unit

In some case studies the teachers made some adaptations to the unit, so that the tasks were more suited to their student groups or curricula. For example, while the teaching and learning activities described in the unit focus on observation skills during the experimental phase, in **CS2 Hungary** the students also

Table 2: Summary of case studies

Case Study	Duration	Group composition
CS1 Portugal	Four lessons (90 min each)	• Groups of 3-4 students (20 students) • Student selected; mixed ability
CS2 Hungary	Two lessons (45 min each)	• Groups of 3-4 students (23 students)Student selected; mixed ability and gender
CS3 Hungary	Two lessons (1x45 min, 1x90 min)	• Groups of 4 students (20 students in total) • Student-selected; mixed ability and gender, some single-sex groups (all-girls)
CS4 Germany	Two lessons (45 min each)	• Student worked in pairs (10 students in total) • Mixed ability and gender (5 boys, 5 girls) • Student-selected course "science experiments"
CS5 Greece	Three lessons (45 min each)	• Groups of 3-4 students (17 students in total) • Teacher assigned groups; mixed ability and gender

collected data through physical measurements of surface area and volume of the simulated oil spill.

The unit as outlined focuses primarily on the behaviour of oil in water. However, this unit may also be used to discuss environmental considerations, as shown in **CS3 Hungary** and **CS5 Greece**. In **CS3 Hungary**, students studied the consequences of an oil spill on life in the sea and the human settlements along the affected coastline. In **CS5 Greece**, the students dipped a feather in the oil water, and tried to find a good cleaning agent to remove oil from the bird feathers. In **CS5 Greece**, the students watched some introductory videos at the start of the lesson, after which the topic for investigation was introduced.

CS4 Germany describes the most significant adaptation to the unit, whereby the teacher focused the problem on oil pollution and potential methods for clean up. The students did not use a worksheet, and the implementation was very open. As a result, the students investigated a range of factors related to oil spills, and in particular to methods for removal of oil from water. One group investigated the topic of removal of oil, while another group looked at the effect of oil on feathers, wool and sand. A third group "invented" a technique for the removal of oil from water and a further group tried to burn the oil on the water surface.

3.2 Assessment strategies

The **Black tide – oil in the water** SAILS inquiry and assessment unit was recommended to teachers for the assessment of *planning investigations and scientific reasoning*, however implementation has shown that this activity is appropriate for the assessment of the four SAILS inquiry skills – *planning investigations, developing hypotheses, forming coherent arguments, working collaboratively* – and *scientific reasoning*, as outlined in Table 3. Although the skills developed during these activities are valuable contributors to a students' overall *scientific literacy*, no teacher chose to assess this dimension in the case studies. However, within the case studies, the students' increase in understanding of both the properties of oil in water, and how the experiment provides a model of a real-world oil spill is observed.

Table 3: Inquiry skills identified by teachers in the case studies

CS1 Portugal	• Planning investigations
CS2 Hungary	• Planning investigations • Working collaboratively • Scientific reasoning (defining variables)
CS3 Hungary	• Developing hypotheses • Planning investigations • Working collaboratively
CS4 Germany	• Planning investigations
CS5 Greece	• Planning investigations • Forming coherent arguments • Working collaboratively

The assessment was conducted through the analysis of students' artefacts in almost all case studies, which included worksheets (all case studies, except **CS4 Germany**) and presentations (**CS5 Greece**). The teacher also assessed students' skills through direct observation of students working in groups, for example in **CS2 Hungary**. Some teachers used rubrics for in-class evaluation of performance (**CS3 Hungary**), although they may also be used for evaluation of student artefacts after the lesson. Peer-assessment was used in **CS4 Germany** and **CS5 Greece**; in both case studies students provided oral comments on the ideas of other students. In **CS5 Greece**, the teacher provided assessment tools for use for peer-review, which helped students understand the assessment criteria. In all case studies, the teacher provided formative assessment through oral feedback, in particular during collaborative work. In some cases, the teacher provided written feedback at the end of the activity.

In **CS1 Portugal**, the teacher used the rubric shown in Table 1 to assess three dimensions of *planning investigations* – defining goals, defining strategies and procedures, and identifying and selecting appropriate resources. The instrument contains three performance levels, where level one corresponds to the lowest level and level three to the highest level. The teacher prepared this tool in advance of the implementation, but did not use it for the first lesson. Instead, she evaluated students' work and provided written comments after the first lesson. In the next lesson, the teacher returned the students' work with written feedback, and they had the opportunity to read the feedback and to ask questions. The teacher then used the assessment tool to follow the development of the students' skill, through questioning students and answering their queries.

In **CS2 Hungary**, the teacher provided formative assessment during the lesson and each group was given oral feedback. Teacher observation was used to assess skills exhibited during group work. The teacher posed three questions at the end of the second lesson: "What variables did you notice during the experiment? Which variable or variables did you think were fixed? To what extent does your experiment support the idea of the group?" and used the responses to these questions for the assessment of students' *scientific reasoning* (ability to identify variables). The assessment criterion was for students to be able to identify the fixed variable in the research problem. However, the teacher observed that they struggled with this concept. The students' work was submitted to the teacher at the end of the second lesson; the teacher evaluated the worksheets while engaging the class in discussion about the activity.

In **CS3 Hungary**, the teacher used both formative and summative assessment. During the lesson, the teacher guided the students with facilitating questions and observed the students' work during the task. The teacher used a 4-level rubric for the assessment of performance in the inquiry skills (Table 4). The groups were given grades based on the collected worksheets and the photographs they took during the activity.

Table 4: Assessment of inquiry skills in CS3 Hungary

Skill assessed	Extending	Consolidating	Developing	Emerging
Working collaboratively (participation)	Always participates in the work and works on the task throughout the class.	Mostly participates in the work and usually works on the task.	Participates in the work but does not make good use of time or spends little time on the task.	Does not participate in the work, does not make efficient use of time or is occupied with something other than the task.
Working collaboratively (cooperation)	Treats others with respect and shares responsibilities.	Usually treats others with respect and shares responsibilities.	Sometimes lacks respect in interacting with others.	Often lacks respect in interacting with others.
Developing hypotheses (research question)	The research question is precise and detailed.	The research question is unambiguous.	The research question is somewhat incomplete.	The research question or its formulation is incomplete or incorrect.
Planning investigations (inquiry process)	The research design is appropriately constructed based on the hypothesis; the experiment gives a complete answer to the research question. The individual steps of the experiment are described accurately. The independent and dependent variables are correctly identified.	The research design is reasonably constructed based on the hypothesis; the experiment gives an answer to the research question. The steps of the experiment are described. Most independent and dependent variables are identified.	The research design is incorrectly constructed based on the hypothesis; there are mistakes in the hypothesis. Some steps of the experiment are described but some crucial details are omitted. Some independent and dependent variables are identified.	The research design is not related to the hypothesis or contains serious mistakes. There are fundamental problems with the experimental procedure. Dependent and independent variables are not identified.

In **CS4 Germany,** the teacher mainly used two different formative assessment strategies – peer-assessment and classroom dialogue. Peer-assessment was relatively informal, where students commented on the ideas of other students when they discussed their ideas for investigations. In addition, the teacher watched, listened and gave advice throughout the unit implementation. Formative assessment was provided on the spot, and focused on specific feedback regarding students' experimental approaches. The teacher did not use rubrics or record criteria in a written format before the unit, although she had a clear idea about her expectations.

In **CS5 Greece**, the teacher used a selection of assessment methods, with an emphasis on formative assessment. During the introductory discussion, the teacher provided formative feedback and posed questions to aid the students in developing their research questions. The teacher used a 3-level rubric to assess students' skill in *developing hypotheses* as poor/needs improvement/good. At the end of the experimental phase, the students used a self-assessment tool to re-evaluate their hypotheses. This was an opportunity to develop their skill in *forming coherent arguments*, and they used a simple form as a guide (Table 5).

Table 5: Re-evaluation of hypothesis (self-assessment tool) from CS5 Greece

The mistake was…			
The correct explanation is …			
	I was right ❐	I edited it ❐	I rejected it ❐

Two peer-assessment opportunities were identified. First, groups exchanged their work plans and their peers assessed the plans using the peer-assessment tool, which details seven criteria for forming judgements on *planning investigations* (Table 6). The teacher reported that students had difficulty using the peer-assessment tool for *planning investigations*, but this was their first experience in inquiry and peer-assessment. In the second case, students used a similar assessment tool to critique their peers' skill in *forming coherent arguments* during their final presentations. In this instance, there were no difficulties reported.

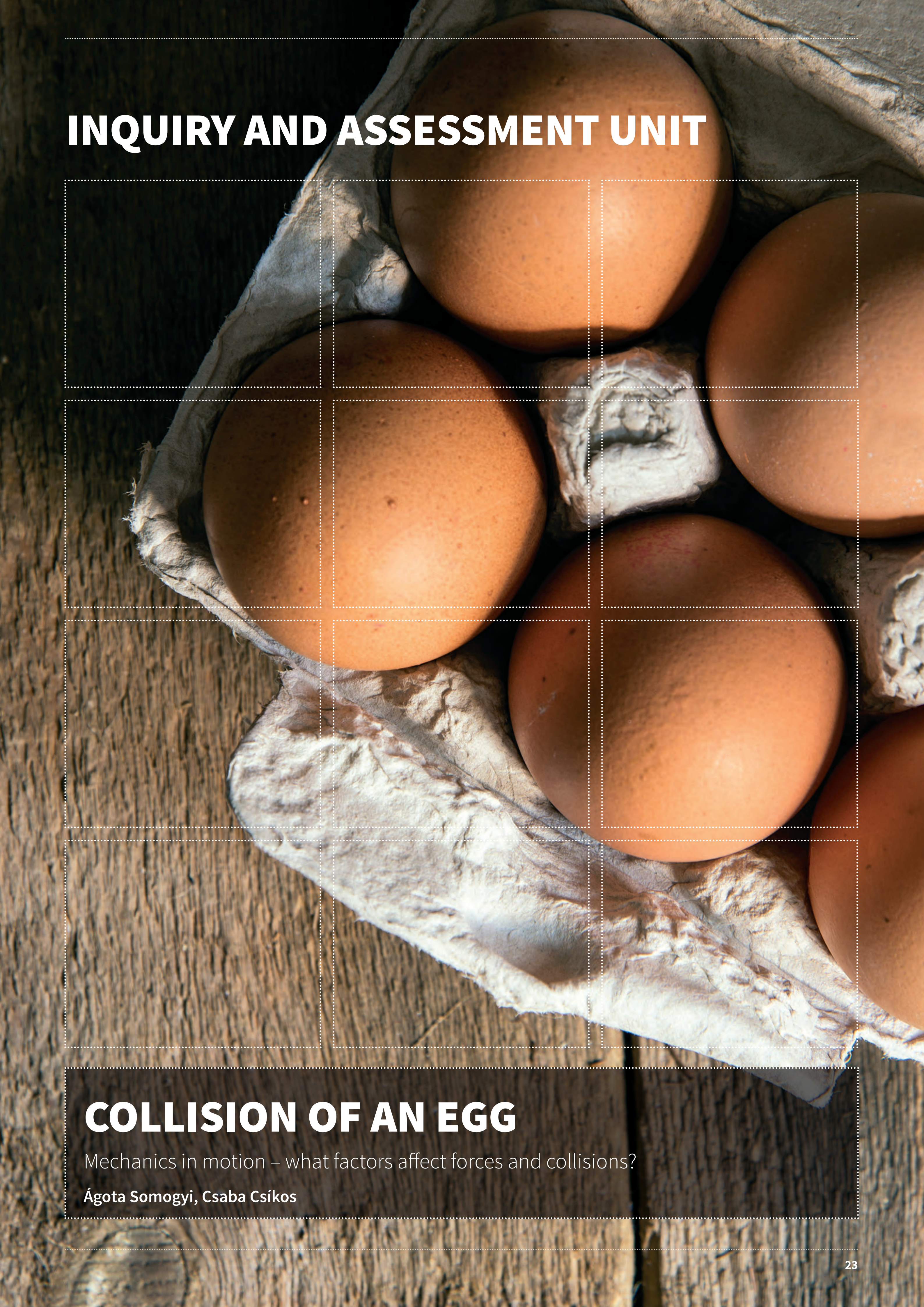
Table 6: Peer-assessment of inquiry plans (planning investigations) in CS5 Greece

Assessment criteria	1 – poor	2 – acceptable	3 – good	Score
1. The description of the plan is clear	No	Needs improvement (some gaps exist)	Yes (no gaps)	
2. The plan includes independent variables	No	Needs improvement (some gaps exist)	Yes (no gaps)	
3. The plan includes dependent variables	No	Needs improvement (some gaps exist)	Yes (no gaps)	
4. The plan includes controlled variables	No	Needs improvement (some gaps exist)	Yes (no gaps)	
5. The plan takes into consideration natural factors (currents, waves, wind)	No	Needs improvement (some gaps exist)	Yes (no gaps)	
6. The plan takes into consideration living beings (such as seabirds)	No	Needs improvement (some gaps exist)	Yes (no gaps)	
7. The plan takes into consideration cleaning issues	No	Needs improvement (some gaps exist)	Yes (no gaps)	
			Total Score	

Students also engaged in self-assessment to evaluate their skill in *working collaboratively* (Table 7). This enabled them to reflect on their strengths and weaknesses when working as part of team.

Table 7: Self-assessment of working collaboratively in CS5 Greece

Assessment criteria	3 - always	2 - sometimes	3 - rarely
1. I actively participated in all discussions of the group			
2. In all discussions I took into consideration the views of all team members			
3. I helped in resolving disputes between team members			
4. I used convincing arguments to support my views			
5. I provided assistance in the team whenever needed			
6. I looked for information on the subject throughout the activity			
7. I completed without delay all the work undertaken to do in the team			



INQUIRY AND ASSESSMENT UNIT

COLLISION OF AN EGG

Mechanics in motion – what factors affect forces and collisions?

Ágota Somogyi, Csaba Csíkos

COLLISION OF AN EGG

MECHANICS IN MOTION – WHAT FACTORS AFFECT FORCES AND COLLISIONS?

Overview

KEY CONTENT/CONCEPTS

- Mechanics – force and momentum
- Collision of a free falling egg with ground surfaces
- Understanding the relationship of egg collisions with daily life situations
- Identification of effects on the forces during collision
- Designing an experiment – identifying variables, taking measurements

LEVEL

- Lower second level
- Upper second level

INQUIRY SKILLS ASSESSED

- Developing hypotheses
- Planning investigations
- Working collaboratively

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

- Scientific reasoning (drawing conclusions, critiquing experimental design)
- Scientific literacy (presentation of scientific data, communicating scientifically)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Student devised materials (experimental plan, graph, documentation of inquiry, recordings, reports)
- Presentations

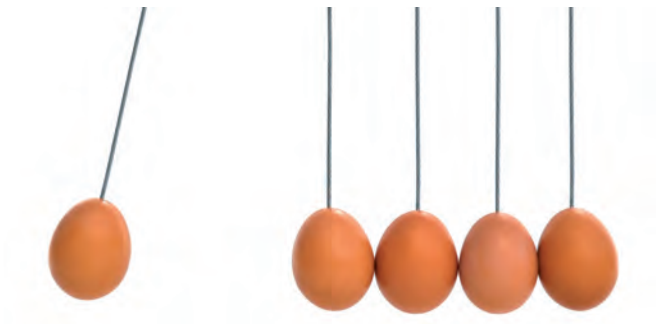
Classroom materials for this Inquiry and Assessment Unit are available at WWW.SAILS-PROJECT.EU

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – COLLISION OF AN EGG

The **Collision** of an egg SAILS inquiry and assessment unit asks students to solve an unstructured problem in the theme of mechanics – "What factors influence forces during collision?" To understand the interactions during a collision, the students study the impacts on an egg. Two approaches are recommended, first to consider "What factors make it possible for the egg to land safely?" and secondly "From how high can you drop an egg into a bucket of flour, without it breaking?" Through this activity, students explore the connection between force and momentum and can apply this knowledge in the context of road safety.

This unit focuses on the inquiry skill of *planning investigations* (designing an experiment), in particular considering variables. In addition, students engage in *developing hypotheses*, and their motivation can be enhanced through immersion in doing science. *Working collaboratively* with peers is important when developing and implementing the research plan. Possible assessment opportunities include teacher observation, evaluation of student artefacts using rubrics and self-assessment.

This unit was trialled by teachers in four countries – Hungary, Denmark, United Kingdom and Germany – producing six case studies (students aged 12-16 years; mixed ability and gender). The teaching approach was open or *open/guided inquiry* in all cases; students were free to plan the experiment but the materials and equipment were provided. Inquiry skills assessed were *planning investigations, developing hypotheses* and *working collaboratively*.



2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The **Collision of an egg** SAILS inquiry and assessment unit was developed by the team at the University of Szeged as part of the SAILS project. In this unit, students are asked to solve an unstructured problem. The theme of the task is that of mechanics, the connection between force and momentum, with some reference to road safety. With consideration to the age group and the background knowledge, the calculations may be skipped.

In this unit, there are several aspects to be considered in the context of inquiry-based learning:

- *Developing hypotheses* (inquiry directed by the students)
- *Planning investigations* (solving of unstructured problems)
- *Forming coherent arguments* (question assisted independent learning)
- *Working collaboratively* (group learning)
- *Scientific reasoning* (using the students' background knowledge)
- *Scientific literacy* (theoretical knowledge gained through inquiry)

Concept focus	Mechanics; identification of variables Egg collisions as a model system for real-world collisions
Inquiry skill focus	Developing hypotheses Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (identification of variables) Scientific literacy (presentation of scientific data)
Assessment methods	Classroom dialogue Teacher observation Worksheets Student devised materials

Rationale (teacher supports)

Goals: Students will learn to plan and implement experiments, be proficient in identification of variables, apply newly learned knowledge to everyday context (e.g. road accidents).

Scientific background: Experimentation with the eggs was developed because the speed on impact is easy to control through the selection of the height from which it is dropped. The mass of the eggs is close to constant. With the modification of the surface of impact, it is easy to identify the role of time during deceleration.

Pedagogy and context: The experiment can be most effectively performed by students aged 14-16 years. There are many opportunities for collisions in sports or on the roads; the altering of forces during these collisions is the basis of developing safety systems. Hopefully the observations by the students will encourage interest in safety.

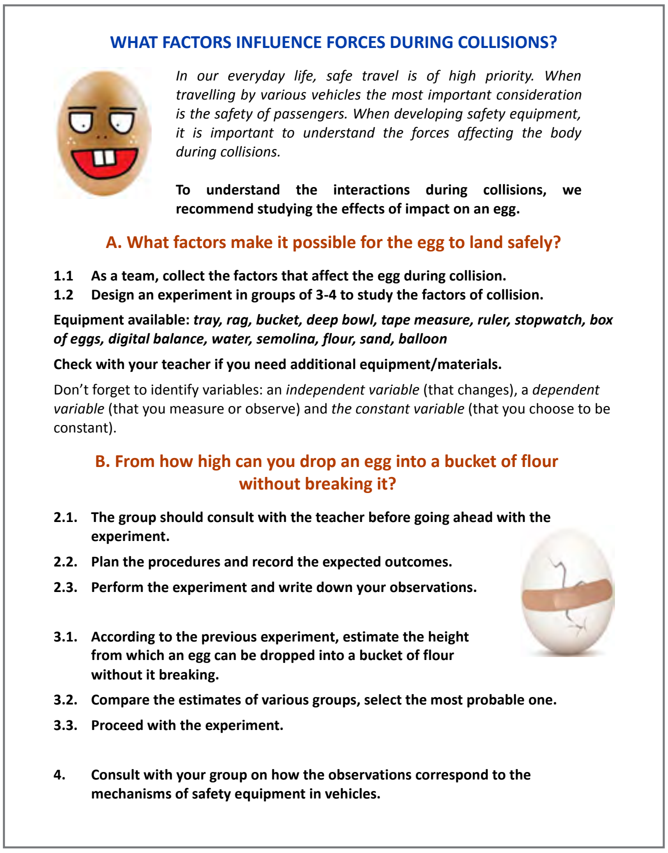
Recommendations: It is important to encourage the students to work as part of a diverse group. This supports critical thinking and teamwork. The teacher should observe student progress and facilitate it with helpful questions. If there is a disagreement, help should be given to resolve the problem in question. Groups should not be allowed to proceed to implementation, unless they have defined all of the variables in their experimental plan. During the planning phase of the experiment, the teacher should listen to the group and guide the designing of the experiment with questions.

Suggested lesson sequence

1. The teacher introduces the topic of "collisions" and encourages students to think about factors that influence impact of collisions. This can be in the context of mechanics or safety aspects.
2. The teacher introduces the task, to investigate the impact of collisions using an egg.
3. Students form small groups (3-4 students) and receive the student worksheet (Figure 1).
4. Students carry out part A of the activity (Question 1.1 Discuss factors that affect the egg during collision and Question 1.2 Design an experiment to study the factors of collision).
5. Students consult with the teacher before moving on to part B of the activity, to ensure that they have identified suitable variables for consideration during their experiment.
6. Students carry out their experiment and record their results and observations.
7. Students review their results, and devise a new experiment to consider influence of height on the collision of the egg. They engage in a class discussion to determine criteria for the experiment.
8. At the end of the experimentation phase, students are asked to transfer the newly acquired knowledge to another context – that of road safety. This seeks to consolidate the new knowledge in their minds.

Possible teacher questions

- What physical variables affect the forces generated on objects?
- How does the change in momentum affect force?
- What does momentum depend on?
- How can an object's momentum be changed?
- What does impact speed depend on?
- How do you calculate the speed of an object in free fall?
- Which variable can be taken as constant?
- How do you find connections between the variables?
- How does the drop height affect the egg's collision?
- How does the surface affect the collision?
- Why does the egg remain intact in flour and in semolina?



WHAT FACTORS INFLUENCE FORCES DURING COLLISIONS?

In our everyday life, safe travel is of high priority. When travelling by various vehicles the most important consideration is the safety of passengers. When developing safety equipment, it is important to understand the forces affecting the body during collisions.

To understand the interactions during collisions, we recommend studying the effects of impact on an egg.

A. What factors make it possible for the egg to land safely?

1.1 As a team, collect the factors that affect the egg during collision.
1.2 Design an experiment in groups of 3-4 to study the factors of collision.

Equipment available: ***tray, rag, bucket, deep bowl, tape measure, ruler, stopwatch, box of eggs, digital balance, water, semolina, flour, sand, balloon***

Check with your teacher if you need additional equipment/materials.

Don't forget to identify variables: an *independent variable* (that changes), a *dependent variable* (that you measure or observe) and *the constant variable* (that you choose to be constant).

B. From how high can you drop an egg into a bucket of flour without breaking it?

2.1. The group should consult with the teacher before going ahead with the experiment.
2.2. Plan the procedures and record the expected outcomes.
2.3. Perform the experiment and write down your observations.

3.1. According to the previous experiment, estimate the height from which an egg can be dropped into a bucket of flour without it breaking.
3.2. Compare the estimates of various groups, select the most probable one.
3.3. Proceed with the experiment.

4. Consult with your group on how the observations correspond to the mechanisms of safety equipment in vehicles.

Figure 1: Student worksheet for the **Collision of an egg** SAILS inquiry and assessment unit

2.2 Assessment of activities for inquiry teaching & learning

There are opportunities throughout this unit for the development and assessment of inquiry skills. Evidence of both content knowledge and skill development can be collected in the form of student artefacts (hypotheses proposed, experimental work plan), through teacher observation and self-assessment. While some assessment tools (3-point rubrics) are described within this unit, teachers should be 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 reasoning* (drawing conclusions based on evidence).

The teachers can provide formative assessment in class, using the rubric shown in Table 1 to assign performance levels, and encourage inquiry through asking helpful questions, such as:

- How would you like to observe the situation?
- What would you like to learn from the experiment?
- What variables do you want to study?

Table 1: Rubric for the assessment of forming inquiry questions

Inquiry skill	Level 1	Level 2	Level 3
Forming inquiry questions	The student is not helped by the question, is not able to recognise the connections.	The student recognises the connection between the question and the experiment, but the question does not help.	The student recognises the connection between the question and the experiment and implements the answer systematically.

To ensure adequate time for the assessment in class, teachers should do some preparation – prepare an evaluation plan and define the primary points for the assessment, implement the task according to given circumstances (adapt as appropriate for your class – based on ability, goals and resources available). In class, the teacher should communicate clearly the modes of evaluation that will be used, and should take into account the students' feeling about the evaluation procedures. After class, the teacher can give formative assessment in writing, evaluate the suitability of the assessment tools and consult with students and other teachers about the inquiry activity.

Developing hypotheses

The teacher can assess students' skill in *developing hypotheses* through teacher observation or using student artefacts in or after the lesson. A suggested 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 expect to happen?
- Why does it happen?
- Can you explain how your hypothesis follows from what you have learnt?

Table 2: Rubric for the assessment of developing hypotheses

Inquiry skill	Level 1	Level 2	Level 3
Developing hypotheses	The student formulates a hypothesis but is unable to explain it.	The student formulates a hypothesis and is able to explain it with the help of questions.	The student explains the hypothesis and supports it with scientific facts.

Planning investigations

The teacher can assess students' skill of *planning investigations* at several stages of this activity – looking at skills in both planning and implementing an experiment. Possible assessment opportunities include teacher observation or by assessing student artefacts, during the lesson or after the activities are completed. A rubric for the assessment of this skill is provided in Table 3. Teacher questions to aid students in *planning investigations* include:

- How can the experiment be implemented?
- Which physical variable should be studied?
- How can a connection be found between variables?
- What can you do in order to accurately control the measurements?
- More specific questions in teacher support.

Table 3: Rubric for the assessment of planning investigations

Inquiry skill	Level 1	Level 2	Level 3
Planning investigations	The student makes suggestions on how the experiment should be carried out, but is unable to proceed and does not understand the process.	The student makes suggestions on how the experiment should be carried out and understands the process, but is unable to proceed.	The student makes suggestions on how the experiment should be carried out and understands the process, can proceed with the planning of the experiment.
Implementing the investigation **Recording observations**	The student implements the experiment with help from the teacher and writes down observations sporadically.	The student implements the experiment with some help needed occasionally and writes down observations inaccurately.	The student implements the experiment without help and writes down observations accurately.

Scientific reasoning and forming coherent arguments (drawing conclusions based on evidence)

The teacher can assess students on their *scientific reasoning* when they are interpreting their results. Possible assessment opportunities include teacher observation or by assessing student artefacts during or after the lesson. A rubric for the assessment of this skill is provided in Table 3. Teacher questions to aid in assessing students performance in *forming coherent arguments* include:

- Can the student draw conclusions based on their results?
- Can the student identify errors or mistakes in the experiment?

Table 4: Rubric for the assessment of scientific reasoning and forming coherent arguments

Inquiry skill	Level 1	Level 2	Level 3
Drawing conclusions	The student demonstrates the experiment, however uses little observation data to explain the hypothesis.	The student demonstrates the experiment, uses the data collected during the experiment to explain the hypothesis.	The student demonstrates the experiment, uses the data collected during the experiment to explain the hypothesis and explains the reasons behind the observations.
Evaluating the experiment **Recognising mistakes**	The student recognises the possible mistakes and determines the credibility of the results.	The student recognises the possible mistakes and determines the credibility of the results. Identifies own mistakes.	The student recognises the possible mistakes and determines the credibility of the results. Explains the effects of mistakes on the results.

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in four countries producing six case studies of its implementation – **CS1 Hungary**, **CS2 Denmark**, **CS3 United Kingdom**, **CS4 United Kingdom**, **CS5 Germany** and **CS6 Germany**. The teaching approach in all case studies was that of *open inquiry* or *bounded inquiry*.

The students involved in the case studies were aged 11-16 years: ranging from just 11 years in **CS3 United Kingdom** to 16 years in **CS4 United Kingdom**. The students in each class were of mixed ability and usually mixed gender, although students were all male in **CS5 Germany**. **CS1 Hungary** and **CS6 Germany** implemented the activity in a single 90-minute lesson. In the other case studies the unit was implemented over several lessons – **CS2 Denmark** two lessons, **CS3 United Kingdom** four lessons, **CS4 United Kingdom** five lessons and **CS5 Germany** three lessons. Students worked in groups throughout the activity.

The skill of *planning investigations* was assessed in all case studies, while *developing hypotheses* was also identified as a key skill for the assessment. Other assessment opportunities included evaluation of *scientific reasoning*, looking at students' ability to identify variables or draw conclusions, and *scientific literacy*, through assessing students' ability to provide scientific explanations for the observed phenomena. The primary assessment methods were classroom dialogue and teacher observation, as well as teacher- and/or peer-assessment of student devised materials and presentations.

3.1 Teaching approach

Inquiry approach used

The teaching approach varied in the case studies; the unit was mainly implemented as an unstructured problem in **CS1 Hungary**, **CS2 Denmark**, **CS3 United Kingdom** and **CS5 Germany** (*open inquiry*), however materials and equipment were provided. In **CS4 United Kingdom**, students were encouraged to generate a list of equipment that they needed for their inquiry, which was made available in the next lesson for implementation. In **CS6 Germany**, after having a class-level conversation, the hypothesis to be tested was agreed, nevertheless, students had the freedom to plan their experiments; thus this was a *bounded inquiry*. Students worked in groups in all case studies, as detailed in Table 5. They usually worked in groups of 4, although **CS2 Denmark** and **CS6 Germany** did not give exact data.

Adaptations of the unit

The unit allows for various implementation designs and various levels of teacher guidance. For example, in **CS3 United Kingdom** students were provided with equipment and materials, and compiled a wish list of further items, while in **CS4 United Kingdom** students devised their experiments and chose all equipment and materials during their planning phase. In **CS1 Hungary**, the teacher asked lots of questions to aid the students, introducing an element of guidance to the inquiry.

Table 5: Summary of case studies

Case study	Duration	Group composition
CS1 Hungary	One lesson (90 min)	• Groups of 3-4 students • Mixed ability and gender
CS2 Denmark	One double lesson (120 min)	• Small groups of students (21 students) • Mixed ability and gender (9 girls, 12 boys)
CS3 United Kingdom	Four lessons (60 min each)	• Groups of 4 students • Mixed gender and ability; including students from "designated special provision" which works with autistic students
CS4 United Kingdom	Five lessons (45 min each)	• Groups of 4 students (24 students) • Mixed ability and gender
CS5 Germany	Three lessons (60 min each)	• Groups of 3-4 students • All boys, mixed ability
CS6 Germany	One lesson (90 min)	• Small groups of students (30 students)

In each implementation, lesson design took into account students' previous experiences in inquiry lessons. For example, in **CS3 United Kingdom** the students aided in design of the assessment tools, while in **CS4 United Kingdom** the teacher did not utilise rubrics. The **CS2 Denmark** students were novices to inquiry, therefore the teacher tried to follow pre-planned sequential lesson phases. In **CS5 Germany**, the teacher modified the activity so that it did not include eggs; rather he looked at the use of inclined planes and collisions of small cars. He found that this context was more in keeping with curricular objectives, but implemented an open inquiry based on the modified premise.

3.2 Assessment strategies

Even though the unit gives the possibility of assessing several inquiry skills, in real classroom situations teachers are advised to focus on at most two (or in exceptional cases three) inquiry skills, as shown in Table 6. In the case of six groups this might mean 6x2 group-level assessment protocols, which in practice seems to be quite a challenge to carry out.

Table 6: Inquiry skills identified by teachers in the case studies

CS1 Hungary	• Developing hypotheses (developing research questions) • Planning investigations (implementing experiment, collecting data) • Scientific reasoning (drawing conclusions, critiquing experimental design)
CS2 Denmark	• Developing hypotheses • Planning investigations (carrying out investigation)
CS3 United Kingdom	• Planning investigations (carrying out investigation) • Scientific reasoning (representing data, drawing conclusions • Scientific literacy (presenting scientific data)
CS4 United Kingdom	• Developing hypotheses • Planning investigations • Scientific reasoning (writing conclusions and evaluations) • Scientific literacy (understanding relevant data and communicating this to others; presenting scientific data)
CS5 Germany	• Developing hypotheses • Planning investigations (carrying out investigations) • Scientific literacy (understanding how things relate to real world context)
CS6 Germany	• Developing hypotheses • Planning investigations (carrying out investigations) • Working collaboratively (debating with peers)

The rubrics presented in the assessment of teaching and learning activities section of the unit served as the basis of formative assessment, even when there were deviations from those. These rating scales provide examples for differentiating between three different levels of student performance. The teacher in **CS1 Hungary** provided formative assessment in class, and reassessed the student artefacts after the inquiry was completed. The teacher then provided oral feedback to the class. This method of assessment was also utilised in **CS5** and **CS6 Germany**. The teacher in **CS2 Denmark** tried to use what she remembered from the rubrics intended for the assessment, but real-life procedures overwrote her plan, and the rubrics became unusable. **CS4 United Kingdom** reports on conscious deviation from the rubrics given in the unit draft, and the teacher assessed students using her own understanding. **CS3 United Kingdom** describes the use of rubrics, which were developed in cooperation with the students (Figure 2). The teacher and students first discussed what qualities were important for each of the skills to be assessed. Ideas from all students were compiled in a draft rubric, which the teacher then compiled in rubrics for use by the students for peer-assessment and for the teacher to use for evaluation of artefacts. The method of assessment ensured that students were aware of the criteria for the assessment and understood what was expected of them.

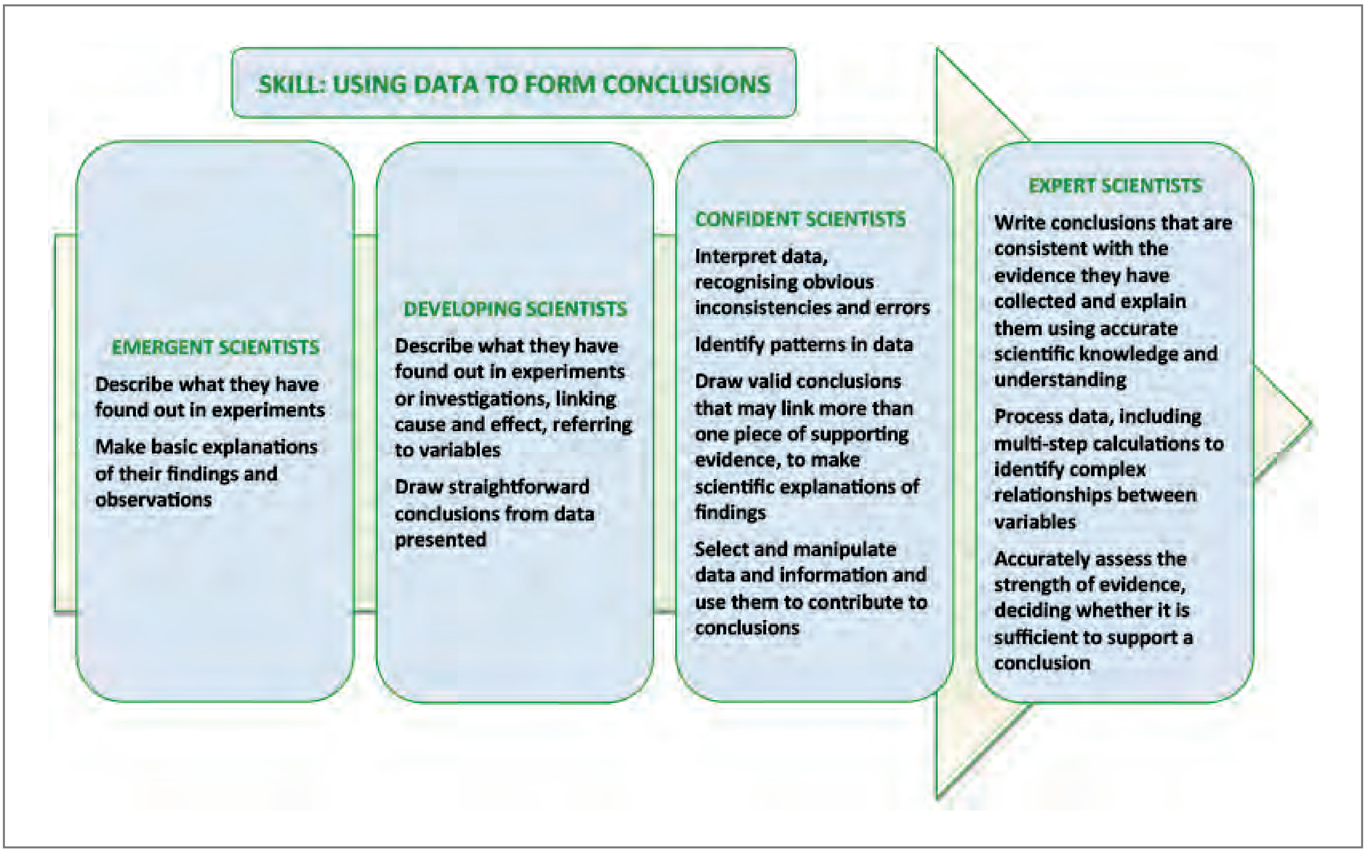


Figure 2: Arrow rubric for peer-assessment of forming conclusions used in **CS3 United Kingdom**

Further examples of peer-assessment can be found in **CS3 United Kingdom**, in which students used a peer-assessment form or checklist for the assessment of inquiry skills in writing conclusions (Table 7) and presenting data (Table 8).

Table 7: Peer-assessment form for writing conclusions

Success criterion	Peer comments
Averages calculated correctly	
Reference to data	
Reference to repeatability	
Suggested reasons for findings	
Use of paragraphs	

Table 8: Peer assessment checklist for presentation of data

Success criterion	Peer comments
Correct graph/chart selected?	
x- axis and labels	
y-axis and labels and units	
Bars the same width	
Bar height accurately drawn	

Planning investigations

This inquiry skill is the focus of the **Collision of an egg** SAILS inquiry and assessment unit. The 3-level scale shown in Table 3 is based on the assumption that students will surely make some suggestions regarding how the experiment should be carried out. This assumption may be far too optimistic, and may only be applicable to the proposed 15-year-old population, or older. Nevertheless, students' suggestions may be of different value, from just raising quick ideas to elaborating whole plans. The two component skills in the rubrics are understanding the process and proceeding with the planning of the experiment. According to the case studies, students' previous involvement in classroom inquiry will give the basis for any rubrics or other ordinal scale assessment. Those who have already had some knowledge about dependent and independent variables may receive feedback based on the quality and feasibility of their chosen variables (for example **CS3 United Kingdom**). Those who are completely new to classroom inquiry, such as **CS2 Denmark**, may be assessed according to their intuitive understanding of keeping constant one variable while manipulating the other. Students' self-assessment may also be used to assess development of this skill (**CS3 United Kingdom** and **CS6 Germany**). In **CS5 Germany**, the teacher explicitly focused on this skill and its assessment involved extensive observation; collecting and commenting on students' ideas proved to be an appropriate formative assessment strategy.

Developing hypotheses

This skill can be measured on a 3-point ordinal scale, as suggested in Table 2. Even at the lowest performance level, students are expected to form a hypothesis, and on higher levels they can justify and explain it. In **CS4 United Kingdom**, the assessment of this skill was based on “how students identified what variable to measure,” while in **CS3 United Kingdom**, peer-assessment was carried out on the basis of “is this hypothesis a testable statement.” In **CS6 Germany**, the teacher found that students had a lot of difficulties with this skill and required a lot of teacher input.

Working collaboratively

This inquiry skill was also addressed in the case studies, albeit not explicitly. In all case studies the students worked in small groups. The teachers observed these groups, and some noted the ability of students to work collaboratively, for example in **CS4 United Kingdom** the teacher observed that teacher-selected groups would be beneficial, to ensure a mix of ability. In **CS5 Germany**, the teacher was satisfied with the students’ ability to cooperate, but noted that students again had varied ability and took on different roles within their groups. In **CS6 Germany**, the teacher had hoped to assess *working collaboratively* through self-assessment of the planning investigations activity, but did not have sufficient time. Of particular interest is **CS3 United Kingdom**, in which students from the designated special provision unit, which works with autistic students, joined the class. The teacher noted that the autistic students were very engaged and worked well as part of a team. The specialist staff member who worked with one autistic boy commented that this collaboration and motivation represented a significant positive change as previous “animosity” seen in some group work had been completely ignored. Thus many opportunities for the assessment of the skill *working collaboratively* were identified, and methods for assessment suggested.

Assessment of other skills

In **CS3 United Kingdom**, the teacher outlines a tool for the self-assessment of other inquiry skills developed during the inquiry process. This learning landscape lists 21 skills that may be demonstrated during an inquiry activity, but that are unlikely to be assessed. Using the learning landscape, students can become familiar with transferable skills and encouraged to consider how these skills may be beneficial in the future. They are asked to choose three skills that they feel they have developed during the current lesson, as well as three skills that they should work on in the future. This learning landscape can be used throughout the school year, to monitor development of these skills.

Name:___________________

LEARNING LANDSCAPE

Personal qualities not often measured by tests.

Creativity	**Collaboration**	**Leadership**
Critical thinking	**Endurance**	**Compassion**
Resilience	**Reliability**	**Courage**
Motivation	**Enthusiasm**	**Independence**
Problem-solving	**Self-awareness**	**Resourcefulness**
Curiosity	**Self-discipline**	**Spontaneity**
Questioning	**Empathy**	**Tenacity**

In green pen explain how you have successfully demonstrated any of these personal qualities.

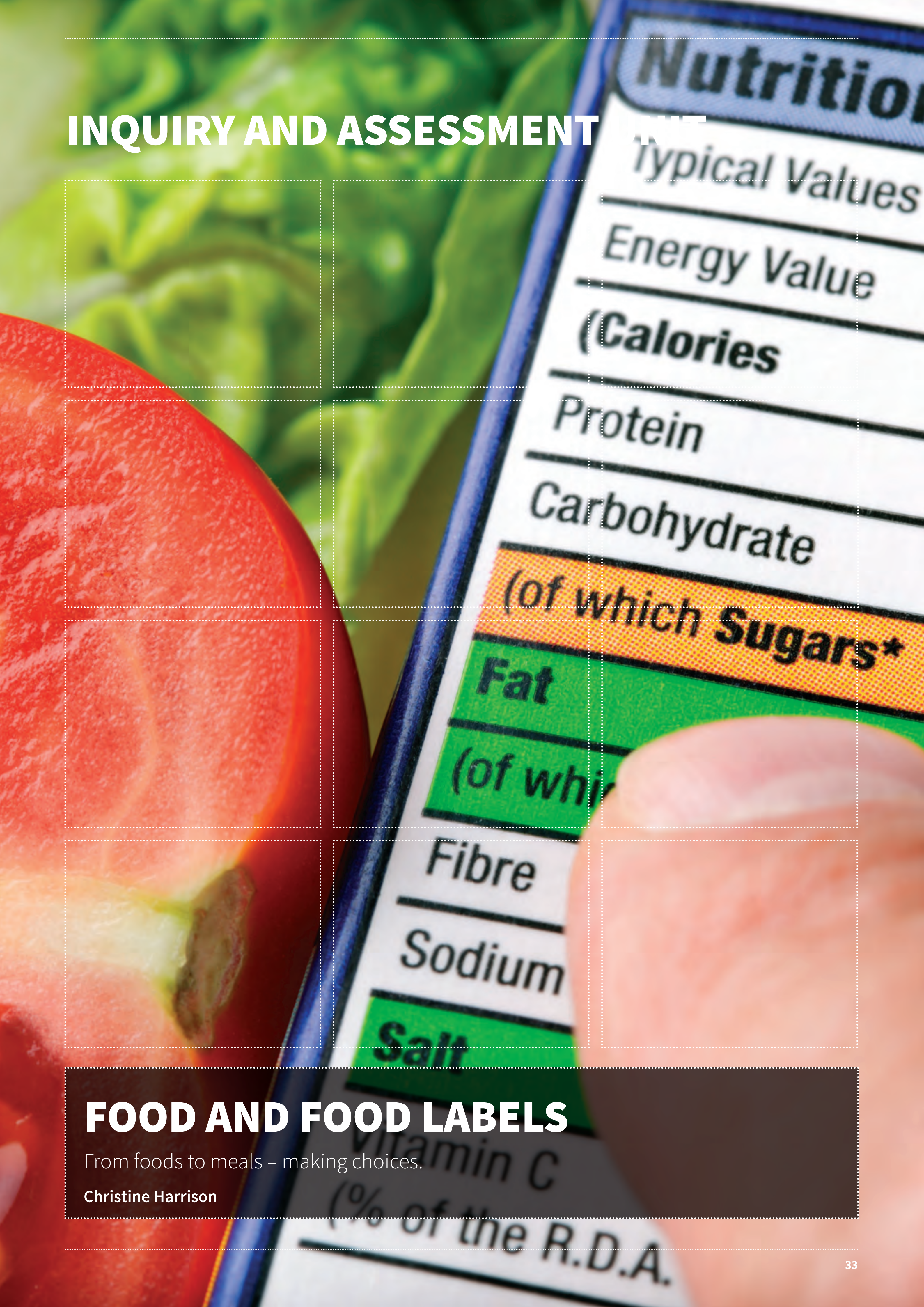
In purple pen explain why you might want to take the opportunity to develop any of these qualities in other enquiries.

Date the boxes you have filled in.

Do not address any ‘qualities’ you have not reflected on as a result of the current inquiry.

Figure 3: Learning landscape used in **CS3 United Kingdom**.

INQUIRY AND ASSESSMENT UNIT



FOOD AND FOOD LABELS

From foods to meals – making choices.

Christine Harrison

FOOD AND FOOD LABELS

FROM FOODS TO MEALS – MAKING CHOICES.

Overview

KEY CONTENT/CONCEPTS

- Nutritional content of different food items
- Balanced diet
- Food groups
- Understand food label information

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 (proportional reasoning; drawing conclusions; collecting scientific data; problem-solving)
- Scientific literacy (analysis and interpretation of scientific data)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Self-assessment
- Worksheets
- Student devised materials (group work placemat, reports)
- Presentations

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – FOOD AND FOOD LABELS

The **Food and food labels** SAILS inquiry and assessment unit was designed to aid students to understand what constitutes a healthy balanced diet. Through the four outlined inquiry activities, students learn to look at the composition of foods and the amounts needed to keep someone healthy. In this way, students become equipped with sufficient knowledge and skills to make informed choices when it comes to their own diet. The unit is recommended for implementation as a *guided inquiry* with students at lower second level.

Two key skills are identified for development in this unit. *Scientific reasoning*, in particular proportional reasoning, is developed as students compare different amounts and types of food in their diet. Students' skills in *working collaboratively* are also developed, through discussion and teamwork. The assessment methods described include classroom dialogue, teacher observation and evaluation of student artefacts.

The unit was trialled by teachers in Turkey, Hungary, Ireland and Portugal – producing five case studies of implementation. Four examples at lower second level are presented (aged 11-15 years), while one of the Hungarian classes and the Portuguese study describe implementation with students at upper second level (up to 19 years). In all cases the unit was implemented as a *guided inquiry*, with some *open inquiry* opportunities. In addition to the assessment of *scientific reasoning* and *working collaboratively*, opportunities for the assessment of skills in *developing hypotheses*, *planning investigations* and *forming coherent arguments* were identified.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The four activities described in the **Food and food labels** SAILS inquiry and assessment unit were developed by the team at King's College London for use in the SAILS project. The unit is presented four activities (A-D), in which students are introduced to food groups and nutritional composition of foods. This is a topic that is revisited many times throughout a child's time in school and one of the main reasons for including it in the curriculum is the hope that children will begin to understand what makes a healthy balanced diet. From this stance, they can then look at their own diet and that of others and make recommendations about how to improve a diet. The problem however is that too often the ideas behind obtaining a balanced diet are not considered in sufficient detail to allow youngsters to understand what a balanced diet means in reality with foods simply categorised as healthy or unhealthy or as fat or protein and the true composition of foods and the amounts needed to keep someone healthy are not looked at. So students are not equipped with sufficient knowledge and skills to make the choices that they need to when it comes to their own diet. The activities presented in this unit aim to support students with developing better ideas about food and incorporate an inquiry-based approach to help students develop the requisite skills and also to motivate students to want to understand these ideas better.

Background Information

A healthy diet involves consuming appropriate amounts of all essential nutrients and an adequate amount of water. Nutrients can be obtained from many different foods, so there are numerous diets that may be considered healthy. A healthy diet needs to have a balance of fats, proteins, and carbohydrates, calories to support energy need and micro nutrients (vitamins and mineral salts) to meet the needs for human nutrition. Fibre in the diet also bulks the food intake and keeps the gut contents moving.

Guidelines have been established which detail the recommended quantities and ratios of nutrients that should be consumed, based on a calorific intake of 2,000 calories, for adults and children aged four years or older. The following tables list the daily values (DVs) for various food groups (Table 1) and recommended daily intakes (RDIs) for vitamins and minerals (Table 2). Implementation of this unit can begin with an introduction to nutrition and the food groups and use these tables as a focal point for discussions.

Table 1: Daily values (DVs) for various food groups

Nutrient	Daily value (DV)
Saturated Fatty Acids	20 g
Cholesterol	300 mg
Sodium	2400 mg
Potassium	3500 mg
Total Carbohydrate	300 g
Dietary Fibre	25 g
Protein	50 g

Table 2: Recommended daily intake (RDI) for vitamins and minerals

Nutrient	RDI	Nutrient	RDI
Vitamin A	900 µg	Biotin	300 µg
Vitamin C	60 mg	Pantothenic acid	10 mg
Calcium	1000 mg	Phosphorus	1000 mg
Iron	18 mg	Iodine	150 µg
Vitamin D	400 IU (10 µg)	Magnesium	400 mg
Vitamin E	30 IU	Zinc	15 mg
Vitamin K	80 µg	Selenium	70 µg
Thiamine (Vitamin B1)	1.5 mg	Copper	2 mg
Riboflavin	1.7 mg	Manganese	2 mg
Niacin	20 mg	Chromium	120 µg
Vitamin B6	2 mg	Molybdenum	75 µg
Folate	400 µg	Chloride	3400 mg
Vitamin B12	6 µg		

Activity A: Packed lunches

Concept focus	Comparing the nutritional content of different food items Calculations using ratios
Inquiry skill focus	Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (proportional reasoning) Scientific literacy (evaluating the nutritional content of food)
Assessment methods	Classroom dialogue Teacher observation Worksheets

Rationale

The idea behind this activity is for students to begin comparing foods in terms of amount, energy values and composition so that they get the idea of proportional reasoning. This activity consists of a number of questions, which include calculations using ratios. It is recommended that the teacher does not provide hints or formulae, as this activity should develop skills in reasoning, rather than mathematics.

Suggested lesson sequence

1. The questions can be provided on a worksheet (Figure 1), orally by the teacher or on a projector (or other approach). Use the first few questions (Q1-3) as whole class activity, with students discussing answers in small groups and reporting back. It is a good idea to use mini whiteboards, voting systems or simply asking other groups to agree/disagree with answers and different ways of working out or articulating how they did each question. The teacher can focus in the interactions on "How did you work that out?" to get students to demonstrate their *scientific reasoning* capabilities. The teacher should take care not to provide formulae or hints, as this cuts short the students' reasoning and makes the task a simple mathematics problem.

2. Once the teacher is satisfied that students are capable of carrying out the mathematical manipulations, the next questions can be investigated. In these, students are asked to consider the nutritional content of food. Again, proportional reasoning is key, and the students use this to form comparisons between different food items.

3. To further develop students' understanding of food labels, an additional question can be posed. In this, students are given a sample food label (Figure 2).

4. A final task in this activity is to facilitate students working in pairs to use food labels to compare the amounts of carbohydrate or fat or protein. When you are sure they have some idea of proportionality ask them to prepare some questions for their peers. Ask students to judge which are the best questions to demonstrate that they can investigate data and use proportional reasoning.

1. John likes apples but his sister, Ruby, only likes kiwi fruit. So when their dad does the shopping he has to work out how many to buy. He reckons that Ruby would need 2 kiwi fruits and John would need 1 apple each day.

   a) How many of each fruit would he need to buy for 5 days in school?
   b) If he buys a saver bag of 8 apples, then how many kiwi fruits does he need to provide for the same number of days?
   c) If he buys a saver bag of 12 kiwi fruits, then how many apples will he need to buy for John for the same number of days?

2. Jack and Amy's mum decided to replace their Saturday sweet treat with fruit. Jack chose strawberries and Amy chose satsumas. Mum decided that for every satsuma that Amy had, Jack could have 3 strawberries.

   a) How many strawberries does Jack get if Amy has 4 satsumas?
   b) How many strawberries does Jack get if Amy has 7 satsumas?
   c) How many satsumas does Amy get if Jack has 15 strawberries?

3. Susan likes pears and her brother Lee likes plums. Their mum decided that for every 2 pears that Susan had Lee could have 5 plums.

   a) How many plums does Lee get if Amy has 4 pears?
   b) How many plums does Lee get if Amy has 10 pears?
   c) How many pears does Amy get if Lee has 20 plums?

4. A lunchbox has a packet of crisps that weighs 25 g and contains 8 g of fat per 100 g of crisps. How much fat is there in 1 bag of the crisps?

   a) 2 g
   b) 8 g
   c) 25 g
   d) 32 g
   e) 100 g

5. Wheetos crisps are sold in 30 g bags and contain 6 g of fat per 100 g of crisp. Quipo crisps are sold in 20 g bags and contain 7.5 g of fat per 100 g. Which bag of crisps contains the most fat?

6. Most crisps contain about 80 g of carbohydrate per 100 g of crisp. Bread has about 40 g of carbohydrate in every 100 g. A slice of bread weighs about 50 g, so what amount of crisps contains the same amount of carbohydrate?

   a) 8 g
   b) 20 g
   c) 25 g
   d) 40 g
   e) 100 g

Figure 1: Example of a student worksheet for Activity A: Packed lunches

7. A 125 g pot of fruit yoghurt has the following food label:

Energy	500 kJ
Protein	5 g
Carbohydrate	25 g
Fat	1 g
Vitamin C	1.25 mg
Calcium	200 mg

   a) How much of each food type would there be in a 250g pot?
   b) How much of each food type would there be in a 100g pot?

Figure 2: Additional question for Activity A: Packed lunches

Activity B: Food cards

Concept focus	Comparing the nutritional content of different food items Introducing food groups – carbohydrates, fats and protein
Inquiry skill focus	Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (proportional reasoning) Scientific literacy (evaluating the nutritional content of food)
Assessment methods	Classroom dialogue Teacher observation Worksheets

Rationale

The Food cards activity offers an opportunity to further develop students' skill in proportional reasoning. The students are asked to consider the nutritional composition of foods that they commonly consume, thus introducing a day-to-day application of this skill. This activity also supports the development of students' understanding of nutrition and making healthy food choices.

Suggested lesson sequence

1. Make some sets of food cards for a range of common foods, including banana and white bread. On the card, put the food name, amount usually consumed in a meal (in grams), amount of carbohydrate, fat and protein in 100 g of the food (Figure 3).
2. Give each pair of students a banana and a white bread food card. Ask them to compare the two foods. Write up the different comparisons on the board.
3. Give each group of students 3-4 more food cards and ask them to find the food with the highest amount of carbohydrate. Ask them to explain how they decided this. Collect the 3 highest cards in and display them so the whole class can see them
4. Now ask the students to find the food with highest protein content out of their remaining cards. Again ask them to explain their process and collect and display the 3 highest cards.

Food name:	Banana (medium)
Total amount (g):	118 g
Carbohydrates (g per 100 g)	23 g
Fat (g per 100 g)	0.3 g
Protein (g per 100 g)	1.1 g

Figure 3: Sample food card for Activity B: Food cards

5. Next ask them to find the food with highest fat content out of their remaining cards. Again ask them to explain their process and collect and display the 3 highest cards.
6. Ask each group to compare the food cards they still have with the high carbohydrate, high protein and high fat cards in the display. How much more of each food group do the "high" foods have?
7. Give each group a plate and ask them to select food cards that represent the foods in a typical meal. Ask them to work out how much carbohydrate, protein and fat the meal contains. Which foods contain most of the carbohydrate? Which foods contain most of the protein? Which foods contain most of the fat?

Activity C: The washing line

Concept focus	Carbohydrate, fats and proteins in the diet Comparing the nutritional content of different food items
Inquiry skill focus	Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (proportional reasoning) Scientific literacy (evaluating the nutritional content of food)
Assessment methods	Classroom dialogue Teacher observation Worksheets

Rationale

In this activity, students consider their own diets, and can see if they are obtaining enough of the nutrients they need, or if their consumption is greater than what is recommended. Students evaluate the food labels of the foods they eat every day, and they examine its content in terms of carbohydrates, fats and proteins. This process supports them in making informed decisions about which foods they should eat more often, and those they should eat less of.

Suggested lesson sequence

1. Set up three pieces of string as washing lines over about a 2-3 m distance. Label one washing line "carbohydrate," the next "protein" and the final one "fat."
2. Give the students three copies of 5-6 food labels for common foods such as bread, chicken, beans, cereal, cheese, potato, tomato, yoghurt, and ask them to rank the foods based on the amount of carbohydrate, protein and fat from the data on the labels. Get the students to put the labels on the three washing lines, using pegs or paperclips, to show the different amounts of each food type. Mark the range and the midpoint with the values on each washing line.
3. Then ask them to pin up other labels (perhaps that they have brought in). How do these food compare with the ones they first placed up?

4. This activity can be developed to look at making changes in their diet. Get students to write out what they eat in a day listing each food or ingredient in a meal separately and ask them to use the details on the washing line to consider amounts of carbohydrate, protein and fat in each meal. The teacher can pose questions such as: "How might you increase the protein in your meal? How could you reduce the fat content of the meal? How could you spread the carbohydrates over more meals? What could you replace food X with, if you want to keep the same amount of protein but reduce the fat?" The key activity here is getting students to explain what each meal contains in terms of carbohydrate, protein and fat and how much of each of these is each food contributing to the meal. In this way, students begin to compare foods and learn how to make choices such as:
   - Cheese is high in protein but also high in fat. By swapping chicken for cheese, I still eat enough protein but take in less fat.
   - Low fat yoghurts reduce the amount of fat, but they still have quite high carbohydrate content in the form of sugars. I would be better having strawberries and plain low fat yoghurt rather than a low fat strawberry yoghurt.
   - A serving of spaghetti and tomato sauce has less carbohydrates and fat than a portion of chips. Both contain about the same small amount of protein.

There is opportunity with this topic to extend this activity further and consider questions such as:

- What are the amounts of carbohydrate, protein and fats in traditional dishes from each country?
- How can a vegetarian ensure sufficient protein in his/her diet?
- How might an athlete's diet differ from a normal diet?
- How to select foods for a day's hike which give a balanced diet but do not weigh too much in your rucksack.
- How might a small child's meal differ from that of an adult?

Activity D: Testing for vitamin C

Concept focus	Comparing the vitamin C content of different food items
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (recording data and observations)
Assessment methods	Classroom dialogue Teacher observation Worksheets

Rationale

Humans are recommended a daily intake of 60 mg of vitamin C. This is approximately a whole large mango or 125 g of pineapple. While this test cannot measure the exact amount of vitamin C in a food, it does provide a way of comparing high, medium and low values of vitamin C in different foods. In this activity, students' skills in *developing hypotheses* and *planning investigations* can be assessed.

Suggested lesson sequence

1. To start the activity, the teacher can demonstrate that a solution of vitamin C decolourises blue 2,6-dichlorophenol-indophenol (DCPIP) solution.
2. Students are asked to consider how they might carry out an investigation on how a person might obtain their daily dose of vitamin C. The teacher can ask some prompt questions, such as "Is it better to have fruit or juice? Juice or squash? Fresh fruit compared to cooked fruit?"
3. Students should first develop a hypothesis to test and then investigate it systematically.
4. Students should test 2 or 3 of the juices provided by the teacher in order to practice their technique (Figure 4), before investigating their own food choices. It should be clear to the students that this test allows them to compare the vitamin C content of foods.

For each group of students:

- Vitamin C solution, 1% (low hazard)
- 2,6-Dichlorophenol-indophenol (DCPIP) solution, 1% (low hazard)
- Graduated pipette, syringe or burette.
- 10 pipettes
- 10 test tubes and rack
- Fruit juice and squash samples
- Citrus fruits, apples, tomatoes

Figure 4: Materials required for testing for vitamin C in foods

2.2 Assessment of activities for inquiry teaching & learning

In this unit, the key skills developed are *scientific reasoning* and *working collaboratively*, and several opportunities for the assessment of these skills have been highlighted. For example, in Activity A: Packed lunches, the assessment of *scientific reasoning* can be achieved by listening to group discussion as they work out the answers to the questions posed and also when groups report back on their answers to the whole class. Questions 1-5 are relatively straightforward, while Questions 6 and 7 require higher order reasoning. Question 8 allows the teacher to differentiate the performance level of students within groups, by placing students in pairs and by the complexity of the food labels provided. The teacher should encourage the students to explain how they reach their answers and get them to compare their methods with those of other students. In this assessment, students' ability to articulate how they solved the problems is more important than obtaining the correct answer.

In this activity, the teacher should be able to distinguish between students that have the ability to:

- Work out proportions when quantities are doubled, halved or simple multiplication of original amount
- Manipulate proportions and explain how they did this (e.g. X in 40 g is 2.5X in 100 g or X in 40 g, so X/4 in 10 g which is 10X/4 in 100 g)
- Manipulate proportions for 2 or more variables and so can compare amounts of food types in food packets of different masses (X g of fat in a 75 g bag is more per 100 g than Y g of fat in a 60 g bag)

The students then use similar reasoning skills associated with proportionality in Activity B: Food cards and Activity C: The washing line, In addition, the student can demonstrate how they can make choices based on their proportional reasoning. The assessment can be carried out in a similar manner to that outlined for activity A.

A 4-level rubric for the assessment of *working collaboratively* is proposed (Table 3), which allows for the assessment of students' skill in collaboration and debating with peers.

In Activity D: Testing for vitamin C, students' skills in *developing hypotheses* and other investigative skills such as *planning investigations* and collection of data can be assessed. A sample rubric for the assessment of *developing hypotheses* is shown in Table 4.

Table 3: Rubric for the assessment of working collaboratively

Emerging	Developing	Crafting	Extending
The student makes suggestions.	The student makes suggestions and takes turns.	The student makes suggestions and listens and responds to suggestions of others.	The student makes suggestions and considers suggestions of others. Asks questions or makes statements that encourage the group to reflect or reach a collaborative decision

Table 4: Rubric for the assessment of developing hypotheses

Emerging	Developing	Crafting	Extending
The student tests a range of juices/squashes for vitamin C but does not form a hypothesis.	The student tests a range and asks which drink/fruit contains the most vitamin C?	The student suggests X contains more vitamin C then Y and carefully sets up the comparison with equal volumes (e.g. juice contains more vitamin C than squash/fresh fruit contains more vitamin C than cooked fruit).	The student suggests X contains more vitamin C than Y, with scientific reasoning as to choice (e.g. heating destroys vitamin C) and sets up a fair test for this.

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in four countries, producing five case studies of its implementation – **CS1 Turkey**, **CS2 Hungary**, **CS3 Ireland**, **CS4 Portugal** and **CS5 Hungary**. The case studies detail implementation at lower second level, as recommended in the unit, except in **CS4 Portugal** and one class in **CS5 Hungary**, which features a 9th grade class (upper second level). The ages of the students involved in the case studies were aged 11-19 years, thus teachers varied the implementation to suit the requirements of their respective class groups. The students in each class were mixed ability and mixed gender, except in **CS3 Ireland** where the students were all female. The case studies were implemented by teachers who had some experience of teaching through inquiry, but the students involved had generally not been taught through inquiry previously.

In **CS3 Ireland** and **CS5 Hungary** the selected inquiry activities were carried out in one lesson of 45-60 minutes. **CS1 Turkey** and **CS2 Hungary** implemented most elements of the unit over two 45-minute lessons. Finally, **CS4 Portugal** implemented one unit activity (food cards) over five lessons (60 minutes each).

The case studies detail a range of implementations and adaptations, and the skills assessed vary from focusing entirely on *working collaboratively* in **CS5 Portugal**, to assessment of each of the SAILS inquiry skills and competencies in **CS2 Hungary**. The assessment methods described include on-the-fly interactions and structured dialogue, teacher observation, evaluation of worksheets and student devised materials and self-assessment (in **CS4 Portugal**).

3.1 Teaching approach

Inquiry approach used

The inquiry approach used across the case studies was *guided inquiry*, as the teachers felt that they needed to introduce some ideas about nutrition and diet before the students commenced the activities. The teachers then set the inquiry question and the students worked collaboratively on the various activities.

Implementation

In all case studies, the students worked in groups (Table 5). All schools, except that of **CS3 Ireland**, were mixed gender, while the Irish school was a girls' school. No specific choices were made by the teacher as to how to group the students for these activities beyond whom the teacher felt would work well together.

In each of the case studies, the students explicitly or implicitly dealt with the concept of healthy diets and food choice. **CS2** and **CS5** (both **Hungary**) carried out most of the activities in the unit, with **CS5 Hungary** dividing some of the activities to be done by younger groups (Activity B: Food cards and Activity C: The washing line) and others for older groups (modified Activity B: Food cards and Activity D: Testing for vitamin C). In **CS5 Hungary**, students produced their own food labels by looking up food composition, when no food labels were available for the activity. Also in this case study, the teacher could not find a supply of chemicals for the vitamin C analysis and so decided to test foods for fat content instead. In the other case studies, the teachers chose particular aspects and activities for implementation. For example, **CS4 Portugal** focused on an adapted version of Activity B: Food cards, as this implementation

Table 5: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Turkey	Activities A, D	Two lessons (45 min each)	• Six groups of 5-6 students (35 students) • Teacher assigned; mixed ability and gender
CS2 Hungary	Activities A-D	Two lessons (45 min each)	• Individually and in six groups of 5-6 students (31 students total) • Teacher assigned; mixed ability and gender
CS3 Ireland	Activity B	One lesson (50 min)	• Groups of 3 students; single-sex (all-girls) • Teacher assigned; mixed ability
CS4 Portugal	Activity B	Five lessons (60 min each)	• Groups of 3-5 students (28 students; 12 boys, 16 girls) • Student selected; mixed ability and gender
CS5 Hungary	Activities B-D	One lesson (45 min)	• Groups of 3-4 students (two classes, 22-24 students) • Student selected; mixed ability and gender

was with an upper level student group, whom were addressing a real-world challenge. These students devised "healthy school snack" kits for adoption in their school, which does not have a student cafeteria. Similarly, in **CS3 Ireland**, the teacher adapted Activity B: Food cards for a discussion-based inquiry on "What do you think junk food is?" **CS1 Turkey** details implementation of Activity A: Packed lunches and Activity D: Testing for vitamin C, as these activities aligned well with the school curriculum and offered an opportunity for the teacher to assess students' research processes, rather than focus only on a final output.

Adaptations of the unit

While there were some changes made to the proposed teaching and learning activities to fit the context of the specific classroom, availability of resources or adaption to particular learning needs of students, the main concept of reasoning through discussion was described in all case studies.

In **CS2 Hungary**, the teacher modified the unit because the students were confident users of the tables of nutritional content and making food cards did not present a challenge to them. Therefore, the teacher devised more advanced versions of Activity B: Food cards and Activity C: The washing line, using an online database to analyse the lunch menu of the school with respect to calorie content and nutritional value. Having identified the key considerations for putting together a school lunch menu, the students were asked to suggest a three-course meal that they would suggest for the school menu. As outlined for activities B and C, this activity encouraged the students to consider the nutritional value of foods they encounter in their daily lives, and to make healthy food choices. In this school, it was not possible to carry out Activity D: Testing for vitamin C using DCPIP, instead the teacher used an alternative redox method using potassium iodide and starch indicator.

In **CS3 Ireland**, the teacher implemented Activity B: Food cards as an inquiry through discussion. The students worked in small groups to discuss and debate the inquiry question "What do you think junk food is?" A whole-class discussion was used to provide formative feedback.

In **CS4 Portugal**, the unit was implemented with an upper second level cohort in a vocational setting. Therefore, the teacher modified Activity B: Food cards to provide a challenge for these students – "How can we maintain healthy food habits if we do not have a cafeteria? How can we have proper snacks between main meals at a low cost and without compromising the nutritive and hygienic quality of food?" To address this, students were asked to propose a "healthy school snack" kit that could be introduced in their school. The implementation took place over five 60-minute lessons, with the first lesson dedicated to defining the problem and discussing assessment criteria. Three further lessons were used to develop proposals (suggested meal, nutritional data for all components, health and hygiene considerations) and in the final lesson students presented and discussed their proposals.

CS5 Hungary describes implementation in two separate classes, where the teacher adapted the unit for use with upper and lower second level students. Again, Activity B: Food cards was modified to include use of an online database to search for information on nutritional composition of foods from daily life. However, the most significant adaptation was for Activity D: Testing for vitamin C. As the reagent DCPIP was not available, the teacher revised this task to test for fats instead. The students had recently learned to separate mixtures and they were able to select and follow the procedure to separate fat. In this way, the teacher was able to assess students' skills in *developing hypotheses* and *planning investigations* during this activity, as outlined in the assessment of inquiry teaching & learning section of this unit.

3.2 Assessment strategies

While, for several of the classes, an inquiry learning approach was a relatively new approach, it was clear that the teachers had begun to look at opportunities for formative assessment as well as documenting summative achievements. Perhaps one of the most relevant findings was that students enjoyed and were motivated by the inquiry activities and the teachers seemed relatively confident in both facilitating the inquiry and assessing it.

In the various implementations, several different approaches to assessment were taken and different skills were identified for assessment (Table 6). All case studies used the context of nutrition and making food choices to introduce the topic, but did not necessarily assess students on this, instead focusing on development of inquiry skills. Most commonly used assessment methods were on-the-fly interactions, structured dialogue and evaluation of students' worksheets or other artefacts.

Table 6: Inquiry skills identified by teachers in the case studies

CS1 Turkey	• Developing hypotheses • Working collaboratively • Scientific reasoning (proportional reasoning, drawing conclusions)
CS2 Hungary	• Developing hypotheses • Planning investigations • Forming coherent arguments • Working collaboratively • Scientific reasoning (proportional reasoning, collecting data) • Scientific literacy (analysis and interpretation of data)
CS3 Ireland	• Forming coherent arguments • Working collaboratively (debating with peers) • Scientific literacy (understanding the nutritional composition of food and making informed food choices)
CS4 Portugal	• Working collaboratively • Scientific reasoning (problem-solving)
CS5 Hungary	• Planning investigations • Working collaboratively • Scientific reasoning (making reasoned decisions) • Scientific literacy (critical thinking; collection and analysis of scientific data)

In **CS1 Turkey** the teacher chose to implement Activity A: Packed lunches to assess students' *scientific reasoning* capabilities, in particular proportional reasoning. The teacher expected that students would develop understanding of proportional reasoning, but did not identify any success criteria or performance levels for this skill. During Activity D: Testing for vitamin C, the teacher was able to assess students' skills in developing hypotheses and *working collaboratively*. The teacher used on-the-fly interactions to provide formative feedback, in particular for lower-performing students. In addition, teacher observation was used to assess performance in *working collaboratively*. The teacher chaired a structured whole-class discussion at the end of the lesson, in which the students explained and presented their research approach to the class, while the teacher participated only as an observer.

The teacher in **CS2 Hungary** took a different approach to assessment, combining both formative and summative assessment. The teacher collected individual student worksheets and graded their work for Activity A: Pack lunches to assess proportional reasoning and analysed the distribution of grades (by student and by question) to identify weaknesses to be addressed. For the assessment of students' skills in *planning investigations, forming coherent arguments* and *working collaboratively*, the teacher devised 4-level rubrics, such as that shown in Table 7.

In the vitamin C investigation, different groups required different amounts of input from the teacher when *planning investigations*. This is reflected in the assessment rubric that the teacher developed. In addition, in this case study the teacher assessed *scientific literacy*, through considering the students' skill in implementation, data collection and the analysis and interpretation of scientific data. The teacher was seeking consistency in recording of information, and expected that students would use tables as appropriate. This was evaluated in connection with *forming coherent arguments* and an ability to make reasoned decisions and enabled the teacher to act formatively in response to the assessment evidence.

In **CS3 Ireland**, the emphasis of the implementation was on development of students' skill in *working collaboratively*, with some observation of the skill of *forming coherent arguments*. The teacher listened to the group discussions and used professional judgement to decide how successful individual students were in contributing to the discussion. The ability of the whole group to form a joint decision was also noted. At the same time, the teacher observed the quality of the discussion towards *forming coherent arguments*.

In **CS4 Portugal**, the teacher chose to focus on the skill of *working collaboratively*, while challenging the students to develop a proposal for a well-adjusted snack, suited to the energy needs of teenagers, and according to the taught contents. A 4-level rubric was prepared, which features criteria for success in both teamwork and debating with peers (Table 8). The criteria were shared with the class before commencing the activity, and the teacher used an observation grid to observe frequency of behaviours during implementation (Table 9). She also expected the students to be able to demonstrate their analysis and interpretation of the data contained in the food composition table, and also to support their snack proposal in class. By listening in to the group discussion, she was able to judge whether they achieved this or not. Afterwards, each group presented their own proposal to the class, which offered another opportunity for assessment. Students completed a self-assessment questionnaire, which addressed their opinions on working as part of a team.

At the end of this activity, the students submitted a comprehensive report to the teacher, for summative assessment purposes. Included in the rubric for the assessment of this report was a criterion for "group work" which was worth 15% of the overall grade. For this criterion, the teacher used observation notes from the lessons to assign a performance level. The students' skills in problem-solving, an aspect of *scientific reasoning*, were developed throughout this activity, but this was not assessed formally.

Table 7: Assessment of forming coherent arguments in CS2 Hungary

Skill	Emerging	Developing	Consolidating	Extending
Drawing conclusions	Students need the teacher's help to use their data as evidence and to measure quantities	The conclusions are incomplete. There is no interpretation. Students need the teacher's help to move on.	The conclusions rest on comparisons and proportions. The conclusions lack interpretation. The quantities are calculated with the teacher's help.	The conclusions are correct and are based on arguments from correctly interpreted evidence
Making reasoned decisions	The principles are formulated in general terms without consideration of the data.	Partial reliance on the data. Incomplete or occasionally erroneous decisions.	The decisions are correct and are based on the data but some elements are absent.	The decisions are correct and complete; they cover daily calorie intake, the general calorie content of meals and the proportions of individual nutrients.

Table 8: Rubric for assessment of working collaboratively in CS4 Portugal

Skills	Emerging	Developing	Consolidating	Extending
Teamwork **Interpersonal relationships and group functioning (emotional literacy)**	Observes and accepts the colleagues' proposals in the organisation of the group work, but gives no suggestions; merely accepts what the colleagues are doing (due to difficulties in interpersonal relationships).	Participates in the organisation of the group work, but only makes one or two suggestions that add little value to what was already done (due to difficulties in interpersonal relationships).	Participates in the organisation of the group work and gives positive suggestions contributing to a productive group dynamic.	Participates in the organisation of the group work and significantly contributes to a productive group dynamic, creating positive personal interactions (allowing the improvement of others and raising the work level).
Debating with peers (discussion)	Presents the obtained results without explaining how they were achieved.	Presents the results and describes how they were obtained.	Presents the results and explains the reasoning for obtaining them.	Presents the results, explains the reasoning for obtaining them and discusses those results.

Table 9: Registration grid for assessment of working collaboratively in CS4 Portugal

Behaviour	Student x	Student y	...
Does not interrupt when others speak			
Questions the colleague regarding what he is saying			
Defends his points of view			
Talks with kindness			
Challenges a quieter colleague to speak			
Congratulates colleagues when they present a positive idea			
Assumes an active role in order to solve conflicts between colleagues			
Defines/clarifies the work's objectives			
Defines/distributes/negotiates tasks among colleagues			
Draws attention to time			
Faced with distractions draws the group's attention to the work			

CS5 Hungary used a criterion-referenced approach and devised 4-level rubrics for the assessment of inquiry skills (Table 10). Critical thinking, which is an important component of the 21st century skills set and a pertinent part of *scientific literacy*, was assessed during Activity B: Food cards and Activity C: The washing line. For the most part, groups were assessed but the teacher managed to assess a few individuals as well. *Scientific reasoning* (making reasoned decisions) builds on critical thinking, and was assessed through teacher observation during Activity B: Food cards. During Activity D: Testing for fats, the students worked in teams to plan an experiment to establish the fat content of a particular food. During this task, the teacher could assess skill in both *planning investigations* and *working collaboratively*.

In both **CS3 Ireland** and **CS5 Hungary**, students used a placemat/window to record individual contributions and to decide on a group response (Figure 5). These were evaluated by the teacher to assess how the students cooperated and collaborated. In this way, it was possible for the teacher to evaluate student performance individually and as a group.

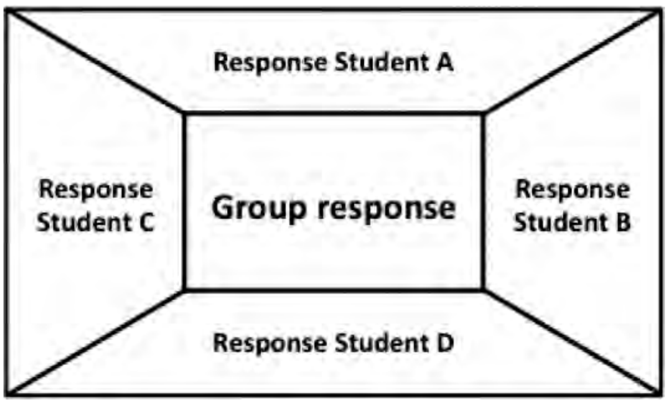


Figure 5: Placemat/window for peer discussion

Table 10: Assessment of skills in CS5 Hungary

Skill	Emerging	Developing	Consolidating	Extending
Critical thinking (scientific literacy)	Correctly orders a sufficient number of food cards for each nutrient with no interpretation.	Correctly orders a sufficient number of food cards for each nutrient, draws appropriate conclusions about individual groups of nutrients and occasionally about combinations of 2 nutrients.	Correctly orders all available food cards and draws appropriate conclusions for a combination of 2 or 3 groups of nutrients. Brings up considerations of quantity in discussion.	Correctly orders all available food cards and draws appropriate conclusions about all groups of nutrients in combination. Makes a valid point about quantity in discussion.
Scientific reasoning (making reasoned decisions)	Mentions ideas but does not write them down. Does not respond to the arguments of others.	Mentions ideas and occasionally writes them down. Occasionally responds to the arguments of others.	Speaks and writes ideas in the form of decisions and occasionally supports these ideas with arguments. Represents a critical stance in discussion.	Speaks and writes ideas in the form of decisions and invariably supports them with appropriate arguments. Adopts or refutes others' arguments as appropriate.
Planning investigations	Does not have any ideas about how to plan the investigation or actively participate in the teamwork. Follows the calculation of the answers passively.	Has some ideas about how to plan the investigation and what method to use but has no confidence in implementation. Needs help to calculate the answers.	Chooses an appropriate method of investigation and can support the choice with arguments. Can plan the details of the investigation. Can calculate the answers correctly.	Speaks and writes ideas in the form of decisions and invariably supports them with appropriate arguments. Adopts or refutes others' arguments as appropriate.
Working collaboratively	Written communication lacks confidence, information or is entirely absent. Communicates more fluently in speech but lacks purpose.	Communicates fluently in writing but some information is missing. Attempts to express independent opinion but lacks confidence. Oral communication is more fluent and usually has purpose.	Communicates fluently in writing and expresses independent opinion with confidence. Communicates fluently and with purpose in speech but the arguments are not always apt. Listens to others and occasionally reflects on their opinions.	Communicates fluently in writing and expresses independent opinion with confidence. Communicates fluently and with purpose in speech and presents apt arguments. Listens to others, reflects on their opinions, shows flexibility and gives in to arguments if appropriate.

INQUIRY AND ASSESSMENT UNIT

GLOBAL WARMING

Global warming – how can we cool it?

Christian Rydberg, Gultekin Cakmakci

GLOBAL WARMING

GLOBAL WARMING – HOW CAN WE COOL IT?

Overview

KEY CONTENT/CONCEPTS

- Greenhouse effect
- Carbon cycle
- Global warming

LEVEL

- Lower second level
- Upper second level

INQUIRY SKILLS ASSESSED

- Forming coherent arguments
- Working collaboratively

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

- Scientific reasoning (argumentation; making comparisons)
- Scientific literacy (analysis and interpretation of scientific data; using scientific data)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials (written arguments)
- Presentations

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – GLOBAL WARMING

The **Global warming** SAILS inquiry and assessment unit aims to enable students to consider scientific data and determine whether or not the evidence supports the phenomenon of global warming. An additional activity presents an opinion piece, which the students should critique to judge its scientific merit. This activity may be implemented at lower or upper second level depending on the curriculum's objectives, and is proposed as a *bounded inquiry*.

The key skills that can be developed through these activities are *forming coherent arguments, working collaboratively* and *scientific reasoning*. Students also enrich their *scientific literacy* through the evaluation and use of scientific data/ information. The assessment method emphasised is that of self-assessment, and rubrics are provided for students to use for evaluation of their own work.

The unit was trialled by teachers in Denmark, United Kingdom and Belgium, producing four case studies of classroom implementation. These four case studies describe the experiences of students at both lower and upper second level, aged 14-18 years. The participating classes consisted of both mixed and single gender (all-girls), and students were of mixed ability. The key skills assessed were *forming coherent arguments, scientific reasoning* and *scientific literacy*, with an emphasis on the analysis and interpretation of scientific data and distinguishing opinions from facts. The assessment methods used include self-assessment, peer-assessment, classroom dialogue and evaluation of student's worksheets and other artefacts.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The activities in the **Global warming** SAILS inquiry and assessment unit were developed by the team at Malmö University as part of the SAILS project. In this unit, two activities are outlined. The first activity – "Greenhouse" – was developed by the OECD [1] as a sample science task for PISA assessment, and was adapted for the SAILS project. In this first activity (A: Interpreting the evidence), students are provided with graphs that show the emission of carbon dioxide to the atmosphere over a 135 year period, and the fluctuation in the average global temperature over the same time period. The students are first asked to support the proposed argument that "the increase in mean temperature in Earth's atmosphere is caused by the increased emission of carbon dioxide," and then are asked to argue against the same statement. This activity develops students' skill in *forming coherent arguments*, while also increasing their *scientific literacy* by encouraging critical thinking. In the second activity (B: Forming scientific arguments), an opinion piece on the topic of global warming is provided and students are asked to produce a written response. They should use their knowledge about global warming, the carbon cycle and scientific methods, to address the arguments presented. Students should evaluate the opinion piece, and identify which arguments are based on facts and which are based on values and opinions. In this way they develop their *scientific literacy*, becoming better equipped to evaluate the opinions of others, and to become critical thinkers.

Opportunities within this unit allow for the assessment of the inquiry skill of *forming coherent arguments*, by asking the students to form conclusions and support these using reasoned arguments and evidence. In addition, there is scope for development of the skills of *working collaboratively, scientific reasoning and scientific literacy*.

Activity A: Interpreting the evidence

Concept focus	Greenhouse effect and global warming Interpretation of scientific data to provide evidence to support or to disprove the idea of global warming
Inquiry skill focus	Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (problem-solving, making comparisons) Scientific literacy (explaining phenomena scientifically)
Assessment methods	Classroom dialogue Peer-assessment Self-assessment Student devised materials Presentations

This activity was developed by the OECD, Take the Test Sample Questions from OECD's PISA Assessments, http://www.oecd.org/pisa/pisaproducts/Take%20the%20test%20e%20book.pdf, 2009. Information on licencing of this activity is available at the end of the unit.

Rationale

In this activity, students are provided with information regarding the greenhouse effect, and the concept of global warming is introduced. They are then provided with scientific data, and asked to interpret the data to provide evidence that can support or disprove the hypothesis that the increase in the mean temperature of Earth's atmosphere is caused by the increased emission of carbon dioxide.

Suggested learning sequence

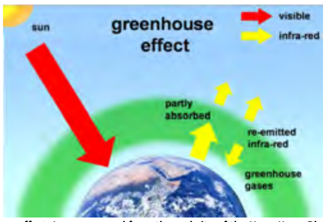
1. The lesson starts with an introduction to the greenhouse effect and global warming. A whole-class debate or small group discussion can be used as a warm-up activity to review prior knowledge and preconceptions. A student handout may be provided, such as that shown in Figure 1.

2. Students are then asked to consider two graphs, one detailing carbon emissions since the Industrial Revolution and the other showing mean global temperature over the same time period. A student handout or worksheet is proposed for this activity (Figure 2).

[1] OECD, Take the Test Sample Questions from OECD's PISA Assessments, http://www.oecd.org/pisa/pisaproducts/Take%20the%20test%20e%20book.pdf, 2009 [accessed October 2015]

The Greenhouse Effect: Fact or fiction?

Living things need energy to survive. The energy that sustains life on the Earth comes from the Sun, which radiates energy into space because it is so hot. A tiny proportion of this energy reaches the Earth. The Earth's atmosphere acts like a protective blanket over the surface of our planet, preventing the variations in temperature that would exist in an airless world. Most of the radiated energy from the Sun passes through the Earth's atmosphere. The Earth absorbs some of this energy, and some is reflected back from the Earth's surface. Part of this reflected energy is absorbed by the atmosphere. As a result of this the average temperature above the Earth's surface is higher than it would be if there was no atmosphere. The Earth's atmosphere has the same effect as a greenhouse, hence the term *greenhouse effect* (see image below).



Greenhouse effect. Image sourced from the website of the Hong Kong Observatory: http://www.hko.gov.hk/climate_change/faq/faq_e.htm#Q4

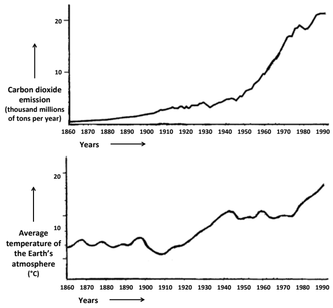
The greenhouse effect is said to have become more pronounced during the twentieth century and the first part of the twenty-first century. It is a fact that the average temperature of Earth's atmosphere has increased. In newspapers and periodicals the increased carbon dioxide emission is often stated as the main source of the temperature rise in the twentieth century.

Figure 1: Handout to introduce the topic of global warming.

Activity A: Interpreting the evidence

Based on "Greenhouse," by the OECD, Take the Test Sample Questions from OECD's PISA Assessments, http://www.oecd.org/pisa/pisaproducts/Take%20the%20test%20e%20book.pdf, 2009.

Student A is interested in the possible relationship between the average temperature of the Earth's atmosphere and the carbon dioxide emission on the Earth. When searching for information, he finds the following two graphs.



Graphs showing emission of carbon dioxide and mean global temperature from 1860 to 1995.

From these two graphs, student A draws the conclusion that it is certain that the increase in the average temperature of the Earth's atmosphere is due to the increase in the carbon dioxide emission.

Task 1. Where in the graphs can support be found for the conclusion made by Student A that the increase in mean temperature in Earth's atmosphere is caused by the increased emission of carbon dioxide? Give supportive arguments for this conclusion with reference to the graphs. Use the rubric to check your answer.

Task 2. Another student, Student B, thinks that the conclusion by Student A is wrong. She compares the graphs and claims that some parts of the graphs do not support the conclusion that the increase in mean temperature in Earth's atmosphere is caused by the increased emission of carbon dioxide.
Identify the parts of the graphs that do not support the conclusion by Student A and present supportive arguments for the conclusion made by Student B. Use the rubric to check your answer.

Figure 2: Student worksheet for Activity A: Interpreting the evidence.

3. The students are given asked to consider the statement "From these two graphs, student A draws the conclusion that it is certain that the increase in mean temperature in Earth's atmosphere is caused by the increased emission of carbon dioxide." Students are asked to form arguments in support of Student A, using evidence from the graphs.
4. After completion of this task, students can engage in peer- or self-assessment. Rubrics are provided, which detail the criteria for assessing skill in using scientific information (see assessment of activities for inquiry teaching & learning section of this unit, Table 1).
5. In the second task in Activity A: Interpreting the evidence, students are asked to consider the conclusions drawn by Student B, who thinks that the conclusion by Student A is wrong (Figure 2). Student B compares the graphs and claims that some parts of the graphs do not support the conclusion that the increase in mean temperature in Earth's atmosphere is caused by the increased emission of carbon dioxide. Students are now asked to form arguments in support of Student B, again using evidence from the graphs.
6. Students can again engage in peer- or self-assessment using the provided rubrics to assess their skills in using scientific information (assessment of activities for inquiry teaching & learning section of this unit, Table 1).

Activity B: Forming scientific arguments

Concept focus	Greenhouse effect and global warming Distinguishing opinion from facts
Inquiry skill focus	Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (argumentation) Scientific literacy (analysis and interpretation of scientific data)
Assessment methods	Classroom dialogue Peer-assessment Self-assessment Student devised materials

Rationale

In this activity, the students read a quote from Governor Rick Perry, from a press conference when Perry described his doubts about global warming. Students are asked to evaluate the quote and distinguish the parts that are scientific evidence and those that are opinion. In this way, they can develop their skills of critical thinking and evaluating evidence to form their own opinions.

Suggested learning sequence

1. The students are asked to carefully review the quotation from Governor Rick Perry, shown in Figure 3.
2. The teacher asks the students, "How would you argue against the argument made by Rick Perry"
3. Students are asked to write their response, presenting their arguments, which should be based on their knowledge of global warming, the carbon cycle and other scientific methods.
4. The teacher can prompt the students, by asking them to consider the types of argument used by governor Perry, "Which arguments are based on facts and which are based on opinions and values?"
5. The assessment of the students' written work can be carried out using peer- or self-assessment, using a rubric (see assessment of activities for inquiry teaching & learning section, Table 2). Aspects for evaluation are analysis of Perry's argument, counter argument offered and justified, and use of scientific information to do so.

Activity B: Forming scientific arguments

Rick Perry is a governor in Texas and was one of the republican candidates for the US election in 2002. The quote below comes from a press conference, when Perry described his doubts about global warming.

"I do believe that the issue of global warming has been politicised. I think there are a substantial number of scientists who have manipulated data so that they will have dollars rolling into their projects. I think we're seeing it almost weekly or even daily, scientists who are coming forward and questioning the original idea that man-made global warming is what is causing the climate to change. Yes, our climates change. They've been changing ever since the earth was formed. /…/ The science is not settled on this. The idea that we would put Americans' economy at jeopardy based on scientific theory that's not settled yet to me is just nonsense."

How would you argue against the argument made by Rick Perry?
Write a text where you use your knowledge about global warming, the carbon cycle, scientific methods, etc. Think about what kind of arguments Perry makes use of – which are based on facts and which are based on values and opinions?

Do not forget to provide scientific justifications for your arguments. Adapt your text in order to convince supporters of Perry's argument. Use the rubric to check your answer.

Figure 3: Student worksheet for Activity B: Forming scientific arguments.

2.2 Assessment of activities for inquiry teaching & learning

This unit is particularly suitable for assessing the skills of *forming coherent arguments* and *scientific reasoning* (argumentation, comparing), and developing students' *scientific literacy* by encouraging students to evaluate scientific data and to make reasoned decisions. Students are facilitated to work collaboratively and collate ideas based on views from team members.

Suggested assessment rubrics are provided for use as peer- or self-assessment tools for evaluation of *forming coherent arguments* and using *scientific information* (scientific literacy).

Table 1: Assessment of skill of using scientific information, Activity A: Interpreting the evidence

Skill assessed	Level 1	Level 2	Level 3
Using scientific information	Makes reference to both graphs (as a whole).	Makes reference to both graphs (as a whole and in detail).	Makes reference to both graphs (as a whole and in detail).
	Presents supportive arguments for at least one of the student's conclusions.	Presents supportive arguments for both of the student's conclusions.	Presents several supportive arguments for both of the student's conclusions.
	Attempts to provide scientifically reasonable justifications for arguments.	Provides scientifically reasonable justifications for arguments.	Provides scientifically valid justifications for arguments.

Table 2: Assessment of skills considered in Activity B: Forming scientific arguments

Skill assessed	Level 1	Level 2	Level 3
Analysing arguments	Identifies any of Perry's arguments.	Justifies whether a selected argument made by Perry is based on opinions and/or scientific facts.	Identifies whether Perry's arguments are based on opinions and/or scientific facts.
Providing counter arguments	Provides a counter argument to any of Perry's arguments.	Provides counter argument to more than one of Perry's arguments.	Provides counter argument to Perry's arguments.
Justifying arguments	Bases own arguments on opinions and/or scientific facts.	Bases own arguments on scientific facts.	Bases own arguments on scientific facts.
Using scientific knowledge	Attempts to use scientific concepts, models, and theories for supporting arguments.	Uses scientific concepts, models, and theories for supporting arguments.	Uses relevant scientific concepts, models, and theories in a correct way for supporting arguments.

3. SYNTHESIS OF CASE STUDIES

The **Global warming** SAILS inquiry and assessment unit was trialled in three countries, producing four case studies of its implementation – **CS1 Denmark**, **CS2 United Kingdom**, **CS3 United Kingdom** and **CS4 Belgium**. The case studies were implemented by teachers with some experience of teaching through inquiry, but the students had varied experience. Those in **CS1 Denmark** and **CS2 United Kingdom** had no prior experience in inquiry, while the students in **CS3 United Kingdom** and **CS4 Belgium** had some experience of inquiry in their classrooms. The unit was implemented in one or two lessons, up to 120 minutes duration.

The case studies describe classroom experiences at both lower and upper second level. **CS3 United Kingdom** and **CS4 Belgium** describe implementation at upper second level, although with two different age ranges, 14-15 years and 17-18 years, respectively. In **CS1 Denmark** and **CS2 United Kingdom** the unit was implemented with students from lower second level. Most implementations describe classes of mixed ability and gender, although in **CS3 United Kingdom** the class was "set 2 of 8," a class of uniform ability formed as a result of standardised testing in the previous school year, and students in **CS2 United Kingdom** were all girls.

The key skills assessed in the case studies were *forming coherent arguments* and *scientific reasoning* (argumentation). In addition, some teachers also assessed students' skill in *working collaboratively* and their *scientific literacy*, evidenced by their ability to analyse and interpret scientific data and distinguish opinions from facts. Self- and peer-assessment were also widely used for evaluation of skills, as well as classroom dialogue and student artefacts.

3.1 Teaching approach

Inquiry approach used

The inquiry approach used in all the case studies is described as a *bounded inquiry* approach, i.e. it was guided in the sense that the teacher prompted engaging questions but there were open inquiry opportunities where students had freedom in addressing the questions.

Implementation

The **Global warming** SAILS inquiry and assessment unit was implemented in full in all case studies (Activities A and B), although the manner in which it was implemented varied depending on students' level and local curricula. Implementation of the unit took place in one or two lessons, as detailed in Table 3. In general, the teachers did not significantly change the unit and trialled it as proposed.

In **CS1 Denmark**, the unit was implemented as part of a topic on energy and environment. The teacher provided an outline of the work on the blackboard, in order to optimise the students' understanding of the tasks to be undertaken. Students were allowed to choose whether to work alone or in pairs, and all but one student chose to work with a peer. In **CS2 United Kingdom**, the implementation was in a single class, so although the entire unit was provided, students were allowed to select a single task that they wished to complete.

In **CS3 United Kingdom**, the teacher noted that engaging students in the task was something of a challenge because it was very wordy with a lot of "dense" text. This teacher suggests that the unit needs more visual appeal – to make it look more

Table 3: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Denmark	Activities A-B	One lesson (120 min)	• Worked in pairs, one student worked alone (19 students) • Student selected; mixed ability, mixed gender pairs
CS2 United Kingdom	Activities A-B	One lesson (50 min)	• Groups of 2-3 students (single sex, female) • Teacher assigned "pods" of 6 students; mixed ability
CS3 United Kingdom	Activities A-B	Two lessons (60 min each)	• Groups of 4 students (20 students) • Teacher assigned; similar ability and mostly mixed gender
CS4 Belgium	Activities A-B	One lesson (50 min)	• Groups of 3-4 students (three classes) • Student selected; mixed ability and gender

interesting and less scary. References to the non-English language text had to be made with a number of groups on a number of separate occasions, despite an earlier whole class explanation. The teacher also mentioned that identifying the specific tasks within the text was an issue. Students were able to identify the first task fairly easily, but most of them failed to identify where the second task was. They also struggled to handle the two arguments simultaneously. This suggests that the task should be modified or that the teacher should closely facilitate the students' learning.

In **CS4 Belgium** the implementation was with upper second level students, who would continue on to study sciences or engineering in university. The teacher provided the material in English to the students, and did not translate the tasks to Dutch. The teacher suggests that future implementation of similar tasks might be done in cooperation with language teachers, allowing students to develop their skills in reading scientific texts. This teacher carried out analysis of grades assigned by self-, peer- and teacher-assessment, and discussed the analysis with the students, to highlight the need to be critical in examination of others' opinions during assessment.

Adaptations of the unit

No significant changes were made in the implementation of this unit in **CS1 Denmark** or **CS3 United Kingdom**. While the implementation in the other two case studies mostly followed that of the proposed inquiry and assessment, some modifications were made. These were to suit the level of the students, the skills chosen to be assessed or to align with state curricula or teaching strategies.

In **CS2 United Kingdom**, the teacher made several changes to the student handout. There were two reasons identified for these changes – first, to personalise the handout to make it more accessible and, second, to increase the challenge. As this was an all-girl school, the teacher included images of two girls to represent "student A" and "student B" in the worksheet for Activity A (Figure 2). In addition, female names were given to the two students (Linda and Alifa), to allow the students to identify more greatly with the students in the task. The teacher provided additional graphs and diagrams to increase the challenge and to allow the students to further develop their skills in analysing and interpreting scientific data. These images included English text, to avoid confusion created by use of non-English text in the original documents provided to the teachers trialling this unit.

In **CS4 Belgium**, the assessment rubrics were used for both self- and peer-assessment. The teacher modified the handout to include a section for student responses and for the assessment.

3.2 Assessment strategies

Within the four case studies, the inquiry skills of *forming coherent arguments* and *working collaboratively* were assessed, as well as *scientific reasoning* (argumentation) and *scientific literacy* (analysis and interpretation of scientific data), as detailed in Table 4. The assessment methods used include self-assessment and peer-assessment, as outlined in the assessment of activities for inquiry teaching & learning section of this unit, as well as classroom dialogue, teacher observation and evaluation of student artefacts (worksheet, student devised materials or presentations).

Table 4: Inquiry skills identified by teachers in the case studies

CS1 Denmark	• Forming coherent arguments • Working collaboratively • Scientific reasoning (argumentation)
CS2 United Kingdom	• Forming coherent arguments • Working collaboratively (communication) • Scientific reasoning (argumentation • Scientific literacy (analysis and interpretation of data)
CS3 United Kingdom	• Forming coherent arguments • Working collaboratively • Scientific reasoning (argumentation) • Scientific literacy (analysis and interpretation of data)
CS4 Belgium	• Forming coherent arguments • Working collaboratively • Scientific reasoning (argumentation, making comparisons) • Scientific literacy (analysis and interpretation of data)

In **CS1 Denmark**, three assessment methods were used – classroom dialogue, assessment of student devised materials and self-assessment. The students asked the teacher questions throughout the lesson, and at the end of the lesson the teacher provided a small oral follow-up to provide formative feedback. In addition, the students handed in their written work, and the teacher commented on their work. The students engaged in self-assessment, as outlined in the unit, but the teacher noted that they had some difficulties with this, as they wording was not student-friendly. Nonetheless, using the rubrics students evaluated their arguments, and modified their work to improve their performance level.

In **CS2 United Kingdom**, the students prepared poster presentations, and peer-assessment using Post-It notes was carried out at the end of the session. The teacher gave students time at the end of the lesson (10 minutes) to give feedback and to improve some of their answers. Initially some students provided only a grade, and did not include feedback or reasoning for their decisions. The teacher prompted them to provide formative feedback by reminding them to include "what worked well" (WWW) and "even better if" (EBI) comments, an approach that they are familiar with from their previous experiences.

In **CS3 United Kingdom**, the teacher observed the students as they worked within their groups and kept mental notes, which influenced the teacher's judgment about how well students achieved in development of inquiry skills. The teacher provided formative feedback during the class discussions (verbal feedback, which the students responded to), allowing students to identify the elements of their attainment and how they could improve their work. The teacher also drew on the student's responses to questions asked during the activity and plenary to further inform his judgment along with an analysis of the written reports produced by individual students.

In **CS4 Belgium**, students assessed their own arguments and those of their peers, by using the two rubrics provided in the unit. Performance levels assigned by self-, peer- and teacher-assessments were analysed and the results shared with the students. The degree of variation between peer- and self-assessment and the grade assigned by the teacher was highlighted. The teacher provided feedback in each class, highlighting the need to be critical in examining the work of others' and to distinguish opinion from fact.

INQUIRY AND ASSESSMENT UNIT

HOUSEHOLD VERSUS NATURAL ENVIRONMENT

The consequences of daily decisions

Iwona Maciejowska

HOUSEHOLD VERSUS NATURAL ENVIRONMENT

THE CONSEQUENCES OF DAILY DECISIONS

Overview

KEY CONTENT/CONCEPTS
- Properties of cleaning and washing agents
- Ecotoxicity

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 (considering the influence of various factors)
- Scientific literacy (drawing conclusions using reasoned arguments and evidence, presenting scientific results, searching for information)

ASSESSMENT METHODS
- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials ("natural" soaps and detergents, documentation of inquiry, final report)
- Presentations
- Other assessment items (true/false test)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – HOUSEHOLD VERSUS NATURAL ENVIRONMENT

The **Household versus natural environment** SAILS inquiry and assessment unit focuses on the environmental implications of the use of cleaning agents. Students investigate the growth of cress in various conditions, allowing them to determine the impact of commonly used household chemicals on the environment. Students assess the consequences of daily decisions taken in their homes and thus develop a sense of responsibility for the actions they take. This unit is recommended for implementation at both lower and upper second level, as a *guided* or *open inquiry* conducted over two lesson periods.

This unit can be used for development of many inquiry skills, in particular *planning investigations, developing hypotheses* and *working collaboratively*. In addition, students can develop their *scientific reasoning* skills through collecting data and drawing conclusions, and enrich their *scientific literacy* by critically evaluating their investigations. Some assessment methods described include teacher observation, use of student artefacts and self-assessment.

This unit was trialled by teachers in Ireland, Greece, Portugal and Poland – producing six case studies of implementation (lower and upper second level students; mixed ability and gender). Key skills assessed were *planning investigations*, *working collaboratively* and *forming coherent arguments*. This activity was shown to enrich students' *scientific literacy*, in particular the ability to present scientific data and to understand the environmental impact of household chemicals. The assessment was based on teacher observation and the evaluation of students' presentations.

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 **Household versus natural environment** SAILS inquiry and assessment unit were based on the "Sustainable washing for a clean environment" project,[1] which was further developed by the FP7 ESTABLISH project unit Chemical care.[2] The activity was adapted for the SAILS project by the team at Jagiellonian University.

Concept focus	Properties of household cleaning and washing agents Ecotoxicity
Inquiry skill focus	Developing hypotheses Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (considering the influence of various factors) Scientific literacy (drawing conclusions using reasoned arguments and evidence, presenting scientific results)
Assessment methods	Classroom dialogue Teacher observation Worksheets or student devised materials Presentations

Rationale

The problem under consideration in this unit is the ecological consequences of the use of cleaning agents at home (e.g. detergents used to clean textiles). The investigation outlined allows students to assess the consequences of everyday decisions in a scientific way. The aim is to give 14 to 18-year-old students an insight into the potential environmental effects of the incorrect use of household chemicals, such as detergents. Various household detergents may be the subject of investigation, which will allow the teacher to match the activities to the students' interests. In addition, the proposed activity may be implemented as a *guided* or *open inquiry*, as appropriate for the student group.

This unit also offers an opportunity to address some common misconceptions, such as "all chemicals are toxic" or the idea that the toxicity does not depend on the concentration – it is important that students learn that some chemicals are not harmful or dangerous at low concentrations. Students are also encouraged to discuss the topic and develop tips on the safe use of cleaning agents and detergents in households, as well as to find information about other ecological tests that are used in industry.

Skills which can be developed include *planning investigations* (designing and conducting an experiment), *developing hypotheses* (identifying scientific questions and putting forward hypothesis), carrying out experiments, *forming coherent arguments* (drawing conclusions using reasoned arguments and evidence), *scientific reasoning* (consideration of the influence of variables) and *working collaboratively* (collaboration and cooperation), all of which enrich students' *scientific literacy*.

Suggested learning sequence

The implementation of the **Household versus natural environment** SAILS inquiry and assessment unit is recommended to cover two separate lesson periods. In the first lesson, students are introduced to the topic and inquiry, after which they design an experiment to investigate the impact of a household cleaning agent on the environment. They are then given a homework task, which should take one week – "conduct your experiment." In the second lesson, students present their findings to the class and engage in whole-class or group discussions to form recommendations for the everyday use of cleaning and washing agents in the home. A final homework task is assigned, in which the students search for information on professional ecological tests.

Lesson 1

1. Introduction

The teacher asks students to list cleaning and washing agents that they and their families use at home. Based on students' prior knowledge (gained from primary school, or other subjects e.g. biology or earth sciences classes) the teacher proposes a discussion on the possible consequences of the use of cleaning agents on the environment. For example, "Wastewater from households is thoroughly cleaned in sewage treatment plants, so that it can be discharged into the surface water system. What would happen if we discharged our wastewater into the environment without subjecting it to any sort of treatment beforehand?" Once the students have had an opportunity to discuss this or similar topics and have engaged with the concepts, the teacher can introduce the next phase of the lesson.

2. Planning an experiment

Students should work together in small groups to plan an experiment to investigate the influence of a cleaning agent on the growth of plants. The unit can be organised either as an *open inquiry* (various cleaning agents, various species – aquatic, terrestrial plants) or *guided inquiry* (influence of laundry detergent on the growth of garden cress), depending on the students' IBSE experiences and competencies. For a *guided inquiry*, the teacher can provide a student worksheet with a short procedure (Figure 1), but this should only be provided after some open discussion.

[1] "Sustainable washing for a clean environment. Chemistry for advanced classes (14 to 18 year-olds)" project between the University of Oldenburg, the University of Rostock and Henkel AG & Co. KGaA, Düsseldorf (2007/08)

[2] Establish Chemical care, http://www.establish-fp7.eu/resources/units/chemical-care [accessed October 2015]

- Discuss with peers what you would like to investigate – ask scientific questions, identify and define variables e.g. different concentrations of the laundry detergent
- Put forward/formulate your hypothesis of the impact of your suggested factors
- Plan/design the experiment to check your hypothesis. Decide what you will observe or measure and how you will make these measurements. Write down your plan.

3. Homework

At the end of the first lesson, the students are given a homework exercise: “Perform/conduct/carry out the experiment to find out the impact of your chosen cleaning agent on the environment.” They are asked to record their observations, for example “How did the plant change under the influence of the cleaning agent?” and to analyse their data to look for trends and relationships. Again, this assignment can be entirely open or a *guided approach*, where the teacher provides a sample table for collection of data, can be used.

Lesson 2

4. Presentation of results

The students present the results of their group work, which should be in the form of tables and graphs, to the whole class. They should draw appropriate conclusions based on the evidence they present. Students are encouraged to compare their results with those obtained by other groups, if possible. They should try to identify any possible sources of inconsistency.

5. Peer discussion and evaluation

After the presentations, the students’ ability to transfer the knowledge gained in their investigation to another context is probed. The students are asked to discuss with their peers and note any recommendations they have formed regarding the everyday use of cleaning and washing agents in the home. Some prompt questions can be useful here, such as, “What is the situation? What should it be? Why isn’t it as it should be? What can be done?” Students should form their recommendations in the group discussion and present them to the class as a poster.

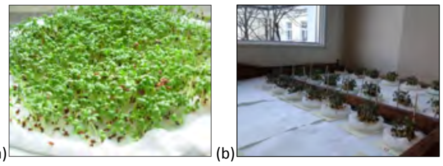
6. Homework

As a final task in this unit, the students are set a homework exercise to search for information on ecological tests using the internet or other sources. For example, students could be asked to investigate the following statement: “Cress is often not suitable for use in ecological tests, because it reacts relatively insensitively to many chemicals. Instead, organisms such as bacteria, algae, water fleas or small fish are used.” They can be asked to find out about professional ecological tests and to describe two examples: What do they test? How do they test it? Students should quote their sources.

Investigating the influence of laundry detergent on the growth of garden cress

In this experiment, the detergent solution represents wastewater, and cress plants represent the environment

Typical apparatus and materials [per pair of students]: 7 dishes (e.g. crystallising dishes), 1 knife, 50 mL beaker, 100 mL graduated cylinder, 2 500 mL beakers, stirring rod, 20 mL graduated pipette, pipette filler, felt-tip pen, liquid detergent for coloured fabrics, 4 trays of garden cress (Figure 1a)



(a) (b)

Figure 1. Cultivation of cress

Procedure: Take the cress out of each tray, together with the mat in which it is growing. Use the knife to cut each mat in two. Place each half in its own dish. One half is left aside. Place the seven dishes in a row and mark them with the numbers 1 to 7. Prepare the solutions.* Leave the cress in the dishes for a period of 5 to 7 days in normal light (Figure 1b). Add tap water as necessary to replace any water that evaporates, so that the volume of solution in each dish remains at its original level.

Proposed concentration of liquid detergent in the series of dishes: **1. Blank sample, **2.** 0.01 mL/L, **3.** 0.1 mL/L, **4.** 1 mL/L, **5.** 10 mL/L, **6.** 100 mL/L, **7.** 1000 mL/L*

Disposal: Pour the detergent solution down the sink. Put the cress dishes in the waste bin.

Figure 1: Example of a student worksheet for guided inquiry

2.2 Assessment of activities for inquiry teaching & learning

In this section we present some tools for formative assessment of the following competencies: students’ prior knowledge, involvement in the discussion, inquiry plans, data presentation, ability to search for information and group work. Several key opportunities have been identified for the assessment of inquiry skills during this activity, and tools for the assessment include observation sheets, rubrics and self-assessment cards. It is recommended that the teacher pre-select some students for evaluation through in-class observation, while all students can be assessed through collection of student artefacts, such as group worksheets.

Working collaboratively

During the introductory lesson, the teacher can observe pre-selected students and assess their skill in *working collaboratively* (engagement) and prior knowledge. An observation chart is recommended for this assessment (Table 1), in which the teacher records the responses given and the level of correctness (full/partial/incomplete/wrong).

Table 1: Observation card for the assessment of engagement

Student name	Engagement (names of cleaning and washing agents)	Engagement (possible consequences of use of the chosen cleaning agent in the environment)	Prior knowledge (correctness of answer)

After implementation of the unit, students can complete a self-assessment questionnaire (Table 2). This is based on a resource developed by the Assessing Group Practice project.[3] The adapted assessment instrument enables students to self-assess their contribution to the group and their ability to cooperate. They can also be asked to identify which two of the described skills they consider to be their strengths, and which two skills they should work on. This facilitates reflection on their skills in *working collaboratively*.

Table 2: Student self-assessment

Assessment criteria	Seldom	Sometimes	Often
1. Effort: I contributed as much as I could to group discussions and to the work required			
2. Risk-taking: I took risks by exploring something new to me			
3. Cooperation: I worked cooperatively with other members of my group			
4. Respect: I listened to others' ideas, respected them, considered their points of view			
5. Collaboration: I was flexible and willing to follow others but also took initiative when needed			
My two most important strengths in group work (from the list above) are:			
Two skills in group work (from the list above) which I need to work on are:			

Planning investigations

During the planning phase of the first lesson, the teacher can use a rubric to assess the group, rather than individual students. The proposed 4-level rubric is cumulative, in which an excellent student should be able to achieve the criteria identified for each performance level (Table 3). The rubric will depend on the teaching approach, and can be revised to reflect an *open* or *guided inquiry*. Evaluation of individual contributions to the group work can be based on students' self-assessment (Table 2). This rubric can be used for on-the-fly evaluation or for analysis of submitted experimental plans.

Table 3: Assessment of planning investigations

Poor	Acceptable	Good	Excellent
The group… propose a cleaning agent and a plant, enumerate 1-2 steps of an investigation plan,	and… propose a factor/variable which they would like to investigate, enumerate basic steps of an experimental plan,	and… formulate a hypothesis, enumerate almost all steps of an experimental plan, consider standardisation of a procedure	and… propose a consistent and complete procedure.

[3] R80 Student Self Evaluation Form for Group Work,

http://www.lancaster.ac.uk/palatine/AGP/resources/r80.doc [accessed October 2015]. A similar Group Work Self-Assessment Rubric is available from http://schools.sd68.bc.ca/cila/ireland/govt/evaluation_group.htm [accessed October 2015]

Assessment of scientific literacy – presentation of scientific data

The second lesson commences with a presentation of results by each of the groups. A rubric is proposed for the assessment of a groups' work (Table 4). Evaluation of individual contributions to the group work can be based on students' self-assessment (Table 2).

Table 4: Assessment of scientific literacy – presentation of scientific data

Poor	Acceptable	Good	Excellent
The group presents results only in descriptive way. The group presents conclusions but neither completely nor correctly and without supportive evidence.	The group presents results in the form of a table or graph. The group draws conclusions, but they are not completely correct.	The group presents results in the form of table and graph. The group draws appropriate conclusions but they are not fully supported by arguments and evidence.	The group presents results in the form of table and graph. The group draws appropriate conclusions that are supported using reasoned arguments and evidence and identifies possible sources of inconsistency.

Assessment of scientific literacy – searching for information

A homework exercise is assigned at the end of the second lesson, where students are asked to search for information about ecological tests. They should be able to find out information and quote their sources. A rubric can be used to assess students' skill in searching for information (Table 5).

Table 5: Assessment of scientific literacy – searching for information

Poor	Acceptable	Good	Excellent
The student finds out information from one internet-based source, does not quote the source. The student describes ecological tests improperly (in an incorrect or incomplete way).	The student finds consistent information from 1-2 sources, but does not pay attention to the independence of the sources and does not quote the source. The student copies a description of ecological tests directly from the source.	The student finds consistent information from at least two substantially different sources and quotes all or almost all sources of information. The student describes ecological tests correctly using his/her own words.	The student finds consistent information from at least two substantially different sources and quotes all sources of information. The student describes ecological tests correctly using his/her own words.

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in four countries, producing six case studies of its implementation – **CS1 Ireland**, **CS2 Greece**, **CS3 Portugal** and **CS4-CS6 Poland**. In all case studies, the students involved had little or limited experience of inquiry learning and only in **CS1 Ireland** had the teacher significant experience in IBSE. The teachers used a *guided inquiry* teaching approach, which included the provision of student worksheets and specific guiding questions.

The unit is recommended for students aged 14-18 years, and was implemented with lower second level classes in **CS1 Ireland**, **CS2 Greece** and **CS3 Portugal** and at upper second level in the Polish case studies (**CS4-6**) and one class in **CS1 Ireland**. The students worked in smaller groups, usually of 3-5 students. The groups were mostly formed independently by the students, but in **CS4 Poland** student groups were assigned by the teacher. Students in most classes were of mixed gender and ability, although in **CS1 Ireland** the class was all female.

The case studies identify the versatility of the unit in that it allowed the teachers to focus on different concepts and inquiry skills to be developed and assessed. It can be used at different levels, as shown in the case studies where it was used with lower and upper second level students. Finally, the case studies demonstrate a range of strategies and assessment data that can be collected to assess student inquiry development.

3.1 Teaching approach

Inquiry approach used

Since most students had not conducted studies using an IBSE strategy before, the teachers chose to use a *guided inquiry* teaching approach. Several of the teachers developed worksheets, which were provided to the students to guide their work (**CS1 Ireland**, **CS2 Greece**, **CS3 Portugal** and **CS6 Poland**).

There was some variation in the level of openness of the guided approaches used at various stages in the activities. In all case studies, examples of students being led by multiple teacher questions are evident.

Implementation

There were variations in how the unit was delivered in the different countries. In all case studies, whole-class discussions were used, but the majority of the activity was carried out in smaller groups. Information on group size and composition, as well as duration of implementation are summarised in Table 6. The group sizes ranged from pairs to groups of five. In general, groups were of mixed gender, although **CS1 Ireland** details implementation in a single sex school (all-girls) and **CS3 Portugal** observes that one single-sex grouping was formed in addition to a mixed gender group.

CS3 Portugal describes an optional implementation, in which students with free time were welcome to come to the lab and carry out the activity. The students in **CS4-6** (all **Poland**) participated as part of extracurricular classes.

The unit was, in most cases, carried out in the form of two lessons separated by independent work done at home or in a laboratory. Where the effect of detergents on the development of cress was examined, students studied the effect of various substances or of different concentrations of one substance. The teachers noticed that students were excited to be working in a laboratory (**CS3 Portugal**); they enjoyed their work and asked for more such lessons (**CS2 Greece**); they got involved in learning (**CS1 Ireland**). It was noted that working with a computer, including searching for information online, was enjoyed by the students.

The unit was implemented in full in all case studies, with little modification from the activities for inquiry teaching and learning

Table 6: Summary of case studies

Case Study	Duration	Group composition
CS1 Ireland	Two lessons (45 min each)	• Students worked in pairs or groups of 3 • Student selected; mixed ability; all-girl school (2 classes)
CS2 Greece	Two lessons (60 min each)	• Groups of 3-4 students (21 students total) • Student selected; mixed ability and gender
CS3 Portugal	Three lessons (50 min each)	• Groups of 3 or 4 students (7 students in total) • Student-selected; one single sex, one mixed gender group • Voluntary participation
CS4 Poland	Two lessons (60 min each)	• Groups of 3-4 students (16 students in total) • Mixed ability and gender; extracurricular class
CS5 Poland	Two lessons (90 min each)	• Two groups of 5 students (10 students in total) • Mixed ability and gender; extracurricular class
CS6 Poland	One lesson (60 min)	• Groups of 2-4 students (12 students in total) • Mixed ability and gender; extracurricular class

described in the unit, with the exception of **CS3 Portugal** in which the investigation looked at the preparation and use of natural, biodegradable detergents as alternatives to commercial cleaners. In **CS1 Ireland**, the lower level students only engaged in theoretical planning and did not carry out their investigations. In addition to investigating the effect of detergents on plants in **CS4 Poland**, the research was expanded to include the impact of salt (used in winter to remove snow from roads). The teacher felt that this connected well with the issues raised in the unit, and will expand the unit to assess effect of vinegar also (as a simulation of acid rain).

Adaptations of the unit

Most groups carried out a study on the impact of cleaning agents on the growth of cress. However, the younger students from **CS1 Ireland** finished their work doing the theoretical part only. Several of the case studies commenced with a discussion on cleaning agents used in households and their potential impact on the environment (**CS1 Ireland**, **CS4 Poland**, **CS6 Poland**). In **CS2 Greece**, however, the teacher presented two short videos (one video concerned how the cleaning agents are made, while the other presented an advertisement of an environment-friendly detergent) as a starting point for the investigation.

The most significant adaptation was reported in **CS3 Portugal**. Using a worksheet as a guide, the students were invited to answer the question "How can we contribute to raising awareness within the educational community on the issue of the environmental impact of human activity?" Students then engaged in a whole-class or group discussion to identify the key ideas emerging from this problem and searched online for information regarding how growth of human populations is affecting rivers and oceans around the world. The second phase (*planning investigations*) focused on identification of chemicals with a high impact on the environment, and proposing alternatives for these. Students were led to consider cleaners and detergents. They then prepared "natural" detergents and investigated their biodegradability using online resources.

In **CS5 Poland**, the students had discussed the impact of chemicals on the environment earlier during their studies, and they had also attended hands-on laboratory classes during which they synthesised detergent and soap. Therefore, they did not engage in a discussion to start the lesson and instead commenced the activity with planning an experiment.

In **CS6 Poland**, the students attended one lesson in which they engaged in planning investigations. They then agreed experimental parameters and a date for submission of presentations, which were sent to the teacher in electronic form. They did not attend a second lesson on this topic.

3.2 Assessment strategies

Within the six case studies, the teachers used a variety of formative and summative assessment strategies; these included teacher observation, teacher questioning, student self-assessment and analysis of student work. The following competences were evaluated: students' prior knowledge, involvement in the discussion, *planning investigations*, data presentation, skill in searching for information and group work.

The inquiry skills and competencies that were assessed are summarised in Table 7. Teacher and student rubrics were used in many of the case studies to help the teachers to make judgements on student work and for the students to assess their own development. Whilst students gained experience of many inquiry skills not all of these were assessed. *Developing hypotheses, forming coherent arguments* and *planning investigations* were each assessed in three of the six case studies, while several case studies describe evaluation of *scientific reasoning* capabilities and scientific literacy (**CS1 Ireland**, **CS4-6 Poland**).

Table 7: Inquiry skills identified by teachers in the case studies

CS1 Ireland	• Developing hypotheses • Scientific reasoning (identifying variables)
CS2 Greece	• Planning investigations • Forming coherent arguments
CS3 Portugal	• Developing hypotheses • Working collaboratively
CS4 Poland	• Developing hypotheses • Working collaboratively • Scientific literacy (searching for information, presentation of scientific results)
CS5 Poland	• Planning investigations • Forming coherent arguments • Scientific literacy (searching for information, presentation of scientific results)
CS6 Poland	• Planning investigations • Forming coherent arguments • Scientific reasoning (data entry and observations skills) • Scientific literacy (presentation of scientific data)

Some project partners and/or teachers developed their own assessment tools, e.g. worksheets (**CS1 Ireland**, **CS2 Greece** and **CS3 Portugal**), a true/false test (**CS6 Poland**) or their own rubrics, which were usually more detailed or more holistic than those provided in the assessment of inquiry teaching & learning section of this unit. For example, in **CS4 Poland**, the teacher prepared an expanded 3-level rubric for the assessment of presenting scientific data. The following criteria were also introduced: clarity, use of all features of the software, ability to present with ingenuity and to arouse listeners' interest, content, language correctness and drawing of conclusions supported by literature (Table 8).

Table 8: Assessment of scientific literacy – presentation of scientific data – in CS4 Poland

Inquiry skills	Standard (2 points)	Whole (4 points)	Extended (6 points)
Data presentation	Content layout is not clear. Features of the presentation software used to a small extent. Presentation not very interesting. Lack of self-confidence in the person who made the presentation. The information/content presented is not interesting, with spelling and punctuation mistakes. Chosen information is of little interest. The results are presented only descriptively. The conclusions are not drawn properly and are without additional support.	Content arranged properly. Features of the presentation software used to a large extent. Presentation interesting but students not well prepared. Information/content is connected with the topic, not many spelling and punctuation mistakes. The results are presented in tables and diagrams (proper descriptions, axes). The conclusions are drawn properly but not completely supported by additional literature.	Content arranged properly and with clarity. Features of the presentation software fully used. Presentation presented in a very interesting way. Accompanied by ingenuity and originality in presentation manner, arousing listeners' interest. The topic is elaborated in a very interesting way. All information is included without mistakes. The conclusions are drawn properly and fully supported by literature.

In **CS6 Poland**, the teacher prepared expanded 4-level rubrics for the assessment of *planning investigations*, observation skills, presentation of scientific data and *forming coherent arguments*. For each skill, there were 2-3 competencies and associated criteria for evaluation of performance identified.

In some cases, the teachers indicated that they had presented the evaluation criteria to the students (e.g. **CS1 Ireland** gave the evaluation criteria to the older students during the first lesson, and to lower second level students in their second lesson), and in other cases they had not. For example, in **CS3 Portugal** the teacher did not disclose the evaluation criteria in advance, but recommends that other teachers implementing this unit should analyse the assessment criteria in advance and should give clear instructions to the students to ensure they have full knowledge of what is to be assessed. In **CS2 Greece**, the teacher found that the rubric used by the students during the peer-assessment was not clearly understood by them, but the teacher believed it was not a problem of the rubric itself but rather a problem of the maturity of the students. In general, the assessment instruments provided in the unit were positively regarded by the teachers (**CS1 Ireland** and **CS2 Greece**).

Developing hypotheses

This skill was chosen for assessment in **CS1 Ireland**, **CS3 Portugal** and **CS4 Poland**. In Ireland, the teacher used the rubrics provided in the unit, without modification. In **CS3 Portugal**, the teacher expected that students would develop a hypothesis, which provides a link to the research question and includes a justification for that hypothesis. In **CS4 Poland**, the teacher used the 0-1 system to evaluate a good/bad hypothesis. In **CS6 Poland**, *developing hypotheses* was evaluated as a component of *planning investigations*, using a 4-level rubric.

Forming coherent arguments

Students' skill in *forming coherent arguments* was explicitly assessed in **CS2 Greece**. This skill was evaluated based on the students' ability to present their data, i.e. they had to evaluate their results, come to appropriate conclusions and present their data scientifically. The teacher used a 4-level rubric to evaluate this skill (Table 9).

Table 9: Assessment of forming coherent arguments in CS2 Greece – presentation of scientific data

Poor	Acceptable	Good	Excellent
The student presents results only in descriptive way. Presents conclusions but neither completely nor correctly and not showing supportive evidence.	The student presents results in the form of a table or graph. Draws conclusions, but they are not completely correct.	The student is able to present results in the form of tables and graphs. Draws appropriate conclusions but they are not fully supported by arguments and evidence.	The student presents results in the form of tables and graphs. Draws appropriate conclusions. Supports conclusions using reasoned arguments and evidence. Identifies possible sources of inconsistency.

In **CS5** and **CS6 Poland**, the teachers evaluated students' skill in *forming coherent arguments* by evaluating their ability to form conclusions based on scientific evidence. 4-level rubrics were used to determine performance level, such as the rubric from **CS5 Poland** that is shown in Table 10.

Table 10: Assessment of forming coherent arguments (drawing conclusions) in CS5 Poland

Low	Acceptable	Good	Excellent
The group draws nearly correct conclusions, but the reasoning is incorrect, e.g. students mix up cause and effect.	The group draws nearly correct conclusions; the reasoning is correct, but not detailed.	The group draws conclusions based on obtained results and identifies factors influencing the observed effects. They explain the conclusions using logical argumentation. They do not analyse potential sources of errors.	The group draws conclusions based on obtained results and identifies factors influencing the observed effects. They justify the conclusions using logical argumentation and present logical verification of the hypothesis. They analyse potential sources of errors.

In **CS6 Poland**, the teacher used a true/false test to evaluate students' skill in drawing conclusions (Table 11), and combined the results of this test with use of a rubric for the assessment of students' overall skill in *forming coherent arguments*.

Table 11: True/false test for assessment of drawing conclusions used in CS6 Poland

Point out all properly formulated conclusions as a result of the experiment carried out. Mark T if the sentence is true or F if it is false.	
1. Negative influence of chemical agents on cuckooflower development increases linearly with the increase of concentration.	**T/F**
2. When the influence effect reaches maximum, then in spite of much more doses it remains almost constant.	**T/F**
3. In this experiment, detergent solutions represent household wastewater and cuckooflower represents the natural environment.	**T/F**
4. Ecotoxicology is a science dealing with the influence of toxic substances on the functioning of ecosystems.	**T/F**

Scientific reasoning (identifying variables; data entry and observation skills)

Scientific reasoning, in this situation, refers to the many contributions that when combined enrich *scientific literacy*, and can include the ability to identify variables, collect scientific data in an appropriate manner and to note and explain observations. In **CS1 Ireland**, students' skill in identifying variables was assessed. The teacher collected worksheets during the lesson, reviewed students' work and returned the worksheets for completion. In this way, the teacher was able to see if students could identify a single variable for investigation ("identify and define variables").

In **CS6 Poland**, students' skill in recording data and observation skills were assessed using a 4-level rubric, as shown in Table 12.

Table 12: Rubric for the assessment of observation skills in CS6 Poland

Inquiry skill	Unsatisfactorily 1 point	Properly 2 points	Good 3 points	Perfectly 4 points
Number of observed parameters	Student does not define observed parameters.	Student observes a change of only one parameter, e.g. the change of leaf colour.	Student observes a change of two parameters, e.g. the change of leaf colour and length of stalk.	Student describes properties of object at the beginning of the experiment and at the time of measurement; observes changes of some parameters, gives probable reason for the changes, uses more than one sense for description of the object.
Writing down results	Student writes down the results carelessly; does not give units; does not give measurement time.	Student writes down the results carelessly, without noting measurement time; omits relevant units; prepares tables, but they are not described or described incorrectly.	Student tries to reliably record the experiment results, gives measurement time; uses appropriate units; prepares a correctly described table.	Student records the experiment results with suitable accuracy and appropriate units, prepares a correctly described and completed table; notes recorded when carrying out the experiment are made carefully.
Documentation of carrying out the experiment	Student does not make any documentation.	Student includes photographs without descriptions.	Student provides documentation, however insufficient detail is provided.	During the experiment student uses various technological resources; photographs are described, e.g. student notes which day is it, what amount of detergent is added, what kind of detergent is given to sample.

Scientific literacy

In **CS2 Greece** and **CS4-5 Poland**, the 3-level rubrics proposed in the unit were applied for evaluation of presentation of scientific data. In **CS6 Poland**, the students did not present an oral presentation; instead the teacher evaluated visual presentations that were submitted electronically. The teacher devised and used a 4-level rubric to assess student performance under three criteria: “Does the student present the data collected? Does the student prepare a table/diagram? Does the student use technological tools for the data presentation?”

In the case of teachers from **CS4-5 Poland**, the skill of searching for information was evaluated on the basis of PowerPoint presentations prepared by the students. The teachers used the rubrics proposed in the unit (or modified versions of the rubrics).

Working collaboratively (teamwork)

Students’ ability to cooperate during group work was evaluated in **CS3 Portugal** and **CS4 Poland**. In both case studies, the teachers used rubrics to evaluate performance levels (Table 13 and Table 14). The teacher from **CS3 Portugal** implemented a teamwork observation sheet for the group in the laboratory (Table 15); the teacher took notes and observed student groups for evidence of empathic listening, assertiveness (exhibits and keeps his point of view), interpersonal support and conflict-management. In addition, in this case study the students completed a self-assessment flow chart, in which they reflected on their contribution to group work and how well they felt they had listened and been listened to.

Table 13: Assessment criteria for working collaboratively in CS3 Portugal

Inquiry skills	Emerging	Developing	Consolidating	Extending
Teamwork **Interpersonal relationships and group functioning (emotional literacy)**	Observes and accepts the colleagues' proposals in the structuring of the group work, but gives no suggestions; merely accepts what the colleagues are doing (due to difficulties in interpersonal relationships).	Participates in the structuring of the group work, but only makes one or two suggestions that add little value to what was already done (due to difficulties in interpersonal relationships).	Participates in the structuring of the group work and gives positive suggestions contributing to a productive group dynamic.	Participates in the structuring of the group work and significantly contributes to a productive group dynamic, creating positive personal interactions (allowing the improvement of others and raising the work level).

Table 14: Teacher rubric for assessment of working collaboratively in CS4 Poland

Inquiry skills	Standard (2 points)	Whole (4 points)	Extended (6 points)
Working collaboratively (teamwork)	Not all members of the group were involved in the work.	All members of the group were involved in the work. Some small disagreements/ conflicts.	Very good cooperation and involvement of all members of the group.

Table 15: Registration grid for observation of working collaboratively (teamwork)

Behaviour	Student name	Student name	Student name	Student name
Does not interrupt when others speak				
Questions the colleague regarding what he is saying				
Defends his points of view				
Talks with kindness				
Challenges a quieter colleague to speak				
Congratulates colleagues when they present a positive idea				
Assumes an active role in order to solve conflicts between colleagues				
Defines/clarifies the work's objectives				
Defines/distributes/negotiates tasks among colleagues				
Draws attention to time				
Faced with distractions draws the group's attention to the work				

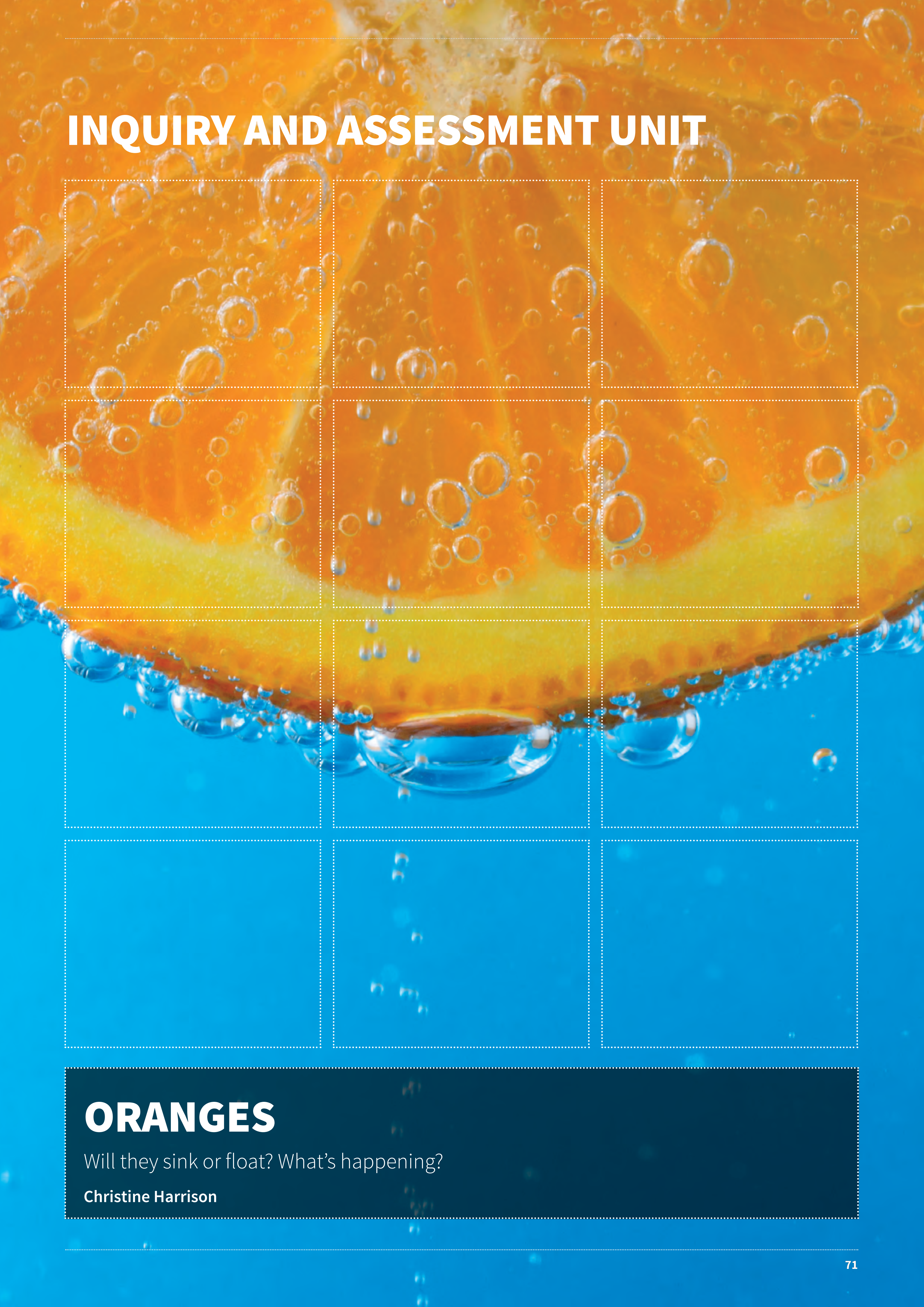
In **CS4 Poland**, the teacher used both a teacher rubric (Table 14) and the group self-assessment tool proposed in the assessment of inquiry teaching & learning section of this unit (Table 2). The self-assessment proved useful for the teacher, when the students conducted an experiment themselves at home, stating, “owing to that questionnaire, it is easy to deduce which person is a leader.” However, the teacher from **CS1 Ireland** negatively evaluated the proposed self-assessment tool, claiming, “The rubrics given were helpful in guiding assessment, except the self-assessment one, which did not provide any real useful feedback.” It should be noted that *working collaboratively* was not assessed in this case study.

Problems encountered

The teacher in **CS2 Greece** was worried that “the students didn’t have any previous experience in inquiry lessons and their answers were a bit unformed. All the groups managed to propose a cleaning agent, a plant and a basic set of inquiry steps. The teacher reported that no-one reached the excellent scale.” The lack of achievement at the higher end of the scale should not be surprising. At least some assessment tools in the unit were intended for those who already know the basics of scientific research methodology, e.g. they know what is required from a well-formed hypothesis, or what dependent and controlled variables are. Other elements, such as e.g. group work self-assessment, do not require training in the area of IBSE, but the principles of appropriate self-assessment should be discussed with the students.

In another case, a teacher found it difficult to separate the group and individual evaluation (**CS5 Poland**), for example “I have evaluated the work of whole groups, because the students shared their work equally”. Another issue was to hand over the evaluation function, typical for the teacher’s role, to the students – “I decided to evaluate each skill with the same table designed by myself. That is because the students carried out the experiment at home, so it was difficult to carry out student’s self-assessment to evaluate the group and cooperation in it” (**CS6 Poland**) and “The students should be heard regarding self-assessment, and difficulties should be identified” (**CS3 Portugal**).

The teachers pointed out that the proposed evaluation methods were laborious, especially the evaluation of students’ homework: “I didn’t expect the homework assessment to have been so time-consuming” (**CS6 Poland**).



INQUIRY AND ASSESSMENT UNIT

ORANGES

Will they sink or float? What's happening?

Christine Harrison

ORANGES

WILL THEY SINK OR FLOAT? WHAT'S HAPPENING?

Overview

KEY CONTENT/CONCEPTS

- Density
- Archimedes principle

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 (recording data and observations)
- Scientific literacy (critiquing experimental design)

ASSESSMENT METHODS

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

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – ORANGES

The **Oranges** SAILS inquiry and assessment unit focuses on studying floating oranges as a model system to relate the physics concept of density and Archimedes principle with students' daily lives. This unit was designed as an inquiry activity that allows teacher to assess during the process of the inquiry. Students work in groups to develop hypotheses about the behaviour of oranges in water, and verify their hypotheses by experimentation. This unit is recommended for implementation at lower second level and the unit activities are presented as an *open inquiry*; however, it has been implemented across the range from *guided* to *open inquiry*.

Implementation of this unit is suggested for the assessment of students' skills in *developing hypotheses* and *planning investigations*, as well as enhancing their *scientific literacy* as they learn to explain the science behind the observed phenomena. Proposed assessment methods include classroom dialogue and evaluation of student devised materials.

This unit was trialled by teachers in Germany, Hungary, Poland, Sweden and the United Kingdom – producing eight case studies of implementation. In Sweden, the implementation was with a group of in-service teachers, while the other case studies were all with lower second level students. In different country contexts, the teachers had varying pedagogic aims and so adapted the unit to suit their classes. *Planning investigations* and *developing hypotheses* were assessed in most cases, while *working collaboratively* was assessed in four of the eight case studies. Key assessment methods used include classroom dialogue, teacher observation and evaluation of student artefacts.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

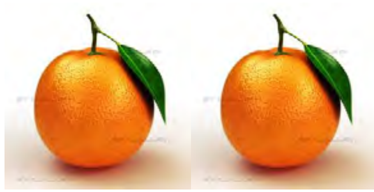
The teaching and learning activities described in the **Oranges** SAILS inquiry and assessment unit were developed by the team at King's College London as part of the SAILS project. This unit was designed initially for teachers in England because they were keen to move away from assessing inquiry skills through laboratory reports and wanted to start assessing during the process of the inquiry. One of the skills they were eager to encourage in their learners was raising their own questions and then devising appropriate methods to test their ideas. Further skills that they were keen to begin encouraging and assessing was teamwork and collaboration, which the teachers felt were important life skills that an inquiry approach can engender. Therefore, this activity is designed to allow students (11-14 years) to raise scientific questions. This unit can be implemented in a single lesson and is valuable for introducing the concepts of inquiry to students.

Concept focus	Density and Archimedes' principle
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific literacy (explain phenomena scientifically)
Assessment methods	Classroom dialogue Teacher observation Student devised materials

Floating orange

Science is about being curious about the world around you. In this activity you are asked to think of some questions and then to work out how you might find some answers to those questions.

Look at and feel the TWO oranges. How are they different? If you placed them in water might they float differently?



Talk with the others in your group and decide on a question you might ask about the oranges. Try out some of your ideas using the apparatus provided. Try and give reasons for any ideas and results that seem to answer your question.

Figure 1: Sample student worksheet

Rationale

In this activity, students are asked to consider the factors that influence the behaviour of an orange in water – why does it float or sink? The activity is introduced as an open inquiry, and students develop hypotheses about what will happen and why. They then devise an investigation to study their research question.

Suggested learning sequence

Materials needed: solid oranges or satsumas and some soft oranges of about the same size, beakers, measuring cylinders, glass rods, thermometers, rulers, string, balance.

1. Students should work in groups of 3-4 students.
2. The teacher provides each group of students with two types of orange and introduces the inquiry question: "Do you think both of these oranges will float? Discuss your ideas and test out any that seem reasonable." This can be achieved using a simple worksheet, which will provide students with the challenge question, but not direct their inquiry (Figure 1).
3. Students explore any ideas they have using general laboratory equipment like beakers, measuring cylinders, thermometers and balances to help them focus on ideas.

   The teacher should circulate around the class, and observe their actions. It is likely that various misconceptions may be revealed such as:
   - It depends on the depth of the water
   - It depends on the size of the orange
4. The teacher should not intervene but allow students to test these hypotheses. It is an important scientific skill to be aware that disproof is as valuable as proving hypotheses correct.
5. Students may test a whole range of questions. For example:
   - Does the waxy skin help it float?
   - Does the heavier orange float lower in the water?
   - Do the oranges float the same in hot and cold water?
   - Is the air in the orange helping it float?
   - How can you make a floating orange sink?
6. They may also do it by seeing how the two different oranges float and then decide to take measurements. If they do start to think about density, let them work out how to measure the volume. Similarly if they are comparing depth of floating, can they work out how to measure it?
7. After 15-20 minutes of open inquiry, the teacher should stop the class and collect a list of questions. The class should then discuss the questions and give comments and advice on which they think are likely to be testable questions.
8. Allow the groups another 15-20 min to test out their question encouraging them to do duplicate investigations and to tabulate or analyse any data they have.
9. Each group can then present their question and findings, either to the whole class or to another group, depending on the time available.

2.2 Assessment of activities for inquiry teaching & learning

In this section we present some tools for formative assessment, aimed at verifying the development of inquiry skills of *developing hypotheses*, *planning investigations* and *working collaboratively*, as well as their ability to communicate what they did and why they did it. This is a very open activity, and can be adapted for evaluation of a variety of skills. The assessment methods include classroom dialogue, teacher observation and evaluation of student artefacts, and may be extended to include peer- and self-assessment.

A suggested 4-level rubric is provided, which details success criteria for students at the emerging, developing, crafting and extending performance levels (Table 1).

Table 1: Assessment of skills developed in the Oranges SAILS unit

Skill	Emerging	Developing	Crafting	Extending
Developing hypotheses **Asking inquiry questions**	The group discuss a number of questions and agrees on one they feel is testable. E.g. "Does the skin/ shape/amount of air in the fruit make it float/ sink?"	The group raise a testable question with reasoning from previous science ideas they have encountered. E.g. "Is it the amount of air that makes the fruit float because this lowers its overall density?"	The group raise a testable question that forms a hypothesis. E.g. "How does the amount of air in the fruit alter its ability to float?"	The group raise a testable question that forms a hypothesis and explains what results to look for to prove or disprove the hypothesis. E.g. "Does removing the peel cause it to sink?" relates to the hypothesis that the waxy skin helps the fruit to float.
Planning investigations **Testing hypotheses**	The group place the fruit in water and then make a change in the fruit (e.g. squashing it flat or making holes in it) and describe what happens.	The group mark the water level on the fruit or container and then make a change in the fruit (e.g. squashing it flat) and take a second measurement of water level or measure the difference in the way it floats after treatment	The group select one variable to test and take measurements of the water level as they make changes in that variable.	The group attempt to set up a fair test that measures changes in the output variable as they change the input variable. They take at least five readings for each.
Communication	The group describe what they did to test their idea	The group describe what they set out to test and present their results	The group explain and present their ideas and results and how they tried to be rigorous.	The group explain what they set out to test, present their results and discuss their confidence in their findings. They also suggest improvements for doing their investigation.

Feedback through classroom dialogue

It would be useful to provide feedback to students on the range of questions raised in this inquiry and discuss with them, as a class, which questions were more useful than others in taking ideas forward. For individual or group improvements, help them see how the behaviours in the next column to the right in the rubric builds on what they achieved in this inquiry.

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in five countries, producing eight case studies of its implementation – **CS1 Germany**, **CS2 Germany**, **CS3 Hungary**, **CS4 Poland**, **CS5 Sweden**, **CS6 United Kingdom**, **CS7 United Kingdom** and **CS8 Hungary**. The activities were carried out with lower second level students in all of the case studies, except **CS5 Sweden**, which details implementation with in-service teachers who had limited experience of the assessment of inquiry activities. Classes were of mixed gender, and students were aged 11-15 years. In the examples with lower level students, the case studies were implemented by teachers who had some experience of teaching through inquiry but the students involved had generally not been taught through inquiry. In general, the case studies concern a single class period of around an hour, with the exception of **CS2 Germany** and **CS3 Hungary**, who carried out the inquiry over nine or three 45-minute lessons, respectively.

The case studies focus primarily on development of inquiry skills and on the assessment of skills in *planning investigations* and *developing hypotheses*. In addition, *working collaboratively* was assessed in four of the eight case studies. Commonly used assessment methods include classroom dialogue and teacher observation, as well as evaluation of worksheets or student devised materials.

3.1 Teaching approach

Inquiry approach used

The inquiry approach used across the case studies ranged from *open* to *guided inquiry*. In **CS2 Germany**, **CS5 Sweden**, **CS6 United Kingdom**, **CS7 United Kingdom** and **CS8 Hungary** an open inquiry approach was taken, where the participants were provided with apparatus to explore ideas and generate a question, which they then investigated. In **CS3 Hungary** and **CS4 Poland**, the teacher set the inquiry question through an introduction and worksheet instructions that guided the students towards generating a question and working out how to test this. **CS1 Germany** took a *bounded inquiry* approach by the teacher providing a broad inquiry question – Do different citrus fruits have the same floating characteristics – which the students then had to plan an inquiry to answer.

Implementation

The **Oranges** SAILS inquiry and assessment unit outlines a single open activity, which teachers can tailor to better suit their student groups. In each of the case studies, the students explicitly or implicitly dealt with density. This led them to take measurements of the way the oranges and other fruits floated in water. Some students adapted the apparatus by drawing scales on the sides of beakers or on the fruit itself to try and get a more accurate measure of how the floating behaviour changed as they changed parameters, such as depth of water, temperature of water, salinity of water or as they changed the fruit by either removing the skin, breaking it into smaller pieces or making holes in the fruit. In all cases they used observational and measurement skills and from these data made inferences that led them to investigate further and find an answer to the question they raised.

In all cases the skill of *planning investigations* was addressed, although in **CS7 United Kingdom** the teacher did not assess this skill. The students showed that they could recognise variables and, in some cases control and manipulate variables. Even when the teacher posed the questions to be investigated, students raised sub-questions, which often served for them to identify variables. In **CS2 Germany**, the students took a broad range of approaches to their inquiry and several of the students needed guidance from the teacher to come up with a relevant inquiry idea. For most of the other classes, the majority of the students were able to decide how they would take measurements of the variables they had identified, with the exception of **CS3 Hungary**, where the students had some difficulty deciding how they would do this and had to be prompted by their teacher. This was a surprise to the Hungarian teacher who decided that the novelty of inquiry perhaps intimidated his students.

All implementations involved working in groups during the inquiry (Table 2), although in most cases the students were required to produce individual written artefacts as well (**CS1 Germany**, **CS2 Germany**, **CS3 Hungary**, **CS4 Poland**, **CS7 United Kingdom** and **CS8 Hungary**). In **CS7 United Kingdom**, the students' posters were not assessed, instead after reviewing the poster the teacher posed a further question to extend the students' learning. In **CS8 Hungary** the emphasis in the class was on verbal descriptions of the process and the teacher encouraged students to make written records simply so that they would begin to develop skill in this area.

CS4 Poland details implementation with two classes, one of which was a workshop for home-schooled children, aged 10-13 years. The teacher found only small differences between the home-schooled cohort and the regular school class. In **CS8 Hungary**, the implementation was in an alternative secondary school, in which the classes contain students that demonstrate a range of ability, including students with behavioural, emotional or learning difficulties. This range of ability is evident in the written artefacts, but the teacher assessed students on the basis of oral descriptions. In **CS5 Sweden**, the implementation was with a group of teachers, rather than students. They carried out the investigation as outlined in the unit, while undergoing peer-assessment.

Table 2: Summary of case studies

Case Study	Duration	Group composition
CS1 Germany	One lesson (90 min)	• Groups of 3-4 students (24 students) • Student selected; mixed ability and gender groups
CS2 Germany	Nine lessons (45 min each)	• Groups of 2-3 students (6 girls, 8 boys) • Student selected; mostly single sex groups
CS3 Hungary	Three lessons (45 min each)	• Six groups of 4 students (24 students) • Student-selected; mixed ability and gender groups
CS4 Poland	One lesson (60 min)	• Groups of 4-5 students (student selected; single sex) • Two implementations – one workshop with home-schooled children
CS5 Sweden	One lesson (80 min)	• Implemented with a group of teachers • Two mixed gender groups of 3 or 4 members
CS6 United Kingdom	One lesson (40 min)	• Seven groups of 3-4 students (31 in total) • Higher attaining students
CS7 United Kingdom	One lesson (60 min)	• Groups of 2-3 students (30 students) • Teacher assigned; mixed ability and gender
CS8 Hungary	Two lessons (130 min in total)	• Four groups of 4-5 students (19 students) • Student-selected, mixed ability and gender

Adaptations of the unit

While there were some changes made to the inquiry to fit the context of the specific classroom or adapt to particular learning needs of students, the skills of raising testable questions and planning an inquiry were carried out and assessed in all case studies. It was clear that teachers had begun to look at formative routes for assessment. It is interesting that the teachers seemed able to assess students' skill in *working collaboratively* during the process of the inquiry. Perhaps one of the most relevant findings was that students enjoyed and were motivated by the inquiry activity and the teachers seemed relatively confident in both facilitating the inquiry and assessing it.

In some case studies the teacher made simple adaptations, such as use of tangerines, clementines or mandarins instead of oranges (**CS3 Hungary**, **CS5 Sweden**) or even providing both fruits within the class (**CS4 Poland**). In **CS1 Germany**, the students investigated lemons, limes and oranges, and the teacher started the learning sequence with the question: "Do different citrus fruits have the same floating characteristics?" **CS2 Germany** also used a variety of fruits, although details of which specific fruits were used were not provided.

In some case studies, the teachers made changes to the worksheet, or chose to omit it entirely. In **CS3 Hungary**, the teacher revised the worksheet so that it was slightly easier to follow and more relevant to the implementation (replaced the image of an orange with one of a tangerine). **CS4 Poland** adapted the worksheet to the greatest extent, changing the implementation from that of open to *guided inquiry*. This was to enable the teacher to evaluate student worksheets that were in a consistent format.

3.2 Assessment strategies

Almost all case studies focused on the planning aspects of inquiry, as suggested in the unit. However, given the open nature of the activity, it was possible for teachers to choose particular aspects for development, as shown in Table 3. *Planning investigations* and *developing hypotheses* were assessed in most case studies, while *working collaboratively* was also widely assessed. Other skills chosen for the assessment were *forming coherent arguments* (in **CS4 Poland** and **CS8 Hungary**), *scientific literacy* (critiquing experimental design in **CS5 Sweden** and explaining phenomena scientifically in **CS8 Hungary**) and *scientific reasoning* (collection of data and observation in **CS5 Sweden**). While **CS5 Sweden** looked to assess all aspects of an investigation, it is important to note that this implementation was with teachers rather than school students and so could take a broader look at the assessment.

Table 3: Inquiry skills identified by teachers in the case studies

CS1 Germany	• Planning investigations • Working collaboratively
CS2 Germany	• Planning investigations (including implementation)
CS3 Hungary	• Developing hypotheses • Planning investigations
CS4 Poland	• Developing hypotheses • Planning investigations (including implementation) • Forming coherent arguments • Working collaboratively
CS5 Sweden	• Developing hypotheses • Planning investigations • Scientific reasoning (data collection and observations) • Scientific literacy (critiquing experimental design)
CS6 United Kingdom	• Developing hypotheses • Planning investigations • Working collaboratively
CS7 United Kingdom	• Developing hypotheses • Working collaboratively
CS8 Hungary	• Developing hypotheses • Planning investigations • Forming coherent arguments • Scientific literacy (use of scientific language, ability to explain phenomena scientifically)

All case studies used a criterion-referenced approach to the assessment and mainly used rubrics, with some using the rubric proposed in the inquiry and assessment unit (**CS3 Hungary**, **CS4 Poland**). The teacher in **CS2 Germany** was aware of the rubric and kept the criteria in mind, but did not apply it formally.

Other case studies describe the use of teacher-devised rubrics, for example a 3-level rubric was developed in **CS5 Sweden**, which was designed for the assessment of grade 6 students (Table 4). This rubric could be used for the assessment of *developing hypotheses, planning investigations, scientific reasoning* (data collection and observations) and *scientific literacy* (critiquing experimental design).

The teacher in **CS7 United Kingdom** presented a rubric for assessing students' skills in *working collaboratively*, which will be applied throughout the year. This rubric outlines success criteria at performance five levels for three skills – participation, communication and explanation (Table 5). In this implementation, only the assessment of participation was noted.

Table 4: Assessment of skills developed in CS5 Sweden

Skill	E	C	A
Developing hypotheses **Forming a research question**	The student contributes to formulating simple questions and planning which can be systematically developed.	The student formulates simple questions and plans which can be systematically developed after some reworking.	The student formulates simple questions and plans which can be systematically developed.
Planning investigations	The student uses equipment in a safe and basically functional way.	The student uses equipment in a safe and appropriate way.	The student uses equipment in a safe and effective way.
Critiquing experimental design (scientific literacy)	The student contributes to making proposals that can improve the study.	The student makes proposals that after some reworking can improve the study.	The student makes proposals that can improve the study.
Documentation and observations (scientific reasoning)	The student draws up simple documentation of their studies using text and pictures.	The student draws up developed documentation of their studies using text and pictures.	The student draws up well-developed documentation of their studies using text and pictures.

Table 5: Assessment of working collaboratively in CS7 United Kingdom

Level	Participation	Communication	Explanation
1	Thoroughly involved in a thoughtful and polite way.	Talks politely and helpfully to other group members and takes instructions well.	Is heard clearly explaining the practical to others or is able to clearly and concisely answer teacher questions using appropriate language.
2	Wants to be very involved but not allowing others to get involved.	Talks to other group members about what is going on, may be a little bossy.	Is heard trying to explain the practical but with some hesitancy and or mistakes or can answer questions posed by the teacher to a certain extent.
3	Will try to help but needs to be encouraged by peers.	Does not say much but follows instructions.	Finds explaining the practical difficult but does try to give a good description of the activity.
4	Will get involved if asked by the teacher.	Says very little and does not respond to others.	Cannot explain practical but does try to describe what the group is doing.
5	Does not help with the practical.	Does not say anything and does not listen to others in the group.	Cannot explain practical and is not sure how to describe what it is the group is doing.

In most case studies, the teachers engaged in on-the-fly assessment during the process of the inquiry, although **CS3 Hungary** and **CS4 Poland** assessed using the worksheet and report on the inquiry. However, in all the case studies where students' skill in *working collaboratively* was assessed, this was achieved through direct teacher observation during the inquiry.

For some skills, the assessment was carried out after class and was based on a written artefact produced in class. Others involved formative assessment that guided the student learning during the class. For example, **CS1 Germany** used "fist to five" and "traffic light cups" during the inquiry for students to signal to the teacher how confident or not they felt with that aspect of the inquiry. The teacher in **CS2 Germany** gave verbal feedback at different stages in the inquiry process. In **CS6** and **CS7 United Kingdom**, the teachers used a range of questions designed to probe understanding during the inquiry process, while, at the same time trying not to lead the students towards a specific route within the inquiry. For example, they asked, "What was your reason behind that choice?" or "Why choose that specific method? Were there others you considered?" In **CS3 Hungary**, the teacher gave feedback at the end of the first lesson, based on his observations of the class activities, and at the beginning of the second lesson, based on the written plan of the inquiry that the students had produced. In this case study, the teacher chose to extend the implementation by an additional lesson period, to allow time for the students to fully develop their understanding of the concept of density.

In **CS4 Poland** and **CS1 Germany**, the teachers reported that the students enjoyed the inquiry activity. In **CS6** and **CS7 United Kingdom**, the students used peer-assessment to both report back on how they had responded to the inquiry but also to set themselves targets for future inquiry activities. **CS5 Sweden** also used peer-assessment with its teacher group. **CS2 Germany** also reports use of peer-assessment when establishing research ideas. In **CS4 Poland**, the teacher provided a written feedback sheet after the inquiry had been assessed.

In **CS1 Germany**, the teacher noted that some groups required different amounts of time during the planning phase, as some groups raised a question and decided to work with that while other groups were more willing to generate a range of questions and then decide which would be best to pursue. Similarly in **CS7 United Kingdom**, the teacher observed that some groups made decisions regarding their research questions quickly, while others struggled to do so.

The teacher in **CS1 Germany** used a variety of assessment methods and tools to enrich the implementation, including the "fist to five" "traffic light cups" methods. For the assessment of skill in *planning investigations* and *working collaboratively*, the class engaged in self-assessment. The students completed questionnaires on work attitude (Table 6), communication skills (Table 7) and the inquiry process (Table 8). The teacher provided formative feedback and supported the students throughout the process.

Table 6: Self-assessment of work attitude used in CS1 Germany

Behaviour	Always	Almost always	Sometimes	Almost never	Never
1. I concentrated on the task					
2. I worked autonomously					
3. I worked methodically					
4. I worked in a team					

Table 7: Self-assessment of communication skills used in CS1 Germany

Behaviour	I achieve this goal totally	I achieve this goal partly	I don't achieve this goal
1. I let my schoolmates finish their argumentations and did not disrupt them.			
2. I did not make inappropriate comments in response to my schoolmates' argumentations.			
3. I did not put my schoolmates under pressure or force them to do what I wanted.			
4. I informed all group members about planned investigations or upcoming inquiry processes.			

Table 8: Self-assessment of the inquiry process from CS1 Germany

Behaviour	I agree totally	I partly agree	I disagree
1. I investigated the relationship between the floating properties of citrus fruits and temperature			
2. I investigated if parts of the fruit show the same floating properties as the entire fruit			
3. I investigated the relationship between the floating properties of citrus fruits and their mass			
4. I investigated the relationship between the floating properties of citrus fruits and volume			
5. I have determined the density of the fruits			
6. I can describe our inquiry process			
7. I can give reasons for our inquiry process			

INQUIRY AND ASSESSMENT UNIT

PLANT NUTRITION

Photosynthesis – how do plants grow?

Katarína Kimáková

PLANT NUTRITION

PHOTOSYNTHESIS – HOW DO PLANTS GROW?

Overview

KEY CONTENT/CONCEPTS

- Photosynthesis
- Plants and chlorophyll (leaves, algae)
- Oxygen, light and organic substances
- Carbon dioxide absorption
- Importance of forest and water ecosystems

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 predictions; forming conclusions; defining variables; argumentation)
- Scientific literacy (evaluating and designing scientific inquiry; explaining phenomena scientifically)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Self-assessment
- Worksheets
- Student devised materials (documentation of inquiry process, experimental plans)
- Presentations

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – PLANT NUTRITION

The **Plant nutrition** SAILS inquiry and assessment unit aids students to learn about photosynthesis, a topic that features in curricula for second level education across Europe. In this unit, students use algae immobilised in “jelly balls” to acquire evidence that light is necessary for photosynthesis to occur. Using colorimetric techniques, they observe that when photosynthesis is occurring, carbon dioxide is decreasing in the environment; the change in carbon dioxide concentration causes the pH of the solution to change, as demonstrated by changes in colour of an indicator. These activities help them to connect observed phenomena and scientific theory.

For lower second level, teachers can use a *guided inquiry* approach; a *bounded inquiry* approach can be considered at upper second level. Students are provided the opportunity to develop inquiry skills such as *planning investigations* (planning and rationale, data recording, graphical representation), *developing hypotheses*, *forming coherent arguments* (reasoning and argumentation) and *working collaboratively* (discussing their decisions and conclusions). The assessment opportunities identified include student observation, group discussions or presentations and evaluation of student artefacts.

This unit was trialled by teachers in Slovakia, Portugal, Hungary and Sweden, with students aged 12-16 years (7 classes in total, mixed ability and gender). The teaching approach used in all case studies was *guided inquiry*. The inquiry skills assessed were *planning investigations, developing hypotheses, forming coherent arguments, working collaboratively* and *scientific reasoning*. Several assessment methods are described, including classroom dialogue, teacher observation and evaluation of worksheets, presentations or other student artefacts.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The activities in the **Plant nutrition** SAILS inquiry and assessment unit were developed Science & Plants for Schools (SAPS)[1] and adapted for the SAILS project by the team at Univerzita Pavla Jozefa Safárika v Kosiciach (UPJS). This inquiry activity is designed for students aged 12-18 years and can be implemented as a *guided* or *bounded inquiry*; students will make some key decisions for their experiments, while other procedures will carried out according to instructions.

Concept focus	Photosynthesis by algae and carbon dioxide absorption
Inquiry skill focus	Developing hypotheses Planning investigations Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (identifying variables; identifying the inverse relationship of carbon dioxide concentration to light intensity) Scientific literacy (explain photosynthesis scientifically)
Assessment methods	Classroom dialogue Teacher observation Worksheets Student devised materials Presentations

Rationale

Using immobilised algae, students investigate photosynthesis. They can start the activity by preparing immobilised algae (in alginate jelly balls), by dripping an alginate solution, containing the algae, into calcium chloride solution. This is a quick method for generating consistent sized beads in a short time. For the investigation, the beads are placed in indicator solution and positioned at various distances from a light source. Students plan how to measure the quantity of algae used, where to position the samples and how to record their data. The samples are allowed to stand for several hours, after which the effect of changes in carbon dioxide concentration can be observed. Changes in the indicator may be measured using colorimetry, comparison to colour charts or standards or by measuring changes in pH using a pH meter.

Suggested learning sequence

1. Students should already be familiar with the concept of photosynthesis; therefore the teacher can start with an initial dialogue about photosynthesis. The teacher can use prompt questions to start the discussion, such as:
    a. Why is photosynthesis important?
    b. How do you know that photosynthesis occurs?
    c. What is the basis of photosynthesis?
    d. What do plants need?
    e. What happens if a plant lacks light?
    f. Is there a way of knowing how much carbon dioxide is in solution?
    g. What does the word "indicator" mean? We will work with an indicator that changes colour depending on how much carbon dioxide is in solution.
2. Next, the teacher should introduce the task – to watch the intensity of photosynthesis by algae. Students are asked to design the experiment, in particular considering how to measure consistent quantities of the algae and where to locate the samples. The algae immobilised in jelly balls can be prepared as part of the activity, or in advance as described in Task 1 in the student worksheet (Figure 1).
3. When students have planned their experiment, the immobilised algae are placed into an indicator of carbon dioxide and the samples are placed at different distances from the light source (Task 2, Figure 2). Students wait some time and then observe how the indicator reacts.
4. Students record their observation data (Task 3, Figure 2) using one of the methods described below:
    a. Compare colour of solution to standards (for younger students).
    b. Use a colorimeter (student activity or teacher demonstration).
    c. Use a pH meter to record pH changes of the indicator.
5. Students are asked to predict and explain the colour change and their observations.

2.2 Assessment of activities for inquiry teaching & learning

This unit is particularly suitable for the assessment of students' skills in *developing hypotheses, planning investigations, scientific reasoning* and *scientific literacy*, in particular looking at students' ability to draw conclusions, explain unexpected results, report, compare and discuss results, and provide suggestions about how to improve investigations. Students work in diverse teams (*working collaboratively*) and produce ideas based on views from team members. Suggested assessment rubrics are provided for evaluation of *planning investigations* (Table 1) and *scientific reasoning* (Table 2).

[1] SAPS 'Algal balls' - Photosynthesis using algae wrapped in jelly balls, http://www.saps.org.uk/secondary/teaching-resources/235-student-sheet-23-photosynthesis-using-algae-wrapped-in-jelly-balls [accessed October 2015]

Photosynthesis

Adapted from student sheet 23 *'Photosynthesis... using algae wrapped in jelly balls,'* devised by Science & Plants for Schools (SAPS, www.saps.org.uk).

Algae can be considered as one-celled plants, and they usually live in water. You are going to use algae to look at the rate of photosynthesis. The algae are tiny and are difficult to work with directly in the water so the first part of the practical involves 'immobilising' the algae. This effectively traps large numbers of algal cells in 'jelly like' balls so that we can keep them in one place and not lose them.

Task 1: Making algal balls

We use sodium alginate to help make the jelly. Sodium alginate is not harmful to the algae.

1. First you need to obtain a concentrated suspension of algae. Do this by removing some of the liquid medium in which they are growing in one of two ways.
    a. Leave 50 cm^3 of dark green algal suspension to sediment out and gently pour off the supernatant to leave approximately 5 cm^3 at the bottom.
    b. Place 50 cm^3 of dark green algal suspension in a centrifuge and spin gently for 5 minutes. Pour off the supernatant, leaving approximately 5 cm^3.
2. Now you have millions of algal cells in a small volume of liquid. It's time to mix them into your 'jelly'.
    a. Pour about 2.5 cm^3 of jelly (sodium alginate solution) into a very small beaker.
    b. Add approximately 5 cm^3 of concentrated algal cells. Stir the mixture with a clean cocktail stick until you have an even distribution of algae in your jelly.
3. Finally we're going to make the balls… Pour the green mixture through an open-ended syringe into a 2% solution of calcium chloride.
    a. Swirl the calcium chloride gently as the drops fall through the syringe to form small balls of algae
    b. Leave for 10-15 minutes in the calcium chloride and then wash the balls with distilled water. (A plastic tea strainer is useful to separate the algal balls from the solution.)

When you have made your algal balls you can use them to determine the rate of carbon dioxide absorption, which indicates how fast photosynthesis is taking place. You can detect carbon dioxide absorption using hydrogen-carbonate indicator.

Hydrogen-carbonate indicator is very sensitive to changes in carbon dioxide level. The indicator is orange/red in colour when equilibrated with atmospheric air. It changes to yellow when more carbon dioxide is added and changes through red to a deep purple colour when carbon dioxide is removed. The diagram below shows an approximate scale.

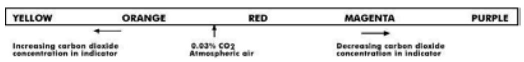


Figure 1: Student worksheet, page 1. Adapted from student sheet 23 *'Photosynthesis... using algae wrapped in jelly balls,'* devised by Science & Plants for Schools (SAPS, www.saps.org.uk).

Task 2: Doing investigations with algal balls

When you place the algal balls into the hydrogen-carbonate indicator solution, the colour of the indicator changes **from orange/red to purple.** This is because the algae are taking carbon dioxide out of the indicator thereby lowering the concentration in the indicator as they use carbon dioxide in photosynthesis.

Plan the variables that you'll record. Here is an outline of how you could investigate the effect of light intensity on the rate of photosynthesis. ***You will need to decide on details of quantities and how to vary the light intensity.***

4. Take several (minimum 3) small glass containers with lids and rinse all of them with a small volume of hydrogen-carbonate indicator.
    a. Add equal amounts of algal balls to each container.
    b. Add a standard volume of indicator to each container.
    c. Replace the lid.
5. Place the containers at different light intensities.
    a. Leave them until there is a visible colour change in some of the containers. (This may take 1-2 hours).
6. Two methods are proposed for measurement of colour change in the indicator
    a. **For lower second level:** Compare your colour changes with the standard buffer solutions.
        - Hold each container to the light and match it to the buffer nearest in colour to your sample.
    b. **For upper second level:** Use a colorimeter to measure the absorbance of your solution.
        - Fill a cuvette ¾ full with distilled water and place in the colorimeter. Press the zero or reset button.
        - Fill a second cuvette ¾ full with the indicator from one of our test solutions. Place in the colorimeter. Press the test button and take the reading. Repeat with each of your test solutions.
7. **Task 3:** Record measured data in a table or graph.

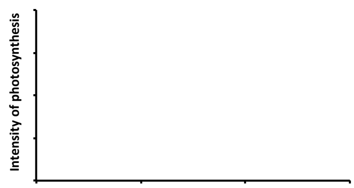


Figure 2: Student worksheet, page 2. Adapted from student sheet 23 *'Photosynthesis... using algae wrapped in jelly balls,'* devised by Science & Plants for Schools (SAPS, www.saps.org.uk).

Planning investigations

For *planning investigations*, there are three key aspects identified where students have the freedom to develop their own inquiry – how to measure the quantity of algal balls in each sample, layout of samples and recording of results. The teacher can ask supportive questions in these three key moments and also watch the debate with peers, which can help him to assess the student's skills (using rubric, Table 1).

Table 1: Rubric used to evaluate planning investigations

	Emerging	Developing	Consolidating	Extending
Distribution of materials	Indicates chosen method	Indicates chosen method and argues its speed	Indicates chosen method and argues its accuracy	Indicates and compare speed and accuracy of chosen method
Layout of samples	Procedure precise, but small distances between samples (10 cm)	The layout is less accurate, time is marked	Able to reason the procedure in practical terms (for example to use the full length of the table)	Able to reason the procedure, builds on the fundamental of photosynthesis
Data entry	Data entered into a continuous text of process	Distinct process and results	Distinct process and results, accurate data entry	Enrolment of data about colour samples and their distance from the light source in self-proposed table

How to divide prepared balls equally

First the students generate the ideas. It is likely that they will propose one of three possible ways (Figure 3):

- Place the same number of balls in each vessel (count),
- Weigh 3 times the same weight, or
- Place the same amount (volume) in each vessel

Each group can choose a way that seems the best for them, and should note their argument for choosing their method. Students should explain their choice in terms of assumption of accuracy and speed. The group must agree on a procedure and on division of labour.

Experimental layout

A second opportunity for the assessment of *planning investigations* is choosing an appropriate location (layout) for three samples at different distances from the light source. Specific distances not given in the instructions; student groups should consult and agree on an appropriate location.

They may have an idea to pack one sample in aluminium or black foil so that it is in complete darkness. Students develop a hypothesis on the likely change of the indicator in light and in darkness. They argue in favour of their own hypothesis, and how to test it.

Recording data and presentation of results and observations

Students are also free to determine their mode of entry of constants and variables. Student groups should agree what information to record and how they will record the data. Parameters that should be recorded include the amount of algae, the volume of indicator added, the distance of samples from the lamp and the time required for the indicator change to occur. The students should decide whether the information should be put into a table and if some data can be expressed as a graph.

Figure 3: Working with the algal beads. Top left: Counting; top right: Weighing; bottom left: Measuring volume; bottom right: Sample layout

Scientific reasoning

Opportunities to assess *scientific reasoning* arise both in experimental setup (defending their choice of measurement method or layout of experiment), as well as in students' ability to draw conclusions based on scientific evidence. These skills can be assessed through teacher observation in class, or by evaluation of student artefacts generated using a rubric (Table 2).

Table 2: Rubric used to evaluate scientific reasoning

	Emerging	Developing	Consolidating	Extending
Argument in support of chosen method	Indicates chosen method	Indicates chosen method and argues its speed	Indicates chosen method and argues its accuracy	Indicates and compares speed and accuracy of chosen method
Drawing conclusions based on evidence	Understanding the procedure	Arguments show understanding of the procedure	Arguments show understanding of the process	Arguments points to the understanding of the purpose of experiment and the principle of action.

Further criteria may be simplified so that they can also be used for self-assessment. It is good for students when the criteria are concrete, and are formulated in additive mode. That is, what needs to be added to the basic skills when to be developed, which means if a skill is consolidated and an example of extending (see example in Table 3).

Table 3: Assessment criteria for sample layout in additive mode

Inquiry skills and processes	Emerging	Developing	Consolidating	Extending
Planning investigations: **Layout of samples**	Procedure precise...	... and the layout is accurate (different light intensity), time is marked...	...and student is able to explain the layout design in practical terms...	and... student is able to reason the procedure, builds on the fundamental of photosynthesis

In this example, if the assessment of a student or a group is *developing* (the procedure is precise and layout of samples is accurate), then the teacher should assist in progressing skill level to *consolidating* by asking, "Explain the design of your experiment."

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in four countries, producing six case studies of its implementation – **CS1 Slovakia**, **CS2 Slovakia**, **CS3 Portugal**, **CS4 Hungary**, **CS5 Hungary** and **CS6 Sweden**. All the case studies were implemented by teachers who had some experience of teaching through inquiry, but the students involved had not been taught through inquiry in **CS1** or **CS2** (both **Slovakia**) and in **CS3 Portugal**. In **CS6 Sweden** and **CS4** and **CS5** (both **Hungary**) the students had some prior experience of inquiry. The students involved in the case studies were aged 12-16 years and of mixed ability and gender.

The activity was implemented as a 180-minute block in **Slovakia**. It was divided into two lessons in **CS3 Portugal**: one 150-minute lesson and another 100-minute lesson. The activity with Elodea (pondweed) instead of algal balls took two 45-minute lessons (**CS4** and **CS5 Hungary** and **CS6 Sweden**). In **CS3 Portugal** and **CS6 Sweden**, the materials required for the activity were not available, and so the unit was implemented as a theoretical planning investigation.

The key skills identified for assessment were *planning investigations* and *forming coherent arguments*, as well as associated *scientific reasoning* capabilities. However, in **CS3 Portugal** the teacher chose to assess skills in *developing hypotheses* and *working collaboratively*. The assessment methods used include classroom dialogue, teacher observation and evaluation of worksheets, presentations or other student artefacts.

3.1 Teaching approach

Inquiry approach used

The inquiry approach used in all the case studies was that of *guided inquiry*, i.e. it was guided in the sense that the teacher posed the initial question but there were open inquiry opportunities in that students had freedom in formulation of predictions and *planning investigations*.

Implementation

During implementation of the activities in this unit, the optimal number of students per class is 15-18. It is possible to work with classes of about 30 students, but the assessment is more difficult for the teacher. With a large number of students an interactive demonstration is recommended, with the inclusion of discussion sequences. The assessment focuses on student proposals relating to the preparation and arrangement of samples, formulation of assumptions and hypotheses.

All teachers organised their students into smaller groups, consisting of 2-4 members. There are examples of single gender groups in **CS3 Portugal**, and also of mixed-sex groups in all case studies. In **CS3 Portugal**, the teacher tried to verify if the predominance of one gender could affect the dynamics in class, but due to small number of groups in which it was possible to watch the gender effect it is not possible to formulate clear conclusions. The students in all of the case studies worked in groups throughout the lessons, but there was variation in both how the groups were chosen and the group size, as shown in Table 4.

Adaptations of the unit

The **Plant nutrition** SAILS inquiry and assessment unit explores the effects of light on the intensity of photosynthesis. A full experimental setup is provided, including the method for controlling the independent and the dependent variables. When implemented by the teachers in the case studies, several types of bicarbonate indicator were used and pH measurement using a meter was described (**CS4**, **CS5 Hungary**).

Some teachers could not implement the algal ball method described in the unit, because they did not have access to suitable algae colonies and could not make the jelly with alginate (**CS4 Hungary** and **CS5 Hungary**). Instead they used some algae from a water tank (Elodea). In **CS3 Portugal** and **CS6 Sweden**, the unit was implemented as a theoretical planning

Table 4: Summary of case studies

Case Study	Duration	Group composition
CS1 Slovakia	One lesson (180 min)	• Groups of 3 students • Teacher assigned
CS2 Slovakia	One lesson (180 min)	• Groups of 3-4 students • Self-selected
CS3 Portugal	Two lessons (1x150 min, 1x100 min)	• Groups of 3 students • Teacher assigned
CS4 Hungary	Two lessons (45 min each)	• Groups of 3-4 students
CS5 Hungary	Two lessons (45 min each)	• Groups of 3-4 students
CS6 Sweden	Two lessons (45 min each)	• Groups of 2-3 students

investigation, as the materials required for the activity were not available. In **CS3 Portugal**, students developed a hypothesis after researching the inquiry question, viewing a video of the implementation of the investigation and analysing a set of experimental data.

In all case studies, it was necessary to review students' prior knowledge before introducing the inquiry activities. The teachers ensured that students already knew the principle of photosynthesis; this was achieved through a moderated conversation before the teacher introduced the activity. Students formed self-selected groups (**CS1 Slovakia**) or the teacher randomly organised students (**CS2 Slovakia**, **CS3 Portugal**). Groups were able to choose the format for recording their documentation and for the final presentation their work (PowerPoint presentation, poster, video documentation). Students in **CS3 Portugal** were told they would have to produce a written document using a word processor (e.g. Microsoft Word), where they would write the group's answers to the activity questions. During the lesson, an introductory work document was provided to each student, with the objectives and the theoretical framework (**CS3 Portugal**). The students had computers with Internet access (one per group), so that they can search about terms/concepts and new information either on the algae or the selected reagents. Students in **CS4** and **CS5** (both **Hungary**) completed worksheets and in **CS6 Sweden** groups prepared a written plan of their experiment.

The student groups attempted to define the problem and the objectives of experiment. They discussed and designed some steps of the procedure, identified which variables are involved, and made predictions about the expected results. The experiment was followed by analysis and interpretation of results, and a group discussion was used to answer to the given questions (**CS1 Slovakia**), or at the end, the students completed a questionnaire (individually) on how the work in their groups went (**CS3 Portugal**). The self-assessment template also focused on how well the student thought their peers understood them during the peer discussion.

3.2 Assessment strategies

Within the six case studies, the inquiry skills of *planning investigations, developing hypotheses, working collaboratively, scientific reasoning* (arguing for a chosen method, drawing conclusions based on evidence) and *scientific literacy* were assessed (Table 5). Formative assessment was useful, in particular for the assessment of *working collaboratively*. Some assessment methods used include:

- Providing feedback through discussion with peers
- Individual assessment of students on the basis of documentation of the experiment
- Teacher questioning and feedback to students
- Students' self-assessment

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

CS1 Slovakia	• Planning investigations • Forming coherent arguments • Scientific reasoning (forming conclusions)
CS2 Slovakia	• Forming coherent arguments • Scientific reasoning (making predictions, forming conclusions)
CS3 Portugal	• Developing hypotheses • Working collaboratively
CS4 Hungary	• Planning investigations • Forming coherent arguments • Scientific reasoning (defining variables, argumentation, forming conclusions)
CS5 Hungary	• Planning investigations • Forming coherent arguments • Scientific reasoning (argumentation, forming conclusions) • Scientific literacy (evaluate and design scientific inquiry, explain phenomena scientifically)
CS6 Sweden	• Planning investigations

In all case studies, except **CS6 Sweden**, the teachers used rubrics to help them to identify the performance level of students or groups for selected inquiry skills. These rubrics describe assessment criteria for four levels of performance – emerging/developing/consolidating/extending. Each student is able to achieve a basic level of skills (emerging), which then develops. Consolidating skill arises from repeatedly practicing. The most skilled students are able to extend this skill. It is not possible to observe and assess all skills at the same time. Simply, the teacher focuses on one or two selected skills at a time.

When students work in groups it is easier to provide formative assessment of the group as a whole. The teacher can note the group's result in a table more easily than evaluating the reasoning of 3 or 4 individual students. The teacher can therefore see more discussion and outcome of groups. Only with practice can he/she be able to observe the work of many individual students during activities. However, a teacher can make a good judgement about of the reasoning skills of individual students, when group work is followed by a phase where each student writes their own conclusions or answers to the teacher's questions.

The teacher in **CS1 Slovakia** used the rubric for *planning investigations* provided in the assessment of activities for teaching & learning section of this unit (Table 1), but altered the criteria for evaluation of students' skill in data entry (Table 6). Table 7 shows the rubrics used by teachers in **CS1** and **CS2** (both **Slovakia**), which provided expanded descriptions of each of the assessment criteria for evaluation of *scientific reasoning* and *scientific literacy* provided in the sample rubric in Table 2.

Table 6: Assessment tool for planning investigations (data entry), used in CS1 Slovakia

Inquiry skills and processes	Emerging	Developing	Consolidating	Extending
3. Data entry	Data entered into a continuous text of process	Distinct process and results	Distinct process and results, accurate data entry	Recording of data about colour and distance from the light in a table designed by the student

Table 7: Rubrics for assessment of scientific reasoning (in CS1 Slovakia) and scientific literacy (in CS2 Slovakia)

Inquiry skills and processes		Emerging	Developing	Consolidating	Extending
Scientific reasoning	**1. Arguments for the benefit of the chosen method**	Indicates chosen method Example: We do it this way.	Indicates chosen method and argues its speed or simplicity Example: We do it this way, because it is easier than finding the colour change in the samples.	Indicates chosen method and argues its sense Example: We achieved changing the concentration of carbon dioxide by choosing different light intensity.	Indicates and compares methods Example: It is the best way to achieve different rate of carbon dioxide concentration that indicates changing rate of photosynthesis.
Scientific literacy	**2. Thinking about photosynthesis based on enrolment and formulation of conclusions**	Understanding the procedure Example: When we do it this way, we see the colour change of indicator.	Arguments show understanding of the procedure Example: The colour change of indicator occurs as the result of different distances from light.	Arguments show understanding of the process Example: The colour change of indicator occurs as the result of photosynthesis.	Arguments point understanding of the purpose of experiment and the principle of action. Example: We achieved higher concentration of carbon dioxide because lack of photosynthesis by decreasing light intensity.

The teacher in **CS3 Portugal** also used 4-level rubrics for the assessment of students' inquiry skills (Table 8), focusing in particular on *developing hypotheses* and *working collaboratively*. The teachers in both **CS4** and **CS5 Hungary** examined students' written work in order to assess their skills in *planning investigations* and *forming coherent arguments*, and defined their assessment criteria as shown in Table 9.

Table 8: Assessment criteria for working collaboratively and developing hypotheses, as used in CS3 Portugal

Inquiry skills and processes	Emerging	Developing	Consolidating	Extending
Working collaboratively **Interpersonal relationships and group functioning (emotional literacy)**	Observes and accepts the colleagues' proposals in the organisation of the group work, but gives no suggestions; merely accepts what the colleagues are doing (due to difficulties in interpersonal relationships).	Participates in the organisation of the group work, but only makes one or two suggestions that add little value to what was already done (due to difficulties in interpersonal relationships).	Participates in the organisation of the group work and gives positive suggestions contributing to a productive group dynamic.	Participates in the organisation of the group work and significantly contributes to a productive group dynamic, creating positive personal interactions (allowing the improvement of others and raising the work level).
Developing hypotheses	Formulates hypotheses that are not consistent with the planning or that are not eligible for investigation.	Formulates hypotheses that are consistent with the planning of the experiment.	Formulates hypotheses that are consistent with the planned experiment and are based on the research questions.	Formulates hypotheses that are consistent with the planned experiment. Those hypotheses are based on the research questions and identified variables.

Table 9: Assessment tool for planning investigations and forming coherent arguments in CS4 and CS5 Hungary

Skills	Emerging	Developing	Consolidating	Extending
Planning investigations	Has some ideas about manipulating the independent variable but the ideas of practical implementation are incorrect. Only plans the measurement of the dependent variable using a given method.	Has some ideas about manipulating the independent variable and identifies errors with the teacher's help. Has ideas for dependent variables other than the given one (e.g. measuring dissolved oxygen level)	Identifies the possibilities provided by the independent variables and has some ideas about how to test them Plans a viable method of manipulating the given independent variable. Has ideas for dependent variables other than the given one and prepares a plan of implementation.	Thinks of a number of independent variables and prepares plans of implementation. Plans a viable method of manipulating the given independent variable and considers possible errors. Has ideas for dependent variables other than the given one and prepares a plan of implementation.
Forming coherent arguments	Does not provide scientific arguments for or against the different experimental plans devised by the group. Occasionally draws conclusions from the data but does not provide scientific arguments for these conclusions.	Provides scientific arguments for the original experimental plan and the various alternative plans devised by the group but the reasoning is not always correct. Analyses the data and occasionally provides scientific arguments but has difficulty with measurement errors and statistical analysis.	Provides accurate scientific arguments for the various experimental plans devised by the group Analyses the data, supports his or her conclusions with scientific arguments, and control for measurement errors.	Provides accurate scientific arguments for the various experimental plans devised by the group and a critique of other plans. Analyses the data critically, uses a statistical approach, control for measurement errors and supports his or her decisions with scientific arguments.

The assessment criteria outlined in the provided rubrics are merely guidelines; as shown, teachers can adapt these criteria to the needs of their own class or develop their own criteria. The students can also use these criteria for self-assessment. Additionally, the criteria can be adapted to the age of the students. For example, in **CS1 Slovakia**, the conclusions formulated by younger students revealed that they focused their attention on *planning investigations*. They did not perceive that this experiment provided proof of photosynthesis. In their conclusions they reported that the indicator changed colour as a variable dependent on the distance of the sample from the light source, but they did not relate the colour change to the change in CO_2 concentration. They also do not have enough experience to design a table for recording of data.

In general, the teachers did not have difficulties in assessing their students. The greatest difficulty seems to be related to the use of teamwork observation grids in **CS3 Portugal**, in which the teacher noted the contribution of each team member (Table 10). This required a lot of the teacher's time, although just two groups were chosen for assessment during this case study. As demonstrated in **CS3 Portugal**, rubrics have also proven useful for the assessment of *working collaboratively* (Table 8). However, watching and recording the rate of activity in a grid was difficult for teachers. They found that they were not able to watch all groups simultaneously. Therefore, it is very helpful to assess *working collaboratively* at the group level, rather than individually (**CS3 Portugal**, **CS4** and **CS5 Hungary**).

Table 10: Registration grid for observation of working collaboratively (teamwork) in CS3 Portugal

Behaviour	Student name	Student name	Student name	Student name
Does not interrupt when others speak				
Questions the colleague regarding what he is saying				
Defends his points of view				
Talks with kindness				
Challenges a quieter colleague to speak				
Congratulates the colleagues when they present a positive idea				
Assumes an active role in order to solve conflicts between colleagues				
Defines/clarifies the work's objectives				
Defines/distributes/negotiates tasks among colleagues				
Draws attention to time				
Faced with distractions draws the group's attention to the work				

Planning investigations and practical implementation of the experiment is time-consuming. For this reason, the assessment is focused only on a few skills. The independent variable was given but the students had to devise ways of manipulating it. Older and more experienced students were free to plan different methods of creating the plant samples and setting levels of light intensity (**CS4** and **CS5 Hungary**). When they discussed their ideas they had an opportunity for critical thinking.

The students' *scientific literacy* improved as a result of their deeper understanding of photosynthesis and the discussion of the practical aspects of the investigation (**CS4** and **CS5 Hungary**). During the introductory phase, the teacher questions had brought the students' prior knowledge of the theoretical process of photosynthesis to the surface. They could think of examples for the role of light and mentioned, for instance, the variation in the amounts of light different plants required and the problem of caring for houseplants

Generally the teachers observed communication between the students while they were working in groups. The groups needed some support and reinforcement. Later the teachers used written work for formative assessment. At the end of the activity some teachers performed summative assessment (**CS4** and **CS5 Hungary**), where the assessment criteria were discussed with the students.

INQUIRY AND ASSESSMENT UNIT

REACTION RATES

Why wait for my vitamin C tablet to dissolve – how can I save time?

Odilla Finlayson

REACTION RATES

WHY WAIT FOR MY VITAMIN C TABLET TO DISSOLVE – HOW CAN I SAVE TIME?

Overview

KEY CONTENT/CONCEPTS

- Rates of reaction
- Acid and carbonate reactions
- Factors influencing rates of reaction (temperature, concentration, surface area)
- Properties of gases

LEVEL

- Lower second level
- Upper second level

INQUIRY SKILLS ASSESSED

- Planning investigations
- Forming coherent arguments
- Working collaboratively

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

- Scientific reasoning (data entry, drawing conclusions; trouble-shooting; identifying variables)
- Scientific literacy (presenting scientific data; critiquing experimental design)

ASSESSMENT METHODS

- Teacher observation
- Classroom dialogue
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials (graphs, group work placemats, investigation plans, reports)
- Presentations
- Other assessment items (homework exercise)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – REACTION RATES

The **Reaction rates** SAILS inquiry and assessment unit uses effervescent vitamin C tablets to introduce students to the concepts of gas production in the reaction of acid with carbonate, and rates of reaction and factors influencing reaction rate. Three activities aimed at lower second level are outlined, although they can be further extended and adapted for upper second level. The activities can be carried out in a sequence of lessons, which would require about ten class periods, or a specific activity can be targeted, requiring about two class periods depending on the skills to be assessed.

The first activity seeks to challenge students with collecting and identifying a gas, while the second activity explores quantitative measurements and graphical representation of data. The final activity explores identification of variables that may affect measurements. Students can develop a number of inquiry skills, in particular *planning investigations* and *working collaboratively*. They furthermore have the chance to progress their *scientific reasoning* capabilities and *scientific literacy*, through critiquing experimental design, interpreting and analysing data and graphical interpretation, and thus develop skills in *forming coherent arguments*.

This unit was trialled by teachers in Hungary, Ireland, UK, Turkey and Germany, with students aged 11-16 years (5 classes in total, mixed ability and gender). The teaching approach in all case studies was that of an *open/guided inquiry*. Inquiry skills assessed were *planning investigations*, and *working collaboratively*, as well as the assessment of *scientific reasoning* (drawing conclusions). A broad range of assessment methods was used, ranging from in-class observation to evaluation of artefacts after the lessons, and including peer- and self-assessment.

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 **Reaction rates** SAILS inquiry and assessment unit were developed for the SAILS project by the team at Dublin City University (DCU). There are three activities in this unit; each activity is described below, with its rationale, suggested lesson sequence and some teacher questions. Proposed methods for assessment during this unit are included, which may be used by teacher/peers to make judgements on student performance. Activity A: Designing an investigation is a preliminary activity to challenge the students with collecting and identifying a gas. Activity B: Determining reaction rate explores quantitative measurements, and graphical representation of data. This introduction to quantitative measurement leads into Activity C: Altering reaction rates, in which students identify variables that may affect measurements.

Activity A: Designing an investigation

Concept focus	Production and properties of CO_2 Acid-carbonate reaction
Inquiry skill focus	Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (argumentation) Scientific literacy (critiquing experimental design)
Assessment methods	Classroom dialogue Worksheets Student devised materials

Rationale

Students are asked to identify what is in the bubbles that are released when an effervescent vitamin C tablet is placed in water. The intention is that students need to design a way to trap the gas and identify it through an investigation of its properties. On completion of their investigation, students share and discuss their experimental design and results with their peers. They justify their conclusions based on the evidence that they have collected.

Suggested lesson sequence

1. The teacher carries out a quick demonstration, placing an effervescent vitamin C tablet in water and asking students to note their observations (without hypothesis).

2. Based on student observations, the teacher introduces the activity and challenge investigation to "Identify the gas present in the bubbles." Note that this part of the activity could be carried out in the preceding class and for homework students could plan how they would investigate this problem and present to the teacher a list of equipment needed. For this inquiry, it is necessary for students to first collect the gas produced, and then test its characteristics. Examples of methods for collection of gases are shown in Table 1.

3. Students are divided into groups and spend the lesson designing and carrying out their investigation. Students are allowed to modify their investigation. Throughout this stage students are instructed to document their workings and final conclusions.

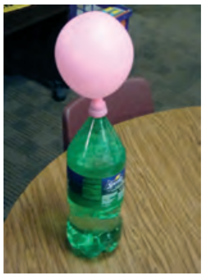
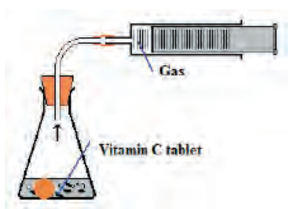
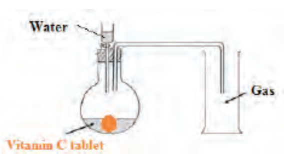
4. Once the gas is collected, students must carry out a number of tests to investigate its properties and to identify it. They can note its smell, colour and density, test its pH using litmus paper and check if it supports combustion, etc.

5. When the practical work is completed, students present their conclusions based on their experimental evidence.

6. The teacher chairs a whole-class discussion to (a) draw out examples of good experimental design and how it can be identified and to (b) examine students' solutions to the investigation.

7. The teacher can collect the reviewed practical documentation for the assessment.

Table 1: Examples of students' experimental methods to trap the gas

	Reaction set-up	Method detail
1	 **Figure 1:** Trapping gas using a bottle and balloon	• Tablet is dropped into a bottle of water • Balloon is secured around the top of the bottle • Gas is collected in the balloon
2	 **Figure 2:** Trapping gas using a gas syringe	• Tablet is placed in the conical flask • Gas is collected in the syringe
3	 **Figure 3:** Trapping gas using a gas collection tube	• Tablet is placed in a round bottom flask • Gas is collected in a gas collection tube

Possible teacher questions

- What do you observe when the tablet is placed in the water?
- What are the bubbles? What are they composed of?
- What do you notice regarding the movement of the tablet when it is dropped in water?
- Is a reaction occurring? If so, how do you know?
- What evidence have you determined to suggest that the gas is CO_2?
- How can you be sure that your experimental conclusions are valid?

Activity B: Determining reaction rate

Concept focus	Acid-carbonate reaction Distinguish between reacting and dissolving Handling of gases
Inquiry skill focus	Planning investigations
Scientific reasoning and literacy	Scientific reasoning (proportional reasoning)
Assessment methods	Student devised materials (experimental plan)

Rationale

Students are provided with a challenge, such as: "In the morning, I take an effervescent vitamin C tablet; however I usually have to drink it while there is still solid in the bottom of the cup. Can you measure the time it takes for the reaction to finish?" This activity can build on Activity A in that students are now familiar with handling gases and in this activity they now determine a way of measuring the rate of reaction. In Task 1 they must devise a way of measuring the rate experimentally, and in Task 2 they execute their chosen method to generate data for interpretation.

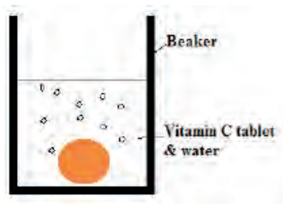
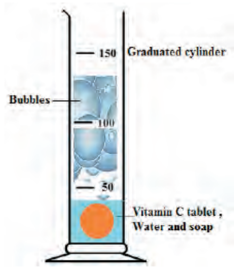
Task 1: Students devise a way of measuring the rate experimentally, e.g. measure the rate of formation of bubbles, measure the length of time for all the bubbles to disappear, measure the rate of production of gas using syringe for example. Students should also take into consideration good experimental design – such as developing a fair test, reproducibility of results and validity of their results. As different groups of students will develop their own experimental methods to determine the rate, a class discussion can then follow which focuses on the variation in the answers obtained, leading to the conclusion that results are dependent on the criteria that was used to determine when the reaction had finished. In this way, it raises the point that experimental results are dependent on the criteria set and that different experimental set ups can give different answers – even though both sets of results are valid and reproducible. The class can then either all decide on the same criterion to define the "end of reaction" or can refine their experimental method(s) to focus on reproducibility of their method.

Task 2: After Task 1, students will have developed their method to determine the rate of reaction and so now they measure the rate during the reaction. In this part, the students should devise a table to record their data and determine the change in the number of bubbles/volume of bubbles/volume of gas, etc., over time. This data can then be presented graphically and interpreted.

Suggested lesson sequence for Task 1

1. Divide the class into groups and distribute the challenge. Allow the students to plan their investigation, taking note of their experimental design. Note that students should not be given any apparatus until after they have set out their design, as seeing particular apparatus in front of them will limit their thinking in terms of experimental design. Some examples of possible experimental designs are shown in Table 2.

Table 2: Examples of students' experimental methods for measuring rate of reaction

	Reaction set-up	Method detail
1	 **Figure 4:** Measurement of reaction rate based on time for effervescence to cease	• Add the tablet to a known volume of water • Record how long it takes for the bubbles to stop forming
2	 **Figure 5:** Measurement of reaction rate based on time for effervescence to cease (using detergent)	• Add tablet to a known volume of water • Add few drops of liquid detergent. • Record the time it takes for the bubbles to stop moving up the graduated cylinder
3	• Add tablet to known amount of water in Figure 1 earlier • Measure the increase in diameter of the balloon with time	
4	• Add tablet to known amount of water in Figure 2 earlier • Measure the volume of gas produced in the syringe with time	

2. Students carry out their plan and note in particular the time required for the reaction to finish. Students should note the criteria they used to determine that the reaction was finished. This should be given about 15-20 min only, as the focus will be on the criteria rather than on the exact method that they have devised.

3. The teacher should monitor students as they complete the task and question them to justify their approach.

4. Discuss the approach and experimental conclusions as a class with each group contributing their findings and explanation.

5. Discuss the different approaches and suggested criteria for determining the end-point of the reaction. The discussion should highlight the different criteria used, each criteria is valid, giving different answers. Therefore, if we want to compare our results, then we need to agree common criteria. Reproducibility of different approaches can be discussed.

6. Basic calculations can be done to determine the overall rate of the reaction (from the start to the end of the reaction).

Suggested lesson sequence for Task 2

1. This activity is then extended by asking students if they noticed more bubbles at the start or towards the end of the reaction. As there were more at the beginning, can they determine if the rate of the reaction is different if they measure it at the start of the reaction or if they measure it later as the reaction proceeds?

2. Students then decide on how to measure the rate of the reaction over time.

3. Students record their data and present it graphically.

Possible teacher questions

- How do we know that a reaction has occurred?
- What reaction is occurring to produce CO_2?
- How do you know your reaction has stopped?
- Is it important that everyone has the same criteria for the end of the reaction to compare results?
- Is the rate the same at the beginning and towards the end of the reaction?

Activity C: Altering reaction rates

Concept focus	Effect of variables
Inquiry skill focus	Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific literacy (presenting scientific conclusions)
Assessment methods	Student devised materials Presentations (poster)

Rationale

In this activity the students quantitatively explore the concept of variables affecting rates of reaction through experimentation. This is addressed through student completion of a final challenge investigation building on from Activity B: Determining reaction rate: "Usually when I am taking my effervescent vitamin C drink I wait until it has stopped fizzing before I drink it. Some mornings I am running late for school. Can I speed up this reaction?"

In this situation students will be directed to produce quantitative data and include graphical representations of their data. *Working collaboratively* is a key skill that is addressed in this activity. To facilitate this, students will be arranged into different groups at various stages and allocated both individual and group responsibility to complete the challenge. The final part of this activity is for students to develop, explain and defend a public presentation (poster) of their experimental work, thinking and solution to the challenge. Through this activity it is intended to enhance their *scientific literacy* and *scientific reasoning* skills.

Suggested lesson sequence

1. Students are directed toward a challenge that is displayed on the board: "In the morning, I take effervescent vitamin C tablets, however I'm usually running late for school. How can I speed up the reaction so I can have my drink sooner?" and asked to provide quantitative data and graphical representations to explain their solution.

2. They complete a "think-pair-share" activity, where they develop ideas on how to address the challenge.

3. The teacher collates some of the students' initial ideas on the board. It is expected that these will build on the knowledge developed in Activity B: Determining reaction rate, and examine:

   a. Generation of CO_2 released with respect to time graph

   b. Changing amount of water used per tablet (concentration)

   c. Using different amounts of tablets (concentration)

   d. Using hotter water (temperature)

   e. Grinding the tablet (surface area)

4. The teacher divides the class into groups where each group works on (a) initial determination of rate of reaction and (b) determination of change of rate using one of the factors identified, i.e. one group examines concentration and another examines temperature, or groups work on their own suggested factor(s).

5. The groups are rearranged, so that each member joins a new group and has the responsibility of sharing their experimental approach and findings with the new group.

6. Each new group prepares a poster that explains their solution to the challenge. This is displayed in the class and each group defends their proposed solution.

Possible teacher questions

- What does the slope of the graph indicate?
- Is the rate of reaction constant?
- When are the fastest and slowest times for the reaction? How are they represented on the graph?
- Which variable had the greatest affect on the rate of reaction? How can we explain this effect?
- Did your group work efficiently?
- Did everyone in the group have the opportunity to speak?
- Did you assign roles within the group?
- What are your colleague's strengths when working in groups?

2.2 Assessment of activities for inquiry teaching & learning

When dealing with the unit activities, it is important that the assessment is in line with the objectives of the topic and with the curriculum. It is also important that students know before they commence their work how to report their results and how they will be judged. The skill of *planning investigations* is a key inquiry skill for development during the implementation of this inquiry and assessment unit, but opportunities for the assessment of other skills and competencies have been identified for each of the unit activities. For each of the activities, some suggested skills for assessment and criteria for success are outlined.

Assessment of skills in Activity A: Designing an investigation

Planning investigations; critiquing experimental design

- Did the students devise an appropriate method to trap a sample of the evolved gas?
- Did the students devise a range of tests to consider the identity of the gas?
- Did the students use their evidence to suggest a possible identity of the gas?
- Did students suggest improvements to the experimental design or compare different methods as carried out by other groups?

Working collaboratively

- Were all members in the group involved and engaged in the task?
- Did they share ideas?

Scientific reasoning (argumentation)

- Could they identify if CO_2 was produced. Further discussion could identify the reaction (if required).

Assessment of skills in Activity B: Determining reaction rate

Planning investigations; critiquing experimental design

- Did students devise an appropriate experimental design to measure the rate?
- Did the students explain the criteria they used to determine the end of the reaction?
- Could they justify their criteria?
- Did students critique other groups' experimental design – could they identify strengths and weaknesses in their design or criteria?

Scientific reasoning (proportional reasoning)

- Did students correctly present their data graphically?
- Did students correctly identify the rates at different times?
- Could they distinguish between concentration vs. time graphs and rate vs. time graphs?

Assessment of skills in Activity C: Altering reaction rates

Working collaboratively

- Did students work collaboratively?
- Did students (after moving to the new group) communicate the results from the first group effectively and accurately?
- Did the students in the second group compile the data from the 2 sets of results in a coherent fashion?
- Did the students analyse both sets of data and draw appropriate inferences from the combined results?

Forming coherent arguments, scientific reasoning (graphical interpretation; data interpretation and analysis)

- Did the students accurately represent their data?
- Did they analyse the data to determine the change in rate?

Scientific literacy (presenting scientific conclusions)

- Did the students represent their data clearly?
- Did they reach appropriate conclusions from their evidence?

2.3 Further developments/extensions

The **Reaction rates** SAILS inquiry and assessment unit is suggested for implementation with lower second level students. However, a further activity is proposed for use with upper second level students, in which the rate of reaction between sodium carbonate and citric acid is investigated and compared to that between sodium carbonate and ascorbic acid. In addition, a post-unit assessment is proposed, which can be used to evaluate students' understanding and ability to transfer knowledge.

Activity D: Qualitatively determine which reactant (or combination) produces the most CO_2

Concept focus	Distinguish between reacting and dissolving Determining reactivity
Inquiry skill focus	Developing hypotheses Planning investigations
Scientific reasoning and literacy	Scientific reasoning (proportional reasoning)
Assessment methods	Student devised materials (experimental plan)

Rationale

With more advanced chemistry groups, it is interesting to investigate the rate of reaction between sodium carbonate (Na_2CO_3) and citric acid and compare to that between sodium carbonate and ascorbic acid. Students are provided with the following challenge: "The main reactants in an effervescent vitamin C tablet are sodium carbonate, citric acid and ascorbic acid. Plan an investigation to qualitatively determine the reactants that are responsible for the production of the 'effervescence' when the tablet in dropped into water. Justify your experimental results from a theoretical standpoint."

Then students are asked to suggest an explanation of why citric acid is added to these tablets (sodium carbonate reacts with citric acid first to release carbon dioxide, leaving a solution of ascorbic acid). Further questions can be raised, in terms of the amount of citric acid required: What is the limiting reagent? Which is in excess? Are more bubbles produced if more citric acid is added? If more ascorbic acid is added? If more sodium carbonate is added? Do all these effervescent tablets have the same rate of reaction? Students could suggest using different products with varying amount of vitamin C (ascorbic acid). The teacher can assess their ability to transfer knowledge gained during the lessons to a real world application by seeing if they can interpret the labels of the vitamin C products to explain the rates of reaction determined. Some of these tablets contain 1000 mg of vitamin C, which is well in excess of the recommended daily allowance (RDA). To test proportional reasoning, students can be asked, "How many tablets are needed to get your RDA of vitamin C?"

To complete this challenge, students will have to demonstrate their *scientific reasoning* (proportional reasoning). They will have to develop a hypothesis and test it. They should develop a 3x4 matrix to test all possible combinations of the reagents with water. They will have to determine which variables to measure, which variables to keep constant and which variables to change. They will have to set up the experiment appropriately and analytically record their results. Another aspect of this challenge is that students will have to distinguish the difference between "dissolving" and "reacting" as each of the substances will dissolve in water but it is only when the carbonate is combined with the acid that the reaction occurs (formation of a new substance CO_2). They also have to distinguish between the two acids present and the amounts that they are present in the tablet. They are then required to relate their experimental results to a conceptual understanding of acid-carbonate reactions.

Suggested lesson sequence

1. Students should devise a 3x4 matrix to determine all the possible combinations of the three reagents with water.
2. When designing the experiment, students should have considered their hypothesis, the variable that they will measure, variables that they can change and variables that they must keep constant.
3. Students also need to consider the set-up for the experiment, including necessary equipment, and decide on appropriate way of recording results.
4. To follow the reactions, students can investigate changes in pH, colour intensity, etc., to determine reactivity.

Post-unit assessment

Concept focus	Acid-carbonate reactions
Inquiry skill focus	Planning investigations Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (proportional reasoning)
Assessment methods	Other assessment items (written test)

Rationale

This assessment involves assessing students' ability to transfer the knowledge gained in the inquiry activities investigated in this unit to other areas. The questions given below are examples that could be used to determine if students can apply intended learning from the learning sequence into other contexts.

Question 1:

(i) In the reaction of HCl with Mg to form H_2 (reaction HCl + Mg → $MgCl_2 + H_2$), the change in concentration of H_2 is shown on Graph A (Figure 6). From the point shown, draw in how the HCl concentration would change over the same time. (Alternative question (i) Select which line in Graph B (Figure 6) shows how the HCl concentration changes over the same time.)

ii) If the reaction continued until all the Mg was used up, extend Graph A to show how the H2 concentration would change.

Question 2:

In a particular reaction, the concentration of product is graphed against the time of reaction, as shown in Graph C (Figure 7). During which time interval (A-D) is the rate of reaction the fastest? The slowest?

Question 3:

For the reaction shown in Graph D (Figure 8), at which temperature (T1 or T2) is rate of reaction the highest/slowest? Explain your answer.

Question 4:

Marble chips react with acid to produce CO_2 gas. Marble is available as a board, large lumps and as ground powder. Suggest, with explanation, which forms of marble should be used to generate CO_2 most quickly.

Question 5:

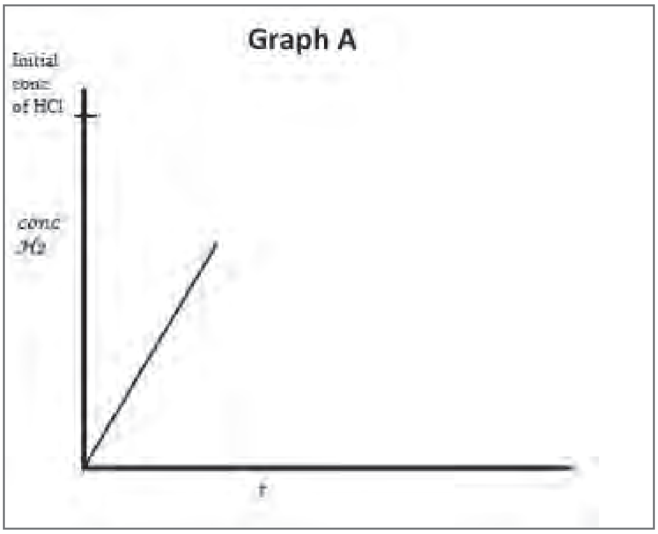
Vinegar is often used to clean surfaces at home. If you have a marble ($CaCO^3$) worktop, would you use vinegar – explain why/why not.

Question 6:

Using a provided set of data showing the amount of CO_2 produced against time:

- Represent the data on a graph
- Determine the overall rate of the reaction

Is the reaction occurring at the same rate over the whole time?



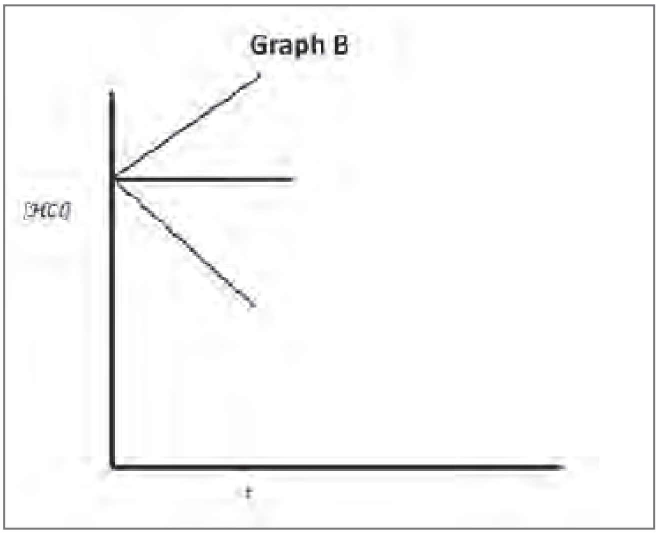


Figure 6: Graphs A and B, for Question 1

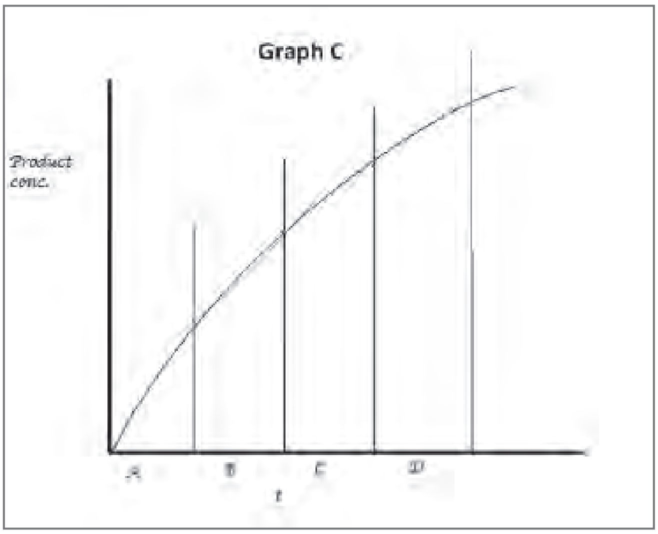


Figure 7: Graph C, for Question 2

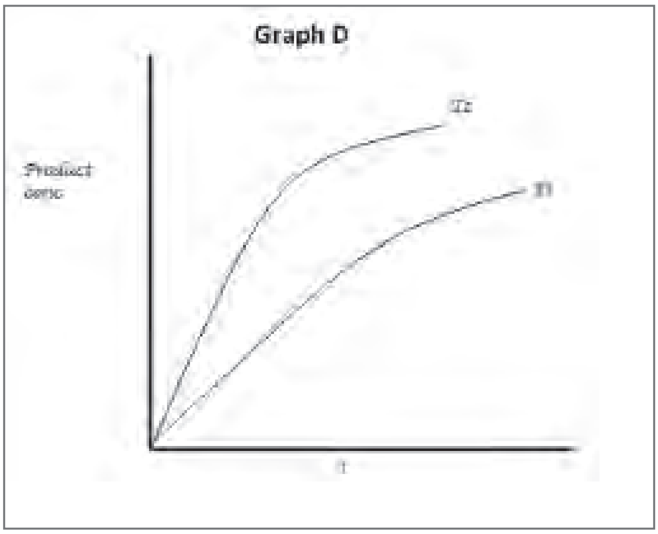


Figure 8: Graph D, for Question 3

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in five countries, producing five case studies of its implementation – **CS1 Hungary**, **CS2 Ireland**, **CS3 United Kingdom**, **CS4 Turkey**, **CS5 Germany**. All the case studies were implemented by teachers who had some experience of teaching through inquiry, but the students involved had generally not been taught through inquiry, except in **CS3 United Kingdom** and **CS5 Germany**.

CS2 Ireland, **CS3 United Kingdom**, **CS4 Turkey** and **CS5 Germany** detail implementation at lower second level, with students aged 11-15 years, and students were 15-16 years old in **CS1 Hungary**. The students in each class were mixed ability, and mixed gender in all case studies, except **CS2 Ireland**, where students were all boys. In **CS5 Germany**, the students were participating in an elective interdisciplinary science course. Generally the case studies describe an implementation duration of approximately 90 minutes (two 40-minute lesson periods or one double lesson); **CS4 Turkey** describes a single 40-minute lesson.

All case studies focused on assessing students' skill in *planning investigations*. Some focus on evaluating their *scientific reasoning* capabilities and skill in *working collaboratively*, as well as other skills. The assessment was achieved through classroom dialogue, evaluation of students' written materials and peer- and self-assessment.

3.1 Teaching approach

Inquiry approach used

The inquiry approach used in all the case studies was that of *bounded inquiry*, i.e. it was guided in the sense that the teacher posed the initial question but there were open inquiry opportunities in that students had freedom in addressing the question. In **CS3 United Kingdom**, the teacher implemented the initial part of the activity (designing an investigation) as a purely *open inquiry*.

Implementation

The students in all the case studies worked in groups at various stages throughout the lessons, but there was variation in both how the groups were chosen and the group size, as shown in Table 3.

This inquiry and assessment unit features three activities, each of which uses an everyday context of an effervescent vitamin C tablet dropped in water to form the basis of the inquiry. The activities focus on the methods to trap the gas and determination of the gas evolved (Activity A: Designing an investigation), methods to measure how fast the reaction occurs (Activity B: Determining reaction rate) and investigation of effects of variables on reaction rate (Activity C: Altering reaction rates). All of the case studies revolved around the practical activity. All of the case studies at lower second level (**CS2 Ireland**, **CS3 United Kingdom**, **CS4 Turkey** and **CS5 Germany**) focused on the inquiry skill of *planning investigations*, as well as *working collaboratively* and *forming coherent arguments* using *scientific reasoning* (identifying variables, data entry, drawing conclusions) and *scientific literacy* (critiquing experimental design). With the exception of **CS1 Hungary**, all the case studies started with Activity A: Designing an investigation, as it was an introductory inquiry and appropriate for lower second level students. **CS3 United Kingdom** implemented a modified version of Activity C: Altering reaction rates, looking at the variables affecting the rate of reaction, without using quantitative data. **CS1 Hungary** started with Activity B: Determining reaction rate and led on to Activity C: Altering reaction rates, with a student group from upper second level.

Adaptations of the unit

In **CS1 Hungary**, the teacher provided a student worksheet to aid in guiding the inquiry process. Students planned their investigations as a group, and then participated in a whole-class discussion to identify reaction parameters.

Table 3: Summary of case studies

Case Study	Activities implemented	Duration	Group size and selection method
CS1 Hungary	Activity B Activity C	One lesson (90 min)	• 5 groups of 4 students • Self-selected
CS2 Ireland	Activity A	Two lessons (40 min each)	• 6 groups of 3-4 students • Self-selected
CS3 United Kingdom	Activity A Activity C	Two lessons (45 min each)	• 6 groups of 3-4 students • Teacher assigned groups to be mixed ability and mixed gender
CS4 Turkey	Activity A	One lesson (40 min)	• 5 groups of 5 students • Teacher assigned groups
CS5 Germany	Activities A-C	One lesson (90 min)	• Groups of 3 students • Self-selected

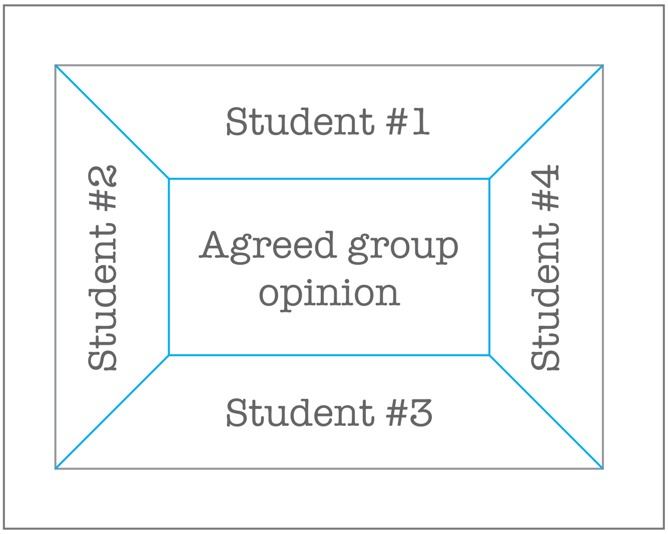


Figure 9: Example of group work placemat from **CS2 Ireland**

In **CS2 Ireland**, following an extensive brainstorming session and discussion on properties of different gases, the students were shown three different experimental methods to collect the gas and they critiqued the methods. Following this, the students had to devise a suitable effective way to collect and identify a sample of the gas. The students used a group work placemat, on which each student wrote their suggestions, which were then debated by the group and an agreed group opinion was determined (Figure 9). This teacher also prepared a student worksheet, but in the case study highlights that this may have directed the inquiry too much, and closed down open learning.

In **CS3 United Kingdom**, the learning sequence is described where the teacher allowed the students to first plan the investigation, then present their plans to another group who critiqued their plan. The students did not get a chance to implement their method – however the teacher noted that doing so would be beneficial. The teacher used a "lolly sticks" method for selecting students for questioning, the name of each student was written on a "lolly stick" and sticks were drawn at random. Therefore, all students must be prepared to answer questions, not just the confident or out-going students.

In **CS4 Turkey**, the students were in 6th grade, at which stage students understand concepts of physical and chemical change, but have not yet learned about chemical reactions. Therefore, the teacher modified the lesson sequence to provide an introduction to this topic. The aim of the investigation was to determine how to collect a gas (but not to identify it). Student planned and implemented their investigations.

In **CS5 Germany** the unit was implemented in full, although the teacher added an additional step to research the methods for identifying gases. The students had not covered this topic previously, and without this knowledge would not have been able to continue to later activities. The teacher tried to ensure that the inquiry was very open, and did not provide guidance in the planning and execution of the investigations.

3.2 Assessment strategies

Within the five case studies, the inquiry skills of *planning investigations, forming coherent arguments and working collaboratively* were assessed in different ways. Additionally, content knowledge, evidence of *scientific reasoning* and *scientific literacy* were assessed (Table 4). While the case studies highlighted the development of several inquiry skills, the assessment was only described for a few of these skills. For some skills, the assessment was carried out after class and was based on a written artefact produced in class. In other situations, formative assessment guided the student learning during the class.

Table 4: Inquiry skills identified by teachers in the case studies

CS1 Hungary	• Planning investigations • Forming coherent arguments • Working collaboratively • Scientific reasoning (data entry, drawing conclusions) • Scientific literacy (presenting scientific data)
CS2 Ireland	• Planning investigations • Working collaboratively • Scientific literacy (critiquing experimental design)
CS3 United Kingdom	• Planning investigations • Working collaboratively • Scientific reasoning (trouble-shooting) • Scientific literacy (critiquing experimental design)
CS4 Turkey	• Planning investigations • Forming coherent arguments
CS5 Germany	• Planning investigations • Scientific reasoning (identifying variables)

Planning investigations

Evidence of the students' skill in *planning investigations* was captured in the written plan generated by the students in **CS1 Hungary** and **CS3 United Kingdom**. In **CS4 Turkey**, the plan was presented as a drawing with explanations and assessment judgement was made after the activity, based on the level of detail presented. **CS5 Germany** focused on provision of formative feedback, with some assessment opportunities identified as teacher observation, review of protocols and peer-assessment of posters showing the planned experiments.

In **CS1 Hungary**, the teacher assessed the students' work and developed a holistic 3-level rubric in order to assess the skills addressed in the class: planning and implementing an investigation, graphical representation, cause and effect, and reasoning from evidence (Table 5). This rubric was used to evaluate the student work on a worksheet and graphs and feedback was given during the lesson and feedback on graphs given at the subsequent lesson. The students' *scientific reasoning* was determined from the graphs presented by the students and their conclusions drawn from the graphs. Some student difficulties were noted – such as the identification of dependent and independent variables and choosing the scales for the axes.

Table 5: Assessment scale used in CS1 Hungary

	Competencies	Beginner	Intermediate	Advanced
Inquiry skills	**Planning investigations Implementing an experiment**	The group needs the teacher's guidance to complete the task, their questions are not pertinent to the task, they record their results inconsistently. They do not know what the different pieces of equipment are used for.	The group needs occasional help. Their questions are not always pertinent. They record their results consistently but with omissions. They lack confidence in using equipment.	The group works without help. Their questions are pertinent to the problem. They record their results accurately. They can choose the appropriate equipment.
Inquiry skills	**Graphical representation**	The independent and dependent variables are confused, the scale of the graph is inappropriate, graph title is omitted.	There are some inaccuracies in the graph, some labels are missing, the graph title is inaccurate.	The graph is accurate, the scales of the axes are appropriately chosen, the title is accurate (shows what is plotted as a function of what)
Scientific literacy	**Causality Forming coherent arguments**	The members of the group do not recognise the chemical nature of the observed phenomenon, they do not know what is happening.	The members of the group have only partial knowledge of the chemical content of the observed phenomenon and they lack confidence in the knowledge.	The members of the group understand the chemical process observed and identify the cause-and-effect relationship without help.
Scientific literacy	**Proportional reasoning**	The summary is incoherent; it does not focus on what is important.	The summary contains some inaccuracies or omissions.	The summary is coherent and the reasoning is easy to follow.

CS2 Ireland features an example of teacher-led self-assessment. Students recorded their observations from the demonstration and put words on their brainstorm wall. The teacher provided prompt questions, to which students could add their own questions, whereupon the students critiqued a selection of gas capture methods. It is interesting to note here that the teacher felt that there was a greater opportunity for learning if the students had created their own critiques followed by a brainstorming, thus reducing the teacher-led impression for the students. This teacher intentionally did not develop specific rubrics as it was intended that students would conduct a self-assessment. Annotated student work is given in the case study.

CS3 United Kingdom details an example of formative peer-assessment. After generating their research plans in groups, the students critiqued those from another group, and were asked to suggest possible improvements stating why. This aided in increasing students' *scientific literacy*, as they were able to demonstrate their understanding of the topic, and evaluate inquiry processes.

Forming coherent arguments; scientific reasoning; scientific literacy

In **CS1 Hungary**, *scientific literacy* was evaluated and assessed through the identification of cause-and-effect relationships and the use of scientific evidence to form coherent arguments. The assessment was based on the worksheets and graphs handed in by the students, teacher's notes from observation of the work process and the students' brief summaries. The teacher used a 3-level rubric for evaluation of this skill, as shown in Table 5, and was satisfied with the student groups' performance, as they gave confident, clear and well-structured presentations of their results.

The teacher in **CS4 Turkey** also describes evaluation of students' skill in *forming coherent arguments*, which was assessed formatively through question and answer sessions during the lesson. When students were able to formulate a hypothesis and conduct an appropriate experiment for its investigation, the teacher felt that the learning aims were achieved well.

In all case studies, students developed their *scientific reasoning* during the planning of an investigation, as they needed to consider what research question to address and how to address it. They considered the variables that they might need to control, the data that they should record and formed conclusions at the end of the process. The strong emphasis in this unit on the skill of critiquing experimental design is ideal for strengthening students' *scientific literacy*, encouraging them to become critical thinkers and to understand the scientific phenomena involved in an everyday experience.

Working collaboratively

The case studies show examples of working collaboratively being assessed by the teacher as well as being self-assessed. In **CS1 Hungary**, this skill was not explicitly assessed; however, the teacher observed students working well together and noted that one group of students, who were normally quiet in class, were very lively and motivated while working on this activity. In **CS4 Turkey**, the teacher observed the groups working and noted how one member of one group acted as the group's teacher and how different personalities influenced the group working together.

In **CS2 Ireland**, the group work placemat was used to determine each individual's input to the group and provided evidence of the student work (Figure 9). Students were encouraged to share criticisms of methods in small groups and in whole-class discussions. The students engaged in a whole-class brainstorming session to identify keywords for the investigation. This teacher shared the "criteria for success" for the lessons with the students, which for *working collaboratively* was "willingness to engage in group work and whole-class discussion."

In **CS3 United Kingdom**, the teacher used self-assessment to determine the quality of the group work. Students completed a questionnaire on how they worked within their groups and how they treated the other gender. This was an opportunity for them to reflect on their own contributions to the group and identify any interpersonal skills that they could improve.

Dialogue

Through teacher-student discussion, misconceptions as to the nature of the gas evolved in the investigations were determined. In **CS4 Turkey**, a short dialogue is transcribed that indicates the student forming arguments based on a misconception. Likewise in **CS1 Hungary**, students looked at the vitamin C packaging to help identify the gas and again through dialogue, the teacher became aware of the misconception. The teacher action following these dialogues is not noted in the case study.

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].

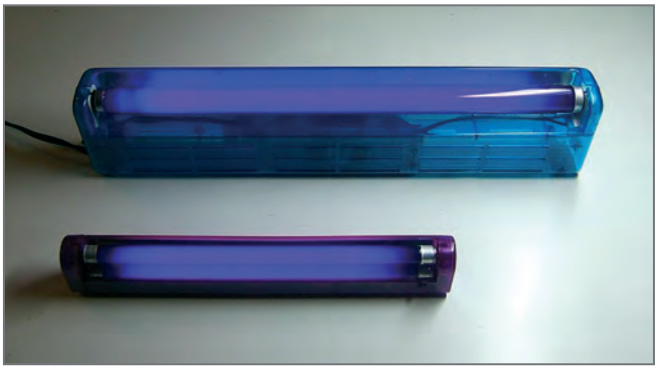


Figure 1: UV lamp, also known as a "black light"

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:

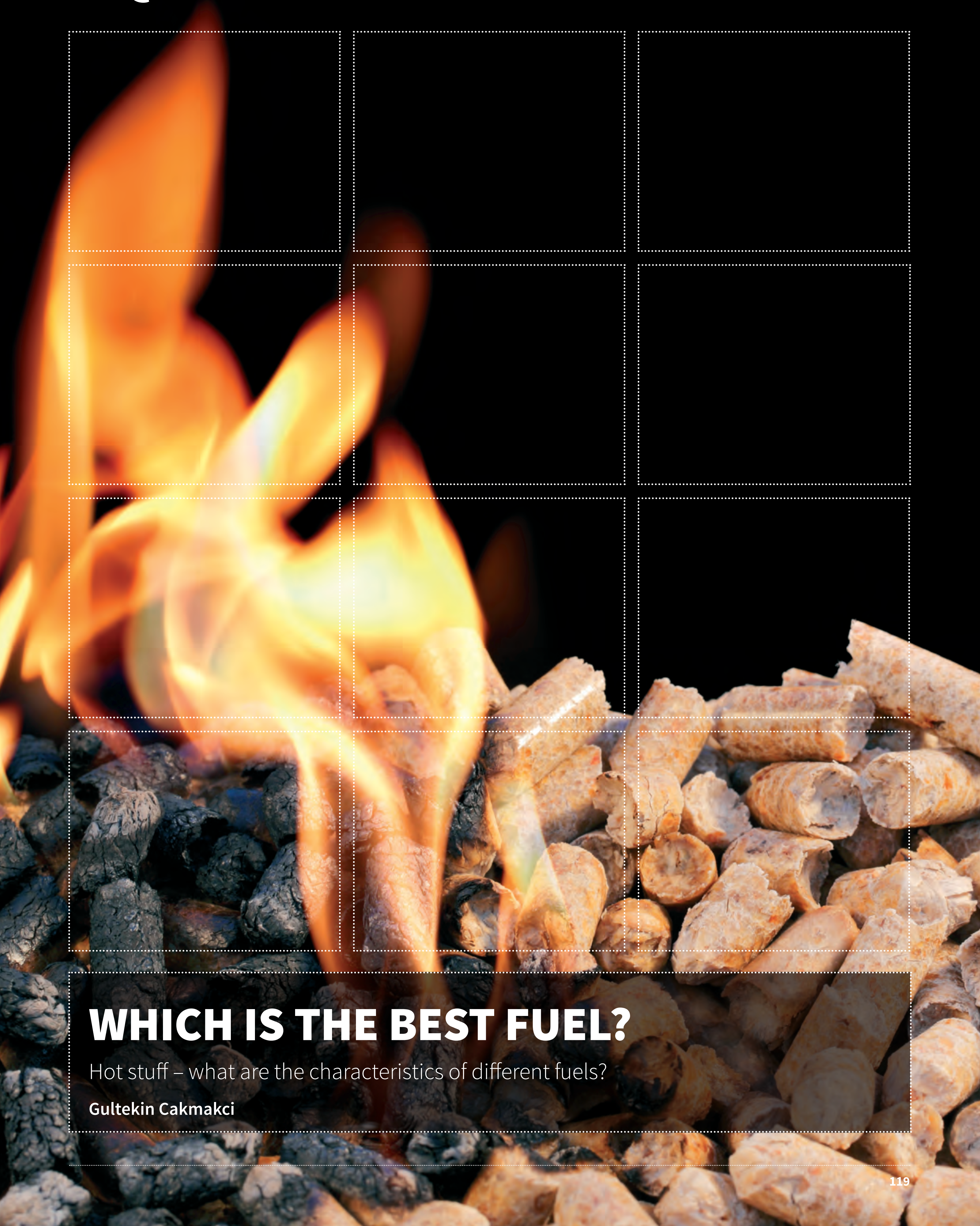
- Oral feedback through questioning during the lessons
- Written feedback in the form of brief questions after the planning lesson
- Peer-assessment of the final poster
- Self-assessment of group skills at the end of lesson 1 and 2
- Teacher marking of the final work and a competency level assigned.

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.

INQUIRY AND ASSESSMENT UNIT



WHICH IS THE BEST FUEL?

Hot stuff – what are the characteristics of different fuels?

Gultekin Cakmakci

WHICH IS THE BEST FUEL?

HOT STUFF – WHAT ARE THE CHARACTERISTICS OF DIFFERENT FUELS?

Overview

KEY CONTENT/CONCEPTS

- Enthalpy
- Heat energy
- Heat energy changes
- Calorimetry

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 (collection of scientific data; defining variables)
- Scientific literacy (analysis and interpretation of scientific data)

ASSESSMENT METHODS

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

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – WHICH IS THE BEST FUEL?

The **Which is the best fuel?** SAILS inquiry and assessment unit aims to encourage students to realise that fuels have different heats of combustion and allow them to realise that the meaning of "best" can change depending on the context. This is achieved by planning and carrying out an experiment to measure heat energy changes and finding enthalpies of combustion experimentally. This activity may be implemented at lower or upper second levels depending on the curriculum's objectives and full implementation requires four lessons.

Through this unit, students are provided the opportunity to develop a number of inquiry skills such as *developing hypotheses, planning investigations* (designing and conducting an experiment), and *forming coherent arguments* (drawing appropriate conclusions using reasoned arguments). In addition they build their *scientific reasoning* capabilities by collecting meaningful data, and enrich their *scientific literacy* through analysis of scientific data and presentation of scientific conclusions.

This unit was trialled by teachers in Turkey, Poland, Greece and Denmark, producing case studies of implementation at both lower and upper second level. Students were aged 14-18 years, and of mixed ability and gender. The teaching approach used in all case studies was *bounded* or *guided inquiry*, with some open opportunities. All four SAILS inquiry skills were assessed – *planning investigations, developing hypotheses, forming coherent arguments* and *working collaboratively* – as well as *scientific reasoning* capabilities. The assessment methods described include classroom dialogue, teacher observation, group discussion or presentations and evaluation of student artefacts.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The activities in the **Which is the best fuel?** SAILS inquiry and assessment unit were developed as part of the PARSEL project.[1] The teaching and learning activities were adapted for the SAILS project by the team at Hacettepe University.

In this unit, four key aspects or concepts are identified for development:

- Fuels have different heats of combustion;
- The meaning of "best" can change depending on the context, and that different factors can be considered in determining the best fuel;
- Planning and carrying out an experiment to measure heat energy changes, and
- Determining enthalpies of combustion by burning a compound and measuring the temperature rise in a known volume of water that is heated by combustion of a known mass of the compound.

This unit has been designed for use at both lower and upper second level; depending on the teacher's aims, different aspects can be emphasised. There are four activities outlined in the unit. In Activity A: Introduction, the students are consider the topic of fuels and the research question, "Which is the best fuel?" In the Activity B: Planning an investigation, the students plan how they might investigate the research question, and in Activity C: Carrying out an investigation, they carry out an experiment to investigate the question. These activities can be presented as an *open* or *bounded inquiry*, allowing the students an opportunity to design the experiment. In this case, variables to control (such as the amount of water to be used), the apparatus required and the precautions needed, are not mentioned. In an alternative scenario, using a *guided inquiry* approach, the design can be simplified by giving the actual experimental instructions and allowing the students to carry out the experiment. Time can then be spent discussing the meaning of "best" as a group activity. In the Activity D: Conclusions, the students form conclusions, determine their choice of the "best fuel" and explain their choice.

Opportunities within this unit allow for the assessment of the SAILS inquiry skills of *developing hypotheses, planning investigations* (designing and conducting an experiment), *forming coherent arguments* (supporting conclusions using reasoned arguments and evidence) and *working collaboratively*. In addition, there is scope for development of *scientific reasoning* capabilities through identifying and defining variables operationally, collecting and documenting meaningful data, and explaining any unexpected results. This unit allows for enrichment of *scientific literacy* through analysis of scientific data, drawing appropriate conclusions, reporting and discussing results and understanding the scientific principles underlying combustion.

Activity A: Introduction

Concept focus	Understanding enthalpy Fuels – examples and criteria for identifying the "best" fuels
Inquiry skill focus	Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (problem-solving, making comparisons)
Assessment methods	Classroom dialogue Student devised materials

Rationale

In this activity, students review their prior knowledge and preconceptions around the topic of fuels and combustion. This can be achieved through individual reflection, small-group discussion or whole-class brainstorming. The teacher can guide the students to identify examples of fuels and their various uses. Once students understand the underlying concepts, the teacher introduces the inquiry task – "Which is the best fuel?" In this discussion, students should work towards identifying the characteristics of a "good" fuel, and how this can vary depending on function.

Suggested learning sequence

1. The lessons can begin by revising the meaning of "fuel." This can be done by each student writing down their interpretation, followed by the teacher soliciting responses from members of the class and building up a description of a fuel on the blackboard.

2. By means of a brainstorming session, the teacher can gather examples of fuels and where they are used. At this stage the idea is to get a wide range of suggestions, rather than limiting the discussion to the range of fuels that might be used in the experiments. Thus examples such as nuclear fuel or electricity are just as acceptable as petrol, diesel, natural gas or kerosene.

3. Following this, the teacher could raise the question – which fuel is best? The students can discuss the meaning of "best" as a group discussion. To ensure the discussion can begin, the teacher can give each group a hand-out on possible meanings of "best" related to fuels. At this stage the teacher will need to limit the fuels under consideration, by suggesting, for example, that the students only consider liquid fuels. Various ideas could be solicited from the class.

[1] Popularity and Relevance of Science Education for Scientific Literacy (PARSEL), which was funded by the European Union's Sixth Framework Programme in 2006, http://icaseonline.net/parsel/www.parsel.uni-kiel.de/cms/indexe27e.html?id=76 [accessed October 2015]

Activity B: Planning an investigation

Concept focus	Planning an investigation to compare fuels Heat of combustion, enthalpy
Inquiry skill focus	Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (identification of variables)
Assessment methods	Classroom dialogue Teacher observation Student devised materials

Rationale

In this activity, the students develop an experiment to investigate which is the best fuel, building upon the ideas suggested previously. At the end of the lesson, students are expected to be able to prepare a workable plan for carrying out the experiment. They should discuss their experimental plan with colleagues in a group and modify their plan as appropriate. They will also plan how to determine the calorific value of fuels and identify appropriate calculations.

Suggested learning sequence

1. The teacher asks the students, "Can you suggest how we could find out which is the best fuel?"
2. Students should tackle this question in groups. The teacher will need to guide the students in the planning part of the experiment (as he/she goes around the various groups), by trying to get the students to suggest the following
   a. Something (water) is heated by burning each fuel in turn;
   b. What needs to be constant for each experiment;
   c. Could this be a fixed mass of water?
   d. The amount of fuel used needs to be measurable;
   e. A measure of the heat given out can be made from the rise in temperature of the water;
   f. Measurement of the amount of fuel before and after the experiment will indicate the amount of fuel used;
   g. By measuring the time taken for the fuel to burn, it is possible to determine which fuel heats the water the fastest.
   h. By knowing the cost of the fuel per given quantity, it is possible to determine the most economical fuel. Possible fuels to use may be paraffin, methylated spirits (ethanol), methanol or candle wax (spirit burner not required in this case).
3. The teacher should encourage students to put forward other points that may or may not be used in the experiment, such as that the water needs to be at the same temperature at the beginning of each experiment, heat losses need to be minimised/measured and the vessel in which the fuel is contained needs to be identical in each case.
4. The students, in their groups, write out an experimental procedure, suggesting apparatus that might be suitable.

Activity C: Carrying out an investigation

Concept focus	Understanding enthalpy Identifying the "best" fuels
Inquiry skill focus	Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (collecting scientific data) Scientific literacy (making informed choices of fuel for particular functions)
Assessment methods	Classroom dialogue Teacher observation Peer-assessment Worksheets or student devised materials

Rationale

This activity may be implemented using a *bounded* or *guided* approach. Students are expected to carry out the experiment in a group, where each member can use a different fuel. Students should record the data obtained in a suitable format, calculate both calorific value and heat of combustion and compare their results with the data from others in the group. Students can discuss the procedures used in the experiment, the steps taken to determine accuracy and the limitations of the set-up to give accurate results.

Suggested learning sequence

1. After the planning activity, the teacher can discuss the procedure with the class, making sure that suggestions of unsafe practices are discarded. Then, to ensure each group is able to carry out the experiments, the teacher can give a handout or worksheet to each student group, detailing the experimental procedure (Figure 1). The procedure can be modified to more closely follow the students' suggestions, if appropriate.
2. The experiment can be conducted using apparatus as close to the students' suggestions as is practicable. The main components are a spirit lamp (which is a small container with a wick), water (ca. 200 g) in a conducting container (something like a "coke" can), a thermometer (this can also act as a stirrer), balance and a stop clock. A clamp to hold the container and draught shields to minimise heat loss by the movement of air can be extra considerations.
3. Students can repeat the experiment until they obtain two or three consistent results. Methanol, ethanol, propan-1-ol and butan-1-ol can be used as fuels. In their procedure the students need to determine the parameters detailed in the table in Figure 1.

Activity D: Conclusions

Concept focus	Understanding enthalpy Making informed choices of fuel for particular functions
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (making comparisons) Scientific literacy (analysis and interpretation of scientific data)
Assessment methods	Classroom dialogue Worksheets or student devised materials Presentations Other assessment items (homework, post implementation test)

Rationale

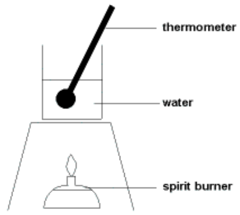
At the end of the lesson, students are expected to be able to provide a report of their experiment, giving details of accuracy, calculations performed and how data is interpreted. They should interpret their results to determine the best fuel and explain their choice. This can be in the form of a written report, an oral presentation during a class discussion or a multimedia presentation.

Suggested learning sequence

1. Once students have finished their experimental activities, they should be encouraged to interpret their results. Depending on the prior knowledge and ability of the class, the teacher can guide the students through the appropriate calculations or use this as a revision exercise.
2. Once the heat of combustion and enthalpy is determined for each fuel, students should discuss their results in small groups or at a whole class level. This should provide an opportunity to identify variation in results, and encourage students to consider experimental errors.
3. Students should then select the fuel that they believe to be the "best" and explain their choice in a scientific manner, using evidence from the inquiry.
4. For further consolidation of newly acquired knowledge, the students can be asked to prepare a report or presentation, carry out some homework tasks, or the teacher can set a post-implementation test.

Enthalpy of combustion experiment

Adapted from Atkinson, J. & Hibbert, C. (2000). AS Chemistry for AQA. Oxford: Heinemann.



Data table

	Fuel A	Fuel B	Fuel C	Fuel D
Initial mass of container (spirit lamp)				
Initial mass of spirit lamp + fuel				
Final mass of spirit lamp + fuel				
Mass of fuel burned (m_f)				
Volume of water in beaker				
Mass of water in beaker (m_w)				
Initial temperature of water				
Final temperature of water				
Temperature rise (ΔT)				
Time for which the fuel was burning				
Heat energy released by the combustion of the fuel				
The enthalpy of combustion of the fuel				
Cost of the fuel used				

Specific heat capacity, c, of water: It takes 4.2 joules of heat energy to increase the temperature of one gram of water by one degree. This value is known as the specific heat capacity of water.

Dependent variable: ____________________________

Independent variable: ____________________________

Controlled variable: ____________________________

Heat energy gained by the water is given by: $q_w = m_w.c.\Delta T$

The heat gained by the water is equal to the heat released by the fuel. Therefore the heat energy released by the combustion of one mole of the fuel under investigation can be calculated using q_w, as long as the mass of fuel used is known.

Figure 1: Student worksheet for guided experiment. Adapted from Atkinson, J. & Hibbert, C. (2000). AS Chemistry for AQA. Oxford: Heinemann.

2.2 Assessment of activities for inquiry teaching & learning

This unit is particularly suitable for assessing *developing hypotheses, planning investigations* and *scientific reasoning* (drawing conclusions; explaining unexpected results; reporting, comparing, and discussing results, and providing suggestions about how to improve investigations). Students are able to work in diverse teams (*working collaboratively*) and can produce ideas based on views from team members. Six key objectives have been identified for development in this unit, as detailed in Table 1. Students should learn that fuels have different heats of combustion and that the meaning of "best" can change depending on the context. They should be able to plan and carry out an experiment to measure heat energy changes, and determine enthalpies of combustion based on their results.

Table 1: Assessment opportunities identified in the unit activities

Objective	Achieved by...	Skill/competency
1. To appreciate that “best” can have more than one interpretation and to suggest the most appropriate meaning in this context	...the students discussing their suggestions given for the “best” fuel. They need to give reasons for their suggestion from a social and scientific point of view.	Scientific literacy (making informed choices of fuel for particular functions)
2. Planning an investigation, interpreting experimental instructions and carrying out an experimental procedure	...the students discussing how to measure the heating ability of a fuel and then carrying out the actual experiment in small groups. They should follow experimental procedures that are an adaptation of those put forward by the students.	Developing hypotheses, planning investigations, working collaboratively, scientific reasoning (identifying variables, collecting scientific data)
3. Undertaking calculations to determine the link between amount of fuel, temperature changes and time taken	...the students calculating the calorific value and heat of combustion from the readings taken during the experiment.	Scientific literacy (explaining phenomena scientifically)
4. Cooperating as a member of a group	...the students working as a group in carrying out the experiment and in the results from the whole class being pooled to obtain a set of results from which the “best” fuel can be determined.	Working collaboratively
5. Communicating orally and by means of a written interpretation	...discussing within a group the meaning of “best fuel” and in developing the working procedures for the experiment. The written interpretation is undertaken by each individual student.	Working collaboratively, forming coherent arguments, scientific literacy (presenting scientific information)
6. Explaining the meaning of fuel and introducing the heat of combustion	...the individual classwork in which students give their ideas in writing, followed by the blackboard summary. Heat of combustion is introduced as the conclusion of the experiment, based on parameters used in the experiment. (An extension could be for students to base the heat of combustion on standard parameters e.g. 1 mole of water heated by 1 °C).	Developing hypotheses, planning investigations, forming coherent arguments, scientific reasoning, scientific literacy (understanding enthalpy in an everyday context)

A suggested assessment scale is provided for evaluation of *planning investigations* and *scientific reasoning*, which features eight success criteria (Table 2). A 3-point scale is suggested – acceptable/needs improvement/poor – although teachers can modify these to more accurately reflect their expectations in their classrooms.

Table 2: Checklist used to evaluate skills in the Which is the best fuel? SAILS unit

Objectives	Acceptable	Needs improvement	Poor/NA
1. Formulate a hypothesis			
2. Design and conduct an experiment			
3. Identify and define variables operationally			
4. Collect meaningful data, organise, analyse data accurately and precisely and draw appropriate conclusions			
5. Explain any unexpected results			
6. Support conclusions, using reasoned arguments and evidence			
7. Collaborate with others to work towards common goals			
8. Report and discuss results, get feedback and deal positively with praise, setbacks and criticism			

3. SYNTHESIS OF CASE STUDIES

The **Which is the best fuel?** SAILS inquiry and assessment unit was trialled in four countries, producing four case studies of its implementation – **CS1 Turkey**, **CS2 Poland**, **CS3 Greece** and **CS4 Denmark**. The unit was implemented at both lower and upper second level. In **CS1 Turkey**, the unit was carried out with 22 pre-service science teachers in their first year of training (around 17-18 years) and in **CS2 Poland** the unit was trialled with students aged 17-18 years. In **CS3 Greece** and **CS4 Denmark** the unit was implemented with lower second level students, aged 14-16 years. In all cases, the students were of mixed ability and gender.

The teachers in the case studies all had prior experience in teaching though inquiry, but most students had no prior experience with inquiry, except in **CS1 Turkey**, where students had experience with inquiry from previous laboratory sessions. The unit was implemented in one to three lessons, over a total duration of 90-135 min. Most case studies implemented it in full, although **CS2 Poland** implemented the introductory activity as a homework task prior to the laboratory session.

The assessment methods used included classroom dialogue in all case studies, but other methods varied depending on implementation. **CS2 Poland**, **CS3 Greece** and **CS4 Denmark** used self-assessment strategies, while **CS1 Turkey** and **CS3 Greece** also used peer-assessment. In all case studies, except **CS4 Denmark**, the teacher evaluated student artefacts as part of the assessment.

3.1 Teaching approach

Inquiry approach used

The inquiry approach used in all the case studies was that of *guided* or *bounded inquiry*, i.e. the initial investigation topic was proposed by the teacher but students had freedom in how they could investigate the topic. In **CS1 Turke**y and **CS3 Greece**, the teachers used a *guided approach*, while in **CS2 Poland** and **CS4 Denmark** students were given more possibility of freedom in the work and a *bounded inquiry* approach was used, with minimal guidance by the teacher.

Implementation

The **Which is the best fuel?** SAILS inquiry and assessment unit was implemented in full in all case studies, although the manner in which it was implemented varied depending on students' level and local curricula. Implementation of the unit took place over 1-3 lessons (total duration 90-135 minutes). Students worked in mixed ability groups (Table 3).

Both **CS1 Turkey** and **CS2 Poland** detail implementation at upper second level, with students aged 17-18 years. In **CS1 Turkey**, the class consisted of pre-service teachers, in their first year of training. The unit was implemented as a *guided inquiry*, and students were provided with a worksheet detailing the "research cycle" to help structure their approach to the investigation. Six different steps were outlined in this research cycle; at each stage different skills were identified for development:

- Writing a research question,
- Formulating a hypothesis,
- Planning the investigation/experiment,
- Conducting the experiment, and evaluating results
- Interpreting the data/generating knowledge,
- Discussing the results, presenting the results/reflection.

CS2 Poland describes implementation through an extracurricular, voluntary class, held at a university laboratory. Before the class, the students were informed about the topic to be discussed and the teacher sent them worksheets, which they were asked to complete individually before coming to the lesson. The aim of the worksheet was to introduce the topic, and thus the implementation began with the planning investigations phase. In the laboratory, a bounded inquiry approach was used. The teacher wanted students to develop their skill in note-taking and observations in the inquiry process, and so did not provide a structured worksheet.

CS3 Greece and **CS4 Denmark** detail implementation with lower second level students, aged 14-16 years. In CS3 Greece, the teacher

Table 3: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Turkey	Activities A-D	One lesson (90 min)	• 4-6 students per group (22 students, 5 male) • Teacher assigned groups; mixed ability; some mixed gender, some all-female; pre-service teachers
CS2 Poland	Activities B-D	Three lessons (45 min each)	• Two groups of 2-3 students (5 students total) • Student selected groups; mixed ability and gender
CS3 Greece	Activities A-D	Two lessons (60 min each)	• Groups of 3-4 students • Teacher assigned groups; mixed ability and gender
CS4 Denmark	Activities A-D	Two lessons (45 min each)	• Groups of 4-5 students (two classes; 21/24 students) • Teacher assigned groups; mixed ability and gender

modified the unit to deliver objectives of the Greek curriculum and used a *guided approach*. The lesson as adapted and implemented by the teacher focused on the following aspects:

- Appreciating the uses of different kinds of fuels in practice,
- The meaning of "best" can change depending on the context, and that different factors can be considered in determining the best fuel,
- Carrying out an experiment using simple measurements (temperature and time) in order to investigate the "best" fuel in the context of cooking.

In this case study, the investigation planned and implemented was not as described in the teaching and learning activities, but it allowed students to develop the same skills and apply their knowledge in an everyday context.

In **CS4 Denmark**, the unit was implemented as suggested in the teaching and learning sequence, but students were given great freedom and the teacher gave minimal guidance. This was implemented as a *bounded inquiry*, in which the students identified the fuels to investigate, the parameters for investigation and they critiqued their experimental design and engaged in troubleshooting when the investigation was not proceeding as they had hoped. The teacher chaired whole-class discussions and asked prompt questions, but otherwise did not become involved in the planning and implementation.

Adaptations of the unit

While the implementation in most case studies followed that of the teaching and learning activities described, there were some modifications made. These were to suit the level of the students, the skills chosen to be assessed or to align with state curricula or teaching strategies.

CS1 Turkey details little change from the suggested lesson sequence, although the teacher provided a guiding worksheet, which detailed the "research cycle" and provided structure for their inquiries. Similarly, **CS4 Denmark** does not deviate significantly from the teaching and learning activities described, although the implementation was very open and the teacher did not provide any guiding materials or worksheets.

In **CS2 Poland**, some small adaptations were made to accommodate implementation during an extracurricular class. The teacher prepared an introductory worksheet, which was provided as preparatory homework. This replaced the introductory activity in the suggested teaching and learning sequence. For the in-lab implementation, the activities started with the *planning investigations* phase, thus allowing enough time to complete planning, implementation and concluding activities.

CS3 Greece describes the greatest changes to the unit. This was an implementation at lower second level, and therefore the teacher did not introduce enthalpy. The Greek schooling system recommends use of *guided inquiry* approaches, and thus the teacher prepared four worksheets and an experimental worksheet. This implementation focused on three aspects – use of different fuels for different functions, understanding that the meaning of "best" depends on context, and an experimental phase involving the everyday context of cooking. The skills developed were those identified in the suggested teaching and learning activities, but the experiment was simplified to observing the "best" fuels for use in boiling water and for cooking, and defining the meaning of "best" in these cases.

3.2 Assessment strategies

Within the four case studies, the inquiry skills of *planning investigations* and *developing hypotheses* were assessed (Table 4), as well as *scientific reasoning* (collection of scientific data) and *scientific literacy* (analysis and interpretation of scientific results), as suggested in the teaching and learning sequence. Formative assessment was used, in particular for the assessment of *developing hypotheses* and *planning investigations*. The assessment methods used include classroom dialogue, evaluation of worksheets or student devised materials, self-assessment and peer-assessment.

Table 4: Inquiry skills identified by teachers in the case studies

CS1 Turkey	• Developing hypotheses • Planning investigations • Working collaboratively • Scientific reasoning (collection of scientific data) • Scientific literacy (analysis and interpretation of scientific data)
CS2 Poland	• Planning investigations • Forming coherent arguments • Scientific reasoning (organisation and interpretation of data)
CS3 Greece	• Forming coherent arguments • Working collaboratively
CS4 Denmark	• Planning investigations • Scientific reasoning (data entry and observation skills)

In **CS1 Turkey**, almost all of the skills were assessed using the checklist assessment tool provided in the assessment of inquiry teaching & learning section of this unit (Table 2) and by analysing students' worksheets. However, skills in *developing hypotheses* and *planning investigations* were assessed in-class, through effective classroom dialogue. The teacher observed that students were having difficulty with these tasks, and that the hypotheses proposed were often not testable. To address this, the teacher asked each group to read their hypotheses and investigation plan to the class. While these were preliminary workings and did not have much detail, the teacher used this method to check which groups would have managed the whole process without the teacher's intervention. For groups that had a plan or hypothesis that could not be investigated, the teacher gave feedback so they could be changed before conducting the investigation.

In **CS2 Poland**, three skills were selected for the assessment – *developing hypotheses*, defining variables, and collection of scientific data (taking notes/collecting raw data). The teacher provided a worksheet as a preparatory task, but this was not used for the assessment of inquiry skills. The teacher designed a 3-level rubric for the assessment of these skills, which was used when evaluating student notes from the lesson period (Table 5).

Table 5: Assessment of skills developed in CS2 Poland

Skill	Fail	Satisfactory	Very good
Developing hypotheses	The student does not formulate a hypothesis appropriate to the research problem raised.	With the teacher's assistance, the student formulates a hypothesis for the research problem raised.	The student independently formulates a correct hypothesis, adequate for further experiments and referring to a correctly raised research problem.
Defining variables	The student does not define variables associated with the planned experiment.	The student defines some variables, and with the teacher's assistance is able to identify other relevant variables.	The student independently defines appropriate dependent and independent variables.
Collection of experimental data	The student prepares incomplete, unreadable notes containing information unusable in terms of finding an answer to a research question raised.	With the teacher's help, the student is able to write down some information – but not enough to present and interpret the results, e.g. obtained data without symbols and units.	The student independently prepares appropriate notes, taking into account relevant units, quantities and symbols, relationships between quantities reflected in formulas, presenting a logical cause and effect sequence that contains all the necessary information, which, in the end, allows for the calculation of the combustion effect of the tested fuels.

In **CS3 Greece**, the teacher observed the students during the activities and gave on-the-fly feedback. The teacher used a modified version of the checklist proposed in the assessment of inquiry teaching & learning section of this unit (Table 2), and developed a separate rubric for the self-assessment of the *working collaboratively* skill (see Table 6). Student groups also exchanged worksheets to engage in peer-assessment, for which the teacher provided a simple rubric to guide their judgements.

Table 6: Self-assessment of working collaboratively in CS3 Greece

Behaviour	3-always	2-sometimes	1-rarely
1. I actively participated in all discussions of the group			
2. In all discussions I took into consideration the views of all team members			
3. I helped in resolving disputes between team members			
4. I used convincing arguments to support my views			
5. I provided assistance in the team whenever needed			
6. I looked for information on the subject in all phases			
7. I completed without delay all the work undertaken to do in the team			

In **CS4 Denmark**, two key opportunities for assessment of inquiry skills were described. First, the teacher provided a questionnaire, with very open questions, which the students were asked to fill in at the end of the lesson, as follows:

- What have you learned about fuels?
- In this lesson, what have you learned about work methods in physics/chemistry course?
- In this lesson, what have you learned about making explanations and argumentation?
- Overall, what did you think of the lesson?

In the second assessment opportunity, the teacher held an oral discussion for one lesson, in which the following questions were discussed with students:

- Why did some find it difficult to work in this way?
- What was the most important thing you learned?
- Do you think that the procedure you used was the same as that used in a real workplace?










The Strategies for Assessment of Inquiry Learning in Science (SAILS) project was funded under the EU Framework Seven programme (2012-2015) to support teachers in adopting inquiry based science education (IBSE) and assessment of inquiry skills and competencies in science at second level across Europe. The project team from across 12 European countries have collaborated with local science teachers to produce this collection of SAILS Inquiry and Assessment Units - which showcase the benefits of adopting inquiry approaches in classroom practice, exemplifies how assessment practices are embedded in inquiry lessons and illustrates the variety of assessment opportunities/processes available to science teachers. In particular, the units provide clear examples for teachers of how inquiry skills (developing hypotheses, working collaboratively, forming coherent arguments and planning investigations) can be assessed, alongside content knowledge, scientific literacy and scientific reasoning and illustrate the benefits of various types of assessments.

These SAILS Inquiry and Assessment Units have been trialled in over 100 second level classrooms, each unit across at least three different countries and the feedback from teachers was collected in the form of case study reports. As demonstrated in the case studies, the SAILS units can be used to focus on the main skills identified but also can be adapted to focus on particular skills that the teacher may wish to develop. The assessment criteria can also be modified to suit the student age and their experience level with inquiry.

This collection of nineteen SAILS Inquiry and Assessment Units has been published in two volumes by the SAILS partners and electronic versions of these units, case study reports and relevant classroom materials are available for download from the project website: **www.sails-project.eu**

SAILS

Strategies for Assessment of Inquiry Learning in Science