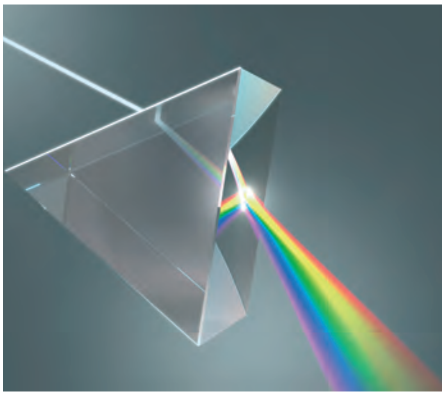
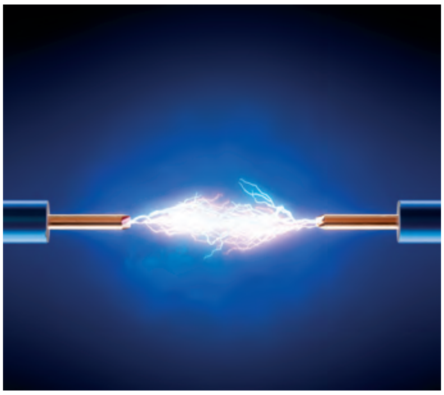
SAILS
Strategies for Assessment of Inquiry Learning in Science





SAILS INQUIRY AND ASSESSMENT UNITS

VOLUME ONE

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Editors

Odilla Finlayson, Eilish McLoughlin,
Emma Coyle, Deirdre McCabe,
James Lovatt, Paul van Kampen

SAILS Inquiry and Assessment Units
Volume 1

ISBN: 978-1-873769-53-9

The SAILS Inquiry and Assessment units have been produced by the SAILS project which has received funding from the European Union’s Seventh Framework Programme for research technological development and demonstration under grant agreement no 289085.

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.

Project partners

Dublin City University, Ireland	Intel Performance Learning Solutions Limited, Ireland	Pavol Jozef Šafárik University in Košice, Slovakia	Jagiellonian University, Poland	Malmö University, Sweden
Kristianstad University, Sweden	University of Southern Denmark, Denmark	The Institute of Education of the Lisbon University, Portugal	King's College London, United Kingdom	University of Szeged, Hungary
ATiT, Belgium	University of Piraeus Research Centre, Greece	Hacettepe University, Turkey	Gottfried Wilhelm Leibniz Universität Hannover, Germany	

WWW.SAILS-PROJECT.EU

CONTRIBUTORS

Belgium (ATiT)

Sally Reynolds (lead national partner)
Peter Andries, Marc Beddegenoodts, Mieke DeCock, Wim Peeters, Werner Tuytens, Mathy Vanbuel, Joasia van Kooten

Denmark (SDU)

Morten Rask Petersen (lead national partner)
Linda Ahrenkiel, Thomas R.S. Albrechtsen, Ulrich Pedersen Dahl, Henrik Falcon, Lotte Mølbak Hansen, Cecilie Ebsen Ourø Jensen, Stine Mariegaard, Claus Michelsen, Lisbeth Højmark van Brakel, Ulrik Lyng Vestergaard, Lisbeth Vive, Birthe Zimmermann

Germany (LUH)

Gunnar Friege (lead national partner)
Maximilian Barth, Thorsten Bell, Matylda Dudzinska, Ingmar Klappauf, Lea Lensment, Christoph Schäfer, Knut Wille

Greece (UPRC)

Symeon Retalis (lead national partner)
Panagiotis Andritsakis, Andreas Georgakakis, Efstathios Mitropoulos , Ourania Petropoulou, Yannis Psaromiligkos, George Stefanidis

Hungary (US)

Benő Csapó (lead national partner)
Ferencné Adorján, Csaba Csíkos, Zita Gál, Ágnes Kissné Gera, Tünde Kontai, Erzsébet Korom, Ervin Lohrman, Lászlóné Nagy, Mária B. Németh, Veronika Németh, Zsuzsa Oláhné Nádasdi, Gábor Orosz, Attila Pásztor, Katalin Radnóti, Ágota Somogyi, Gábor Veres

Ireland (DCU)

Odilla Finlayson (SAILS project coordinator)
Eilish McLoughlin (lead national partner)
Sarah Brady, Enda Carr, Declan Cathcart, Ruth Chadwick, Robert Clarke, Brigid Corrigan, Paul Grimes, Leeane Hinch Sean Kelleher, James Lovatt, Deirdre McCabe, Lorraine McCool, Niall Mahon, Richard Moynihan, Miriam Nugent, Laura Rice, Fiona Sharkey, Paul van Kampen, Kerrie Whelan, Aine Woods

Ireland (Intel)

Joe Greene (lead national partner)
Padraig Coakley, Mark Melia, Martina Roth

Poland (JU)

Paweł Bernard (lead national partner)
Paweł Broś, Robert Czuchnowski, Karol Dudek, Iwona Maciejowska, Kinga Orwat, Lucyna Paul, Dagmara Sokołowska, Mateusz Wojtaszek

Portugal (IEUL)

Cecília Galvão (lead national partner)
Mónica Baptista, Cláudia Faria, Sofia Freire, Cláudia Gonçalves, Pedro Reis, Vanessa de Andrade, Dulce Campos, Paula Castelhano, Teresa Conceição, Luisa Encarnação, Carla Matoso, Ana Vicêncio

Slovakia (UPJS)

Marián Kireš (lead national partner)
Monika Antušová, Mária Brzová, Dorota Černíková, Ľubomíra Cimbálová, Gabriela Franíková, Mária Ganajová, Marianna Ivanová, Zuzana Ješková, Katarína Kimáková, Viera Kováčová, Svetlana Mitrová, Zdena Orvosová, Tibor Révay, Viera Šerešová, Alžbeta Slavkovská, Ivana Slepáková, Ivana Sotáková, Dusan Šveda

Sweden (HKR)

Anders Jönsson (lead national partner)
Carina Agevall, Stefan Einarsson, Lena Ericsson, Kajsa Gavelfält, Nils Jönsson, Kristina Kangasmaa, Ricard Larsson, Cecilia Mattsson, Marina Mattsson, Malin Nilsson, Maria Rosberg, Jenny Sandgren

Sweden (MaH)

Mats Lundström (lead national partner)
Alexandra Andersson, Margareta Ekborg, Anna Falkstedt-Svensson, Jessica Feinberg, Bjorn Forsberg, Åsa Hansson, Myrtel Johansvon, Christian Karlsson, Anna Levin, Sara Lilja, Karin Nilsson, Sofie Nilsson, Johan Öman, Anna Persson, Christian Rydberg, Anne Svensson

Turkey (HU)

Gultekin Cakmakci (lead national partner)
Ali Akinci, Buket Akkoyunlu, Funda Gezer Atak, Cemil Aydoğdu, Ismail Donmez, Betul Sen Gumus, Savas Gungoren, Ayse Gurel, Duygu Mutlu Kaya, Gokhan Kaya, Merve Karden Onsoz, Merve Pekcan San, Metin Sardag, Ipek Ince Sungur, Derya Yahsi, Yalcin Yalaki, Gamze Kavak Yuksel

United Kingdom (KCL)

Christine Harrison (lead national partner)
Katie Barber, Paul Barber, Kwadowo Barney, Paul Black, Sarah Clarke, Ken Dignon, Sally Howard, Amandeep Khan, Anja Luther, Brian Matthews, Stephen Philips, Ed Carew-Robinson, Georgina Turner

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.

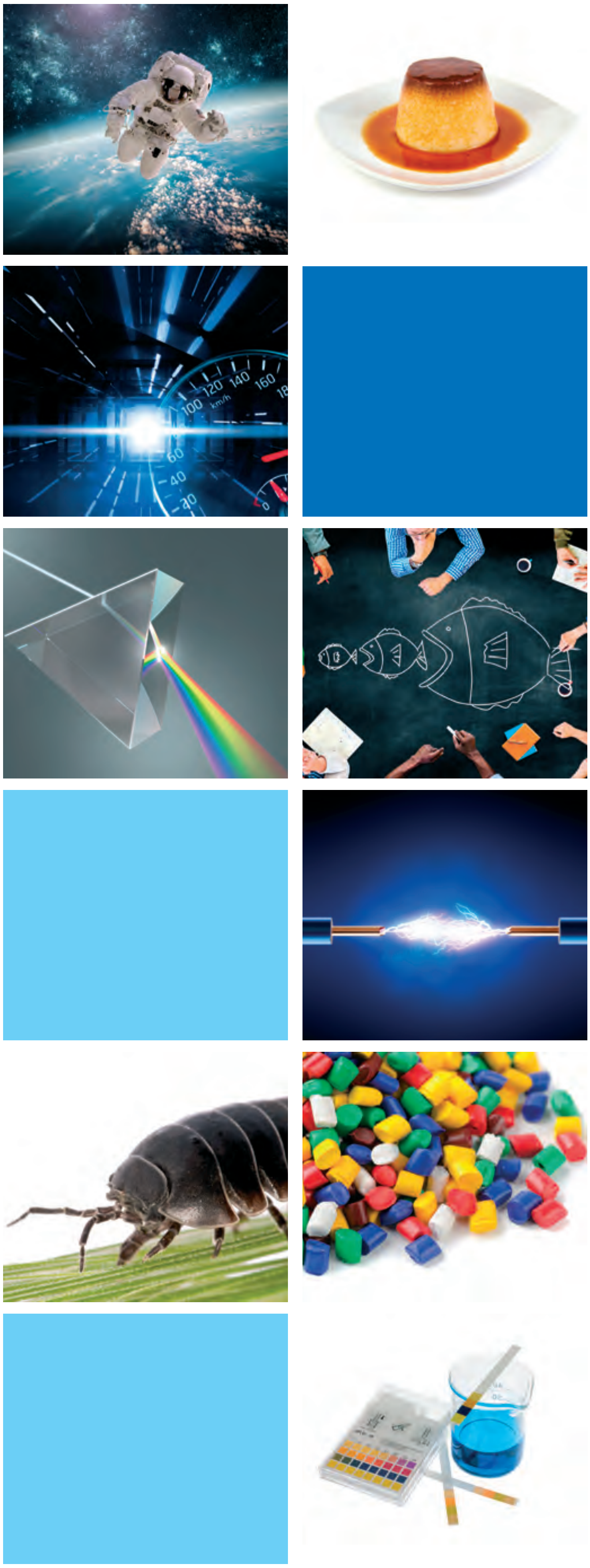
The ***SAILS Inquiry and Assessment Units*** show that a range of assessment methods can be used to assess inquiry skills. As demonstrated in the case studies, the SAILS units can be adapted to focus on other skills that the teacher may wish to develop. The assessment criteria used can also be modified 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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Electric current – lighting up the darkness!

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

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NATURAL SELECTION
Is fitness in the gene or in the animal?

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Are all plastics the same?

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PROOF OF THE PUDDING
Optimising the perfect pudding – an investigation good enough to eat!

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

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How fast can I go? How far can I get? How long will it take me to get there?

Paul Black[a], Gunnar Friege[b], [a]King's College London (KCL), United Kingdom, [b]Gottfried Wilhelm Leibniz Universität Hannover (LUH), Germany

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Christian Rydberg [a], Gultekin Cakmakci[b], [a]Kristianstad University (HKR), Sweden, [b]Hacettepe University (HUT), Turkey

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The consequences of daily decisions

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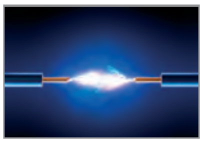

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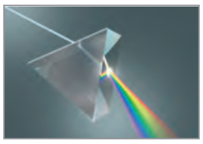

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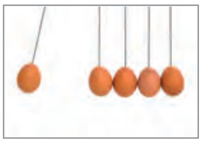

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INQUIRY AND ASSESSMENT UNIT

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ACIDS, BASES, SALTS

ALL ACIDS ARE HARMFUL – OR ARE THEY?

Overview

KEY CONTENT/CONCEPTS

- Acids, bases and salts in everyday life
- Chemical properties – how to detect acids and bases
- Use of indicators

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; observation, classification, making comparisons)
- Scientific literacy (everyday applications of acids and bases; explaining phenomena scientifically)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials (pH scale)
- Other assessment items (post-activity test)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – ACIDS, BASES, SALTS

The **Acids, bases, salts** SAILS inquiry and assessment unit aids students to explore acids, bases and salts as substances that are used in everyday life. The seven activities outlined seek to motivate students to understand basic chemical properties and how to detect acids and bases through experimentation using an indicator. Prior knowledge of terms like chemical elements, compounds, molecular structure, dissolution, is necessary for students to interact effectively with the new material. The unit complies with the curricula of lower second level schools, ages 12-15 years, and the suggested amount of time needed to complete all the activities is about 4 hours.

The students are given the opportunity to develop a number of inquiry skills such as *planning investigations, developing hypotheses, forming coherent arguments* and *working collaboratively*. In addition, they have the opportunity to enrich their *scientific literacy* and *scientific reasoning* capabilities through making justified arguments and presenting evidence to back up conclusions. The assessment opportunities identified include teacher observation, formative assessment during class, assessment of student artefacts, use of rubrics and student self-assessment.

This unit was trialled by teachers in Greece, Turkey and Slovakia, producing six case studies. The teaching approach in all case studies was that of *guided inquiry*. Inquiry skills assessed were *planning investigations, scientific reasoning* and *forming coherent arguments*. Use of a broad range of assessment methods is detailed, including classroom dialogue, peer- and self-assessment and evaluation of student artefacts.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The **Acids, bases, salts** SAILS inquiry and assessment unit was developed by the team at the University of Piraeus Research Centre (UPRC), as part of the SAILS project. The unit includes seven learning activities aimed at lower second level students, aged 12-15 years. The first phase is an introduction to the concepts of acids, bases and salts. Activity A: Introduction serves as an opportunity to review prior knowledge and *develop hypotheses*. The second phase is experimental investigation of proposed hypotheses, in which the students *plan investigations* and implement them. In this phase, students investigate qualitative and quantitative measurement of pH for commonplace acids and bases (activities B-C), before being introduced to salts in Activity D: Identifying salts. The final experimental investigation, Activity E: Acids dissolve salts, bases dissolve fats, enables students to distinguish between acids, bases and salts, based on their solubility properties. The third phase of the unit focuses on drawing conclusions – in Activity F: Conclusions, students consolidate and interpret their results, and relate them to their initial hypothesis. The final phase of this unit, Activity G: Everyday application, looks at application of the acquired knowledge in everyday life, enhancing students' *scientific literacy* through understanding of real world applications of acids, bases and salts.

Activity A: Introduction

Concept focus	Reviewing background to the task Theoretical introduction
Inquiry skill focus	Developing hypotheses
Scientific reasoning and literacy	Scientific reasoning (classification of substances as acids and bases)
Assessment methods	Classroom dialogue Worksheets

Rationale

In this initial activity students are introduced to examples of acids and bases from everyday life, e.g. lemon juice, vinegar, baking soda and toothpaste. Properties of acids and bases are explored initially using the senses (taste, smell, appearance), and then group discussions are used to develop scientific classification of the substances. Students use this knowledge to develop hypotheses, which they can investigate through experimentation.

Suggested lesson sequence

1. The students work in groups (3-4 members per team). The teacher provides each group with six different samples that contain vinegar, lemon juice, orange juice, yoghurt, baking soda dissolved in water and toothpaste dissolved in water.
2. The students taste every sample and record the taste "feeling," the smell, and other general observations for each of the substances in worksheet 1 (Figure 1). Note: these samples are all suitable for human consumption, and this activity should be clearly emphasised as an exception to the rule of never tasting laboratory chemicals.
3. The next step is a discussion with the entire class, facilitated by the teacher, where students narrate possible previous experiences with the aforementioned substances, and also the knowledge of their scientific names is testified.
4. Subsequently, each group writes down a short composition in their worksheets, developing their working hypotheses concerning:
   a. Which substances are similar (to each other),
   b. What are the common characteristics (among them), and
   c. If they are aware of any other substances that have similarities with those provided.

Experimental

Concept focus	Features of acids and bases pH and indicators Understanding salts
Inquiry skill focus	Planning investigations Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (making predictions, classification of substances as acids or bases, drawing conclusions) Scientific literacy (Evaluate and design scientific inquiry)
Assessment methods	Classroom dialogue Worksheets Student devised materials

Rationale

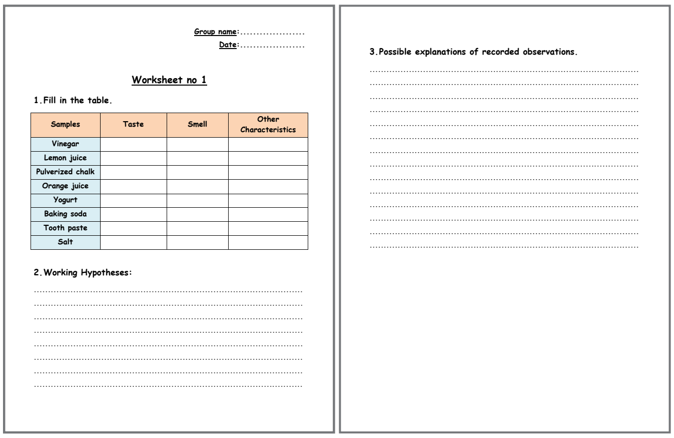
Students carry out scientific experiments in groups to test the hypotheses developed in Activity A: Introduction. They can carry out qualitative evaluation of pH using a red cabbage indicator (Activity B: Qualitative classification of substances using a pH indicator extracted from red cabbage) and quantitative determination of pH (Activity C: Measurement of the numerical value of the pH). From this information, they construct a pH scale with both numerical and colour representations for each sample. Students are then introduced to salts (Activity D: Identifying salts), and they explore the means of distinguishing these three species (Activity E: Acids dissolve salts, bases dissolve fats).

Activity B: Qualitative classification of substances using a pH indicator extracted from red cabbage

In this activity, students use a red cabbage indicator to carry out qualitative measurement of pH of a range of everyday acids and bases. The activity can begin with preparation of the indicator, before planning an investigation to use the indicator to investigate the hypotheses proposed in Activity A: Introduction. Students can use their results to classify the samples based on colour change.

Suggested lesson sequence

1. In this experiment groups use the substances that were used as samples in Activity A: Introduction, as well as six extra samples, which are provided to each group separately by the teacher. The extra samples are detergent dissolved in water, bleach dissolved in water, water with ammonia, saliva, milk and pure water. These extra substances are necessary as they cover the entire pH range.
2. Before experimentation students must prepare a red cabbage indicator. The teacher should have already cut up the red cabbage, to which students add pure alcohol. A few minutes later the colour of the alcohol will be changed to purple because of the red cabbage.
3. The coloured alcohol is then collected in a container and constitutes a natural indicator, which students will use in their experiments. For a time-effective solution, preparation of the indicator can either be done at intervals by the students, or in advance by the teacher.
4. Afterwards, each group pours a small amount of the natural indicator (1 cm^3) in as many transparent cups as the substances tested. Then students slowly add the respective sample until the colour of the indicator does not change any more.
5. During the experiment, groups use a worksheet (Figure 2) to note down the final colour of the indicator and repeat the experiment for the rest of the samples.
6. Thus they perform a first classification of the substances based on the colour change of the indicator.



Group name:……………….
Date:……………….

Worksheet no 1

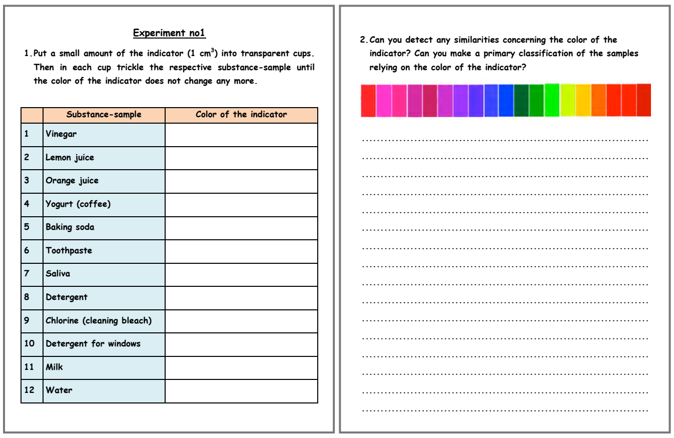
1. Fill in the table.

Samples	Taste	Smell	Other Characteristics
Vinegar			
Lemon juice			
Pulverized chalk			
Orange juice			
Yogurt			
Baking soda			
Tooth paste			
Salt			

2. Working Hypotheses:

3. Possible explanations of recorded observations.

Figure 1: Worksheet for Activity A: Introduction



Experiment no1

1. Put a small amount of the indicator (1 cm^3) into transparent cups. Then in each cup trickle the respective substance-sample until the color of the indicator does not change any more.

	Substance-sample	Color of the indicator
1	Vinegar	
2	Lemon juice	
3	Orange juice	
4	Yogurt (coffee)	
5	Baking soda	
6	Toothpaste	
7	Saliva	
8	Detergent	
9	Chlorine (cleaning bleach)	
10	Detergent for windows	
11	Milk	
12	Water	

2. Can you detect any similarities concerning the color of the indicator? Can you make a primary classification of the samples relying on the color of the indicator?

Figure 2: Worksheet for Activity B: Qualitative classification of substances using a pH indicator extracted from red cabbage

Activity C: Measurement of the numerical value of the pH

In this activity, students measure the numerical value of the pH for each of their samples. For this purpose they can use a pH meter, universal indicator or other suitable methods. They can compare the numerical results to the classification by colour carried out in Activity B and construct a pH scale of their results.

Suggested lesson sequence

1. In this activity, students measure the numerical value of the pH for each sample substance. For this purpose they can use a pH meter to determine the pH value, which they record in the worksheet (Figure 3, page 1).
2. After measurement, a class discussion (with the help of the teacher) ensues, during which students write in their worksheets (Figure 3, page 2) their conclusions concerning the names of the substances, their general chemical types, the alterations that they cause to the indicator and what this entails for their classification in the pH scale.
3. Each group uses the recordings from the first and second experiments (activities B-C) to construct their own pH scale, calibrated both in numbers and colour. For this purpose, the teacher gives groups an A3 cardboard in which they draw a serial number line representing the pH scale. Each group autonomously decides their calibration procedure. In addition, each group is provided with colourful printed sheets (A4 length) from which the students select and cut out the appropriate colours to match with the numeric values of pH that have been defined in the previous experiment.
4. The students should match every substance to the correct point in the numerical pH scale, accompanied by the right colour for this sample.
5. To check the accuracy of the construction each group will exchange their work with two others. If they detect any deviation they should do the measurements again.
6. Students should be provided with an evaluation sheet that captures the process and the criteria for assessing pH scales (Figure 4). The teacher should provide the assessment criteria to the class at the beginning of the lesson.

Experiment no 2

1. Use the pH meter to measure the numerical value of pH for each one of the substances.

	Substance-sample	pH value
1	Vinegar	
2	Lemon juice	
3	Orange juice	
4	Yogurt (coffee)	
5	Baking soda	
6	Toothpaste	
7	Saliva	
8	Detergent	
9	Chlorine (cleaning bleach)	
10	Detergent for windows	
11	Milk	
12	Water	

2. Can you detect any similarities concerning the pH value for these substances? Can you make a primary classification of the samples relying on the pH value of each one?

....

....

....

Figure 3: Worksheet for Activity C: Measurement of the numerical value of the pH

Group name: ....

Peer group name: ....

Assessment of the pH scale

The following table will help you assess the quality of the pH Scale constructed by the peer group.

	Excellent (4)	Good (3)	Needs improvements (2)	Unacceptable (1)	Score
The color of the indicator for each sample is precise					
Numerical values of pH are precise					
Each color is matched with the right numerical value of the pH					
Numerical calibration of the pH scale is precise					
Numerical values as well color values have been placed in the right spots across the scale					
No sample is missing from the scale					
				Total:	

Comments:...

....

The following table will help you assess the appearance of the pH scale made by the peer group.

Criteria	Excellent (4)	Good (3)	Needs improvements (2)	Unacceptable (1)	Score
Readability	No difficulty with reading at all.	There were 2-3 spots that I found difficult to read.	There were 4-5 spots that I found difficult to read.	It was hard for me to read the text. There were over 6 spots that I found difficult to read.	
Size of icons and fonts	Icons and fonts are clear.	Icons and fonts could be clearer. (2-3 bad spots)	Icons and fonts should be clearer. (4-5 bad spots).	Icons and fonts are so small that I hardly recognize them. (6 < bad spots)	
Rips on the pH scale	No rips.	1-2 rips	3-4 rips	5-6 rips	
Smudges and spots on the pH scale	0-1 smudges	2-3 smudges	4-5 smudges	6-7 smudges	
				Total:	

Comments:...

....

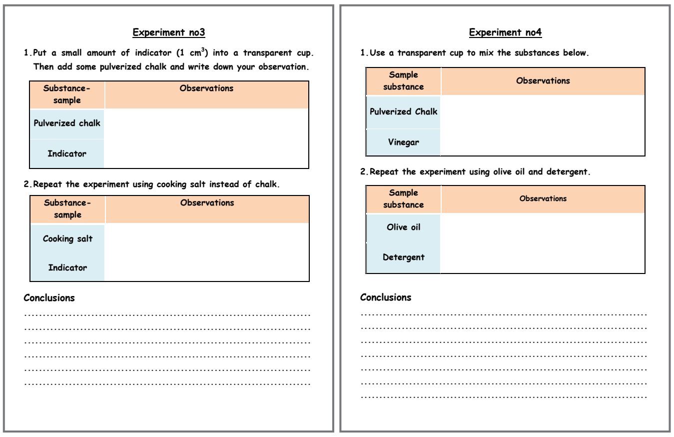
Figure 4: Rubrics for peer-assessment of pH scale constructed in Activity C

Activity D: Identifying salts

During this experiment students will be able to ascertain the existence of salts by using the red cabbage indicator. They investigate chalk and cooking salt using red cabbage indicator, and observe that these substances do not behave like acids or bases. Building on this observation, students come to understand that there is an additional category of substances – salts.

Suggested lesson sequence

1. The students slowly add smashed chalk to a portion of red cabbage indicator and write down their observations on the worksheet provided (Figure 5). They should notice that the indicator colour does not change.
2. Students repeat the experiment with cooking salt and note their observations.
3. Through steps 1 and 2, students should note that unlike with acids and bases, these substances do not change the colour of the indicator. Students are then required to come up with a possible explanation for the phenomenon.
4. The activity ends with a class discussion with the teacher, where all groups present their reasoning.
5. Through the discussion the teacher has the chance to explain that these substances belong to a third category known as salts, that do not change the colour of indicators.



Experiment no3

1. Put a small amount of indicator (1 cm^3) into a transparent cup. Then add some pulverized chalk and write down your observation.

Substance-sample	Observations
Pulverized chalk	
Indicator	

2. Repeat the experiment using cooking salt instead of chalk.

Substance-sample	Observations
Cooking salt	
Indicator	

Conclusions

....

Experiment no4

1. Use a transparent cup to mix the substances below.

Sample substance	Observations
Pulverized Chalk	
Vinegar	

2. Repeat the experiment using olive oil and detergent.

Sample substance	Observations
Olive oil	
Detergent	

Conclusions

....

Figure 5: Worksheets for Activity D: Identifying salts and Activity E: Acids dissolve salts, bases dissolve fats

Activity E: Acids dissolve salts, bases dissolve fats

In this experiment students will find out how salts can be identified through their basic property of dissolution in the presence of acids. Conversely, they observe experimentally the property of bases to dissolve fats.

Suggested lesson sequence

1. Students add vinegar to a glass of pulverised chalk, and write down their observations in their worksheet (Figure 5)
2. They then add a sample of water and detergent to a glass of oil and record their observations
3. This is followed by a discussion through which they come to the conclusion that a property of acids is the dissolution of salts and that a property of bases is the dissolution of fat.

Activity F: Conclusions

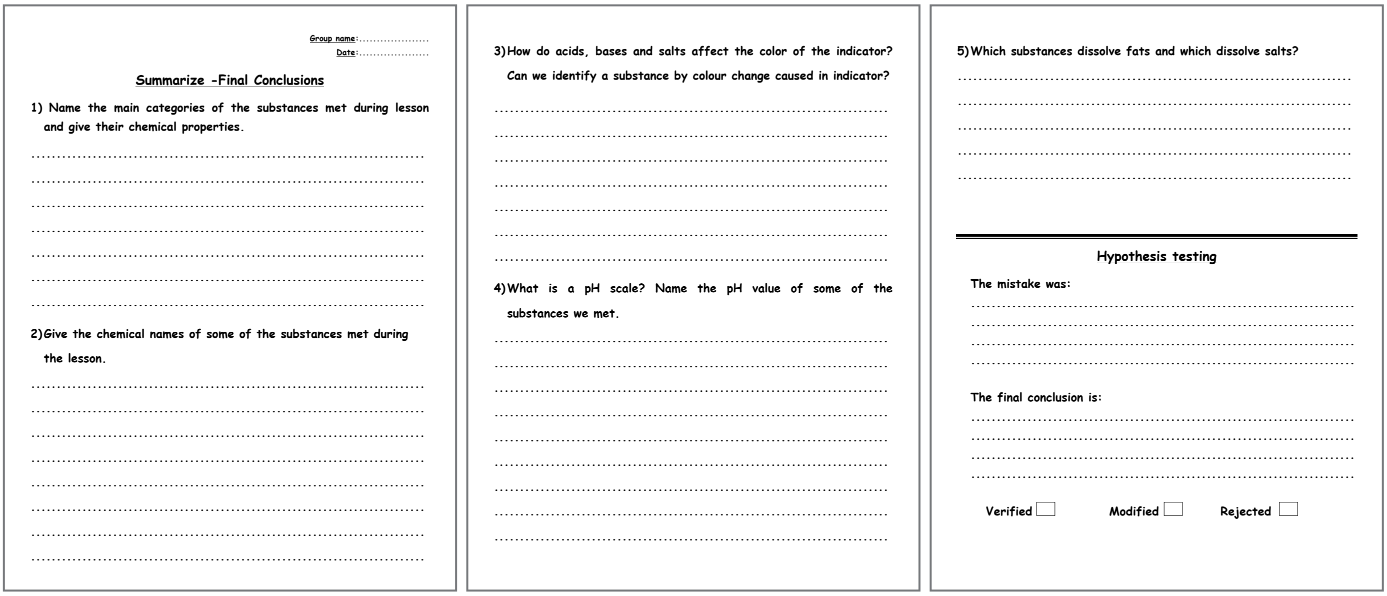
Concept focus	Reviewing results of experiments Drawing conclusions
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (drawing conclusions based on evidence) Scientific literacy (interpret data and evidence scientifically)
Assessment methods	Classroom dialogue Worksheets

Rationale

During this phase, groups summarise through discussion their observations from the previous activities. They draw conclusions based on the evidence they have collected, and relate this to their original hypotheses.

Suggested lesson sequence

1. Based on their observations, students reach their final conclusions, which they record separately in a worksheet (Figure 6). These concern:
   a. Classification of substances in three major groups: acids, bases and salts
   b. Matching substances to the constructed pH scale
   c. The property of acids to dissolve salts and bases to dissolve fats.
2. Then groups go back to their initial hypotheses formed during Activity A: Introduction, which they correct with the help of the respective worksheet (Figure 6, page 3).
3. The teacher works supportively with each group, answering inquiries or resolving disagreements that can arise.


Group name:..................
Date:..................

Summarize -Final Conclusions

1) Name the main categories of the substances met during lesson and give their chemical properties.

2)Give the chemical names of some of the substances met during the lesson.

3)How do acids, bases and salts affect the color of the indicator? Can we identify a substance by colour change caused in indicator?

4)What is a pH scale? Name the pH value of some of the substances we met.

5)Which substances dissolve fats and which dissolve salts?

Hypothesis testing

The mistake was:

The final conclusion is:

Verified ☐ Modified ☐ Rejected ☐

Figure 6: Worksheet for Activity F: Conclusions and tool for hypotheses testing

Activity G: Everyday application

Concept focus	Drawing conclusions Knowledge transfer
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (forming conclusions based on evidence) Scientific literacy (understanding how things relate to real world context)
Assessment methods	Classroom dialogue Worksheets Other assessment items (test)

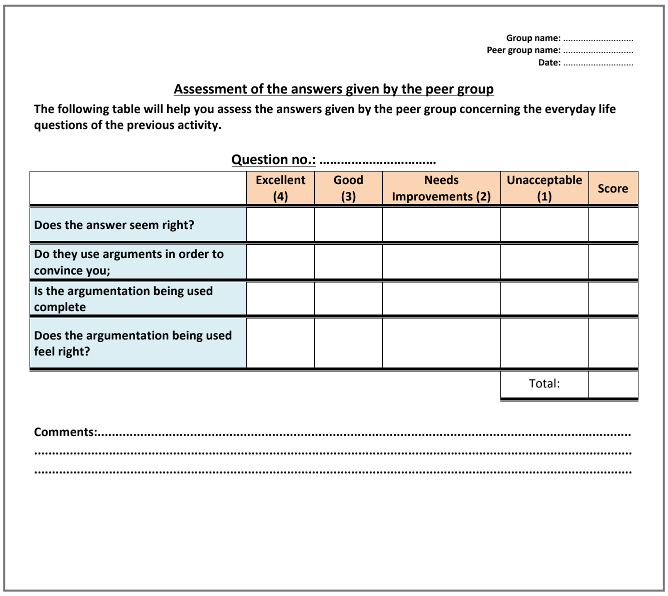
Rationale

In this phase gained knowledge is connected with everyday life. Each group will have to answer some questions, which involve acids and bases related to everyday life. The activity ends with an individual test.

Suggested lesson sequence

1. The groups are asked some questions about everyday examples of acids and bases (as an oral inquiry or on a worksheet):
   a. How may I identify whether a substance is an acid or a base?
   b. It is my turn to clean the bathroom and the kitchen. What detergent is appropriate for each?
   c. How do you make vinegar from wine? How is yoghurt made?
   d. Why does black tea change colour when lemon is added?

   These questions also revise earlier knowledge gained by the students in science courses. In order to answer, groups are free to use their worksheets as well as textbooks.
2. Peer groups use a holistic rubric to evaluate the answers to the above questions. The rubric assesses the accuracy and completeness of students' answers (Figure 7). It provides students with a guide to help them grade the worksheets based on the weight factor of each criterion that is explained in advance to the groups.
3. The discussion headed by the teacher is the last part in order to facilitate the final correction of the answers. Each group now puts a final score on the worksheet and the peer-assessment finishes.
4. With the completion of the scenario every student sits an individual test (Figure 8). The test contains matching questions, fill in the blank questions and short answer questions that assess students' personal performance.
5. Additionally, the teacher assesses the folders that contain the worksheets and peer-assessment forms for each group and she/he also grades the work. The criteria upon which evaluation of the worksheets is done are:
   a. Accuracy of the measurements,
   b. Overall appearance and completeness of worksheets,
   c. The findings,
   d. Student argumentation/justification.
6. The final score can be calculated by combining the marks obtained in each of the activities.



Group name: ....
Peer group name: ....
Date: ....

Assessment of the answers given by the peer group

The following table will help you assess the answers given by the peer group concerning the everyday life questions of the previous activity.

Question no.: ....

	Excellent (4)	Good (3)	Needs Improvements (2)	Unacceptable (1)	Score
Does the answer seem right?					
Do they use arguments in order to convince you;					
Is the argumentation being used complete					
Does the argumentation being used feel right?					
				Total:	

Comments:..

Figure 7: Rubric for peer-assessment of worksheet for Activity G: Everyday application

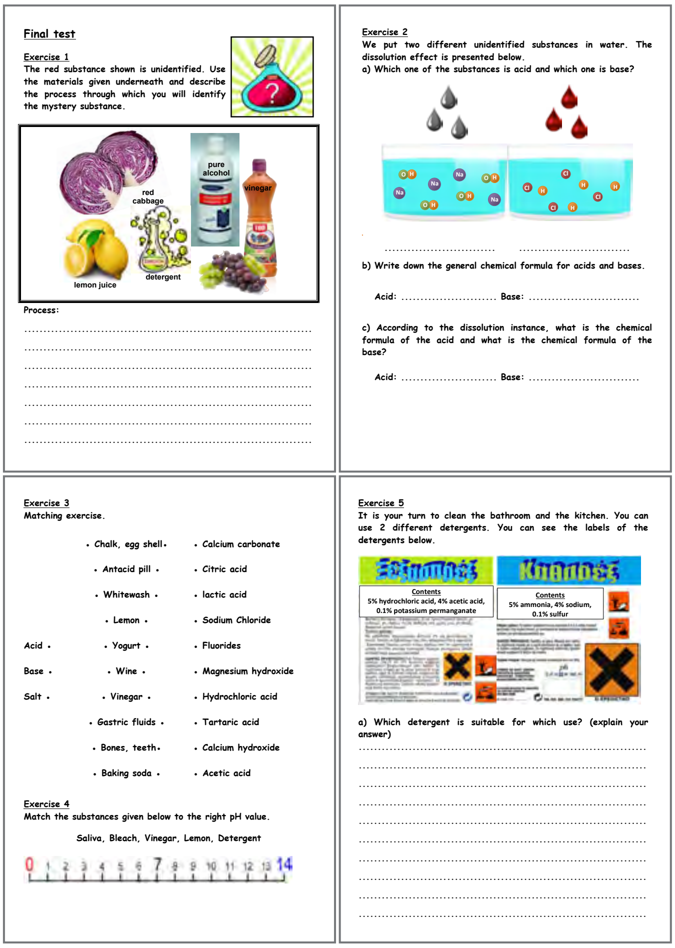


Figure 8: Final test from Activity G: Everyday application

2.2 Assessment of activities for inquiry teaching & learning

There are many worksheets provided in each phase to collect evidence of both content knowledge and development of inquiry skills. Provided within the unit are a set of dedicated assessment tools. For example, rubrics that may be used for assessing *developing hypotheses* and *forming coherent arguments* are included. Evaluation of the pH scale can be assessed through peer-assessment (using a rubric), while *scientific literacy* and content knowledge is assessed through examining the answers given to questions about acids and bases in everyday life (peer-assessment using a rubric). The assessment of *working collaboratively* is achieved through peer- and self-assessment.

Developing hypotheses

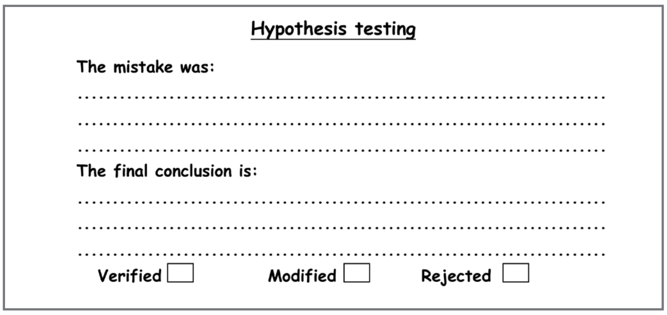
This skill can be assessed using a rubric when reviewing student artefacts from Activity A: Introduction, as shown in Table 1, or through self-assessment by the student (Figure 9).

Table 1: Teacher rubric for the assessment of developing hypotheses

Inquiry skill	Developing hypotheses
Level 1	Student was not able to formulate a hypothesis, not even with the teacher's help
Level 2	Student was able to formulate a hypothesis with the teacher's help
Level 3	Student was able to formulate a hypothesis without additional help

Assessment of the constructed pH scale

A rubric for assessing the pH scale constructed by the peer group is shown in Table 2; this is an expanded version of the peer-assessment shown in Figure 4. To evaluate the appearance of the pH scale, students can utilise the rubric shown in Figure 4.



Hypothesis testing

The mistake was:
....
....
....

The final conclusion is:
....
....
....

Verified ☐ Modified ☐ Rejected ☐

Figure 9: Self-assessment of developing hypotheses

Table 2: Rubric used to evaluate constructed pH scale

	Excellent (4)	Good (3)	Needs improvement (2)	Unacceptable (1)
The colour of the indicator for each sample is precise	All measurements are correct/No mistakes at all	Some mistakes/Most measurements are correct	Several mistakes/ Some measurements are correct/It can be improved	A lot of mistakes/It needs a lot of work to be improved
Numerical values of pH are precise	All numerical values are precise/No mistakes at all	Some mistakes/Most numerical values are precise	Several mistakes/ Some numerical values are precise/It can be improved	A lot of mistakes/It needs a lot of work to be improved
Each colour is matched with the right numerical value of the pH	All colours are matched with the right numerical value/No mistakes at all	Some mistakes/ Most colours are matched with the right numerical value	Several mistakes/ Some colours are matched with the right numerical value/It can be improved	A lot of mistakes/It needs a lot of work to be improved
Numerical calibration of the pH scale is precise	All numerical values are precise/No mistakes at all	Some mistakes/Most numerical values are precise	Several mistakes/ Some numerical values are precise/It can be improved	A lot of mistakes/It needs a lot of work to be improved
Numerical values as well colour values have been placed in the right spots across the scale	All numerical values and colour values have been placed in the right spots/No mistakes at all	Some mistakes/Most numerical values and colour values have been placed in the right spots	Several mistakes/Some numerical values and colour values have been placed in the right spots/It can be improved	A lot of mistakes/It needs a lot of work to be improved
No sample is missing from the scale	No sample is missing from the scale/No mistakes at all	Some mistakes/Most samples are present in the scale	Several mistakes/Some samples are present in the scale/It can be improved	A lot of mistakes/It needs a lot of work to be improved

Forming coherent arguments

The assessment of this skill can be carried out by using a rubric when reviewing student artefacts, in particular their answers to the questions concerning the everyday context of acids and bases in Activity 7: Everyday application. This can be assessed by the teacher (Table 3) or through peer-assessment (Figure 7).

Table 3: Teacher rubric for the assessment of forming coherent arguments

	Excellent (4)	Good (3)	Needs Improvements (2)	Unacceptable (1)
Does the answer seem right?	All points seem right/ No mistakes at all	Some mistakes/Most points seem right	Several mistakes/Some points seem right/It can be improved	The answer is unacceptable
Do they use arguments in order to convince you?	All arguments convinced me/No mistakes at all	Some mistakes/Most arguments convinced me	Several mistakes/Some arguments convinced me/It can be improved	The arguments are unacceptable
Is the argumentation being used complete?	The argumentation is complete/No mistakes at all	Some mistakes/ Most arguments are complete	Several mistakes/ Some arguments are complete/It can be improved	The argumentation is unacceptable

Scientific literacy

There are many opportunities to develop and assess students' *scientific literacy*. In Table 4 and Table 5, examples of self-assessment cards are provided. This skill can also be assessed using an end of lesson test, as detailed in Activity G: Everyday application.

Table 4: Self-assessment card for the assessment of scientific literacy

Self-assessment card	Very well	With deficiencies	I can't do it
1. I understand the classification of substances based on the solution of red cabbage extract...			
2. I was able to get information from the internet or encyclopaedia...			
3. I was able to suggest a procedure for preparing the indicator from red cabbage...			
4. I managed to get indicator from red cabbage...			
5. I was able to sort substances as acids or bases based on the values of pH...			
6. I was able to explain the term indicator...			
7. I was able to explain why water and kitchen salt solutions were not acidic or alkaline solutions...			

Table 5: Example of a self-assessment card after learning the topic "Acids"

Topic: Acids	With significant help from the teacher	With the teacher's help	Independently
1. I can name... ...three acids used at home, and ...three acids used in a laboratory			
2. I can explain... ...what indicators are			
3. I can describe... ...what to do after an acid spill			
4. I know the principle of... ...how to dilute acids with water			
5. I can write down... ...the chemical formulas of three acids			
6. I can determine... ...if an unknown solution is acidic or not			

Scientific reasoning

Again, students' ability to reason can be assessed by evaluation of student artefacts (using a rubric, Table 6).

Table 6: Teacher rubric for the assessment of formulation of conclusions

Inquiry skill	Level 1	Level 2	Level 3
Formulation of conclusions (scientific reasoning)	Student was not able to formulate a conclusion, not even with the teacher's help	Student was able to formulate conclusion with the teacher's help	Student was able to formulate a conclusion without additional help

Working collaboratively (group work and working independently)

These activities offer many opportunities for students to work collaboratively, which can be assessed through teacher observation, peer-assessment and self-assessment. Assessment tables for group work (Table 7) and individual work (Table 8) may be used.

Table 7: Assessment table for working collaboratively (teamwork)

Use the following scale and mark the option which describes you most:	1 Almost never	2 Rarely	3 Sometimes	4 Always
1. I like to work in a group.				
2. I am more comfortable working in a group than working alone.				
3. I like working in a group, because I would not manage the work on my own.				
4. I can listen to ideas of other members of the group.				
5. I can persuade the group about my idea.				
6. I learn more during group work.				

Table 8: Assessment table for working independently

Use the following scale and mark the option which describes you most:	1 Almost never	2 Rarely	3 Sometimes	4 Always
1. I like to work individually				
2. I learn more during individual work				
3. I like my own pace during individual work				
4. I prefer individual work, because the group does not accept my opinions.				

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in three countries producing six case studies of its implementation (**CS1 Greece**; **CS2 Turkey**; **CS3-CS6 Slovakia**). All the case studies were implemented by teachers who had some experience in teaching through inquiry. However, the students involved had not been taught through inquiry before except for the case studies **CS4 Slovakia** (one lesson experience from **CS3 Slovakia**), and **CS6 Slovakia** (one lesson experience from **CS5 Slovakia**).

The ages of the students involved in the case studies were 12-15 years: 12 years in **CS1 Greece**, 14-15 years old in **CS2 Turkey** and 13-14 years in **CS3-CS6 Slovakia**. The students in each class were of mixed ability and mixed gender. **CS1 Greece** was implemented in 4.5 hours, while **CS2 Turkey**, **CS3 Slovakia** and **CS4 Slovakia** were implemented in one hour each. Finally, **CS5** and **CS6** (both **Slovakia**) were implemented in a total of five lessons.

Opportunities for the assessment of the key SAILS skills and competencies were identified throughout the activities, and the assessment methods include classroom dialogue, peer- and self-assessment and evaluation of student artefacts (worksheets, pH charts). **CS1 Greece** includes a post-implementation test.

3.1 Teaching approach

Inquiry approach used

The inquiry approach used in all the case studies was that of *guided inquiry*, where the teacher identifies the problem and poses multiple questions that lead the students to answer inquiry questions. In this mode of inquiry, students are able to exploit pre-existing knowledge in order to formulate initial hypotheses, which will then help them structure their research (*planning investigations*).

Implementation

The students in all 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 detailed in Table 9.

The starting point for the case studies **CS1 Greece** and **CS2 Turkey** was Activity A: Introduction. **CS1 Greece** implemented all activities, while **CS2 Turkey** was focused on activities A-E (introduction and experimental). **CS3 Slovakia** was based on activities B-C (experimental, qualitative and quantitative measurement of pH), and the same class later participated in **CS4 Slovakia**, where the starting activity was Activity D: Identifying salts. Finally, **CS5** and **CS6** (both **Slovakia**) include activities that the teacher proposed as adaptations of Activities B-D. The teacher applied these activities into the teaching of topics “Exploring acidity of solutions” and “Exploring alkalinity of solutions” within the unit “Chemical compounds” with students of 8th grade at primary school.

Inquiry skills addressed

The assessment of activities for inquiry teaching and learning section outlines some assessment tools that may be used in the assessment of *developing hypotheses, planning investigations, forming coherent arguments* and *working collaboratively*, as well as evaluating students’ *scientific literacy*. However, the teachers in each case study identified various inquiry skills for the assessment, as shown in Table 10.

Table 9: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Greece	Activities A-G	4.5 teaching hours (270 min)	• Groups of 4-5 students (23 students) • Teacher assigned
CS2 Turkey	Activities A-E	One lesson (60 min)	• Groups of 3-4 students (18 students) • Self-selected
CS3 Slovakia	Activities B-C	One lesson (60 min)	• Groups of 3-4 students (18 students) • Teacher assigned
CS4 Slovakia	Activities D-E	One lesson (60 min)	• Groups of 3-4 students (18 students) • Teacher assigned
CS5 Slovakia	Activities B-C, with adaptations	Three lessons (60 min each)	• Groups of 3-4 students (25 students) • Self-selected
CS6 Slovakia	Activity D, with adaptations	Two lessons (60 min each)	• Groups of 3-4 students (25 students) • Self-selected

Table 10: Inquiry skills identified by teachers in the case studies

CS1 Greece	• Planning investigations (carrying out investigations, data analysis) • Developing hypotheses • Working collaboratively (debating with peers, teamwork)
CS2 Turkey	• Planning investigations (taking measurements) • Scientific reasoning (observation, classification, making comparisons) • Scientific literacy (building relationships with daily life)
CS3 Slovakia	• Developing hypotheses • Scientific literacy (explaining phenomena scientifically, designing scientific inquiry)
CS4 Slovakia	• Working collaboratively (communication skills) • Scientific reasoning (addressing problem through logic and use of evidence, forming conclusions)
CS5 Slovakia	• Developing hypotheses • Planning investigations • Scientific literacy (explaining phenomena scientifically, designing scientific inquiry)
CS6 Slovakia	• Developing hypotheses • Scientific reasoning (drawing conclusions) • Scientific literacy (explaining phenomena scientifically)

Adaptations of the unit

In **CS1 Greece** the teacher implemented all of the suggested activities as described in the unit. The teaching approach was that of *guided inquiry*. Lower second level curricula in Greece and Cyprus make use of this model in science courses, as it is considered as the optimal teaching approach. In the introductory phase, the teacher presented the concept for research and chaired a discussion with students in order to identify theories about characteristics and similarities between materials tested. Then students developed hypotheses and predictions, which constituted the guidelines for their research. In the experimental phase, the students set up the experiment with the support/guidance of the teacher. During experimentation, students took measurements and recorded their findings. During the third phase, the students engaged in discussion to summarise their observations and records from the previous phase. Based on these observations they reached their final conclusions, which they compared with the initial hypotheses they had developed. The final phase sought to consolidate the newly acquired knowledge. The teacher asked questions and assigned exercises and tasks aimed at the consolidation of the acquired knowledge. Through this, students learned the means to apply newly acquired knowledge in everyday life.

In **CS2 Turkey** the teacher started the lesson by asking students what they eat at breakfast, lunch and dinner to motivate them. Then the teacher asked follow-up questions related to students' answers. For instance, when the students said "sweet, sour or bitter," the teacher responded "why do you feel this sensation?" and "what causes this taste?" After the new question some of the students said that these foods consist of different substances. So each student's answer shaped the next question asked by the teacher during this warm-up activity. Then, the teacher followed the suggested learning sequence. The students used worksheets to record their observation. All groups went through the same stages, they were assessed and feedback was given to the students. When the teacher made judgements on the students' skills, the teacher used the students' artefacts and their observation notes. The students enjoyed the activity, and all students were active and energetic during the activity process. The teacher's encouragement and feedback motivated students. For instance, when some groups did not observe a colour change when the vinegar was analysed, the teacher and students talked about why there was no change. After that, the teacher encouraged the students to do the activity again.

During Activity A: Introduction, the teacher in **CS3 Slovakia** gave additional tasks to the students:

- Find out (on the internet, in an encyclopaedia or textbook) the meaning of the term "indicator"
- Suggest the procedure for how to prepare an indicator from cabbage. What equipment will you need?

This was a warm-up task, as the students did not have prior experience with inquiry-based activities and they needed to know the meaning of the term indicator. Also, the teacher allowed the students to prepare the indicator at home. During the second activity, students worked with homemade indicator (cabbage extract) for qualitative measurement of pH. They searched for the numerical values of pH for their solutions on the internet. To motivate and stimulate students the teacher posed the following open questions:

- Are all substances that taste sour acidic solutions?
- What does the term "indicator" mean?
- How can we prepare an indicator from red cabbage?

In **CS4 Slovakia** the teacher implemented Activity D: Identifying salts with the same class that had participated in **CS3 Slovakia**. As students were already familiar with the function of indicators from the previous inquiry-based lesson, during this activity they observed that the indicator does not change its colour in solutions of powdered chalk and of kitchen salt. They were supposed to explain this phenomenon. The teacher modified the activity in order to fit with the state curriculum for the subject of chemistry. The students mixed acidic and alkaline solutions and observed the phenomena accompanying this experiment. To motivate and stimulate students the teacher used the following open questions:

- Why are the water solutions of chalk and salt neither acidic nor alkaline?
- What is the pH value of chalk and salt solution?
- How many groups of substances do we know according to pH scale?

In **CS5 Slovakia** the inquiry activity was based on the question: “How can chemists recognise an acid?” The students observed colour changes of indicators and they measured the pH of solutions of acids that are used at home and in the laboratory. They also consolidated their theoretical knowledge about the acids they explored and they learned the practical importance of usage of indicators. During the group work, students were asked to divide the subtasks, arrange the tools on the table, pour the examined samples into tubes, add indicators and record the observation process and formulate results of the inquiry. The starting point of inquiry was to understand the procedure in the students' worksheet, its realisation and recording of the observed changes into a suitable table. The organisation of the inquiry was also very important – students had to arrange the samples of solutions of acids and be careful not to confuse samples and indicators. During the teaching the teacher used the questions:

- What do you already know about acids?
- Where can we find acids in everyday life?
- Are these substances important for our lives?
- What does indicator mean?
- What are the safety rules for working with acids?
- What should you do in the event of an acid spill?

In **CS6 Slovakia** the inquiry activity was based on the questions: “How do chemists distinguish acids from bases?” and it was based on Activity E: Identifying salts, as well as on the previous inquiry activity (**CS5 Slovakia**). The unit worksheet was modified, so that the explored samples were solutions of acids and bases, which are used in the laboratory. The questions on creation of hypotheses and conclusions were focused on the colour changes of the samples of acids and bases after adding the indicator. Students participated in this activity after a lesson that dealt with theoretical knowledge about hydroxides. With the inquiry method they not only revised their knowledge about acids, but they also consolidated and expanded their knowledge about hydroxides. During their own inquiry they practically investigated how chemists distinguish acids from hydroxides.

The teacher used the following prompt questions to guide the inquiry:

- What do you already know about acids and about hydroxides?
- Where can we find acids and hydroxides in our everyday lives?
- Are these substances important for our life?
- What is an indicator used for?
- What are the safety rules for working with acids and hydroxides?
- What is the first aid after an acid spill or hydroxide spill?

Students worked in groups to realise their inquiry-based activities. They determined colour changes of solutions using red cabbage indicator and measured pH of acid and base solutions. Students already had experience with inquiry-based methods from a previous lesson, during which they explored acids. In this lesson, bases were investigated using inquiry methods.

3.2 Assessment strategies

Within the six case studies, the inquiry skills of *developing hypotheses, forming coherent arguments, planning investigations,* and *working collaboratively* were assessed in different ways. Additionally the content knowledge and evidence of *scientific literacy* and *scientific reasoning* was assessed. 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.

Developing hypotheses

Evidence of the students' skill in *developing hypotheses* was captured in all case studies except **CS2 Turkey** and **CS4 Slovakia**. The students formulated their hypotheses about what would happen during the realisation of an experiment and recorded this in their worksheets. In most cases the teacher developed his/her own rubric to assess the skill except in **CS1 Greece** where the teacher first asked the groups to self-assess their hypothesis during the conclusion phase and then later checked and corrected their assessments, as suggested in the unit.

In **CS3 Slovakia**, the teacher evaluated student worksheets after the lesson, and used a scoring scale of correct/with mistakes/incorrect/disinterested, to assess the students' skill in *developing hypotheses*. The teacher felt that students had difficulties with this skill, and intends to focus on developing hypotheses in future inquiry-based lessons. Similarly, in **CS5 Slovakia**, the teacher evaluated student responses to the task “read the following work procedure and try to write down what will happen when you add indicator into the acid” using a scoring scale of correct/partly correct/wrong.

The teacher in **CS6 Slovakia** used a three-level rubric, shown in Table 12, to evaluate students' response to the task “Read the following procedure of work and try to formulate a hypothesis about what will happen during the realisation of the experiment. Will the indicator colour for solutions of hydroxides be the same as solutions of acids?”

Table 11: Teacher rubric for the assessment of developing hypotheses in CS6 Slovakia

Inquiry skill	1 point	2 points	3 points
Developing hypotheses	Student was not able to formulate a hypothesis, not even with the teacher's help	Student was able to formulate a hypothesis with the teacher's help	Student was able to formulate a hypothesis individually

Working collaboratively

In **CS1 Greece** and **CS4 Slovakia** there are examples of *working collaboratively* being assessed by the teacher as well as being self-assessed by the student. In **CS1 Greece**, each group member had distinct roles such as secretary (the person who wrote the observations/measurements), assistant secretary, and scientists (the persons who carried out the experiments). These roles did not remain constant, but changed cyclically so that all team members participated in all roles. The teacher observed the groups during the activities and characterised their collaboration as satisfactory. In **CS4 Slovakia**, verification of *working collaboratively* was done using self-assessment tables, which were filled in by students after the inquiry-based activities. Both teamwork and working independently were assessed, using the tools detailed in the unit.

Forming coherent arguments

All case studies included activities where students tried to form coherent arguments. However, this skill was only explicitly addressed in **CS1 Greece**, where the teacher evaluated this skill using peer-assessment (Figure 7) and a rubric (Table 3), which was developed by the teacher and shared with the students.

In **CS3** and **CS5** (both **Slovakia**) the teacher created self-assessment cards for students, which students completed after the lessons (Tables 4 and 5). These were used for evaluation of understanding of the scientific phenomena under investigation, and offer an opportunity for students to demonstrate their skill in *forming coherent arguments* (forming conclusions based on scientific evidence).

Carrying out an investigation (pH scale construction)

There were several points where the teacher could assess the skill of *planning investigations* (carrying out an investigation). The unit proposed a specific assessment point, which was construction of a pH scale following the activities to measure pH (Activity B: qualitative measurement and Activity C: quantitative measurement). There were also two different assessment strategies. In **CS1 Greece** the students constructed the pH scale and the teacher verified the underlying skill using peer-assessment (Figure 4) and a rubric (Table 2), which the teacher had shared with the students. In **CS2 Turkey** the teacher observed the construction of the pH scale and assessed it in a formative way. Finally, in **CS3 Slovakia** the construction of the pH scale were also assessed in a formative way using the scoring scale (correct/with mistakes/incorrect/disinterested).

Content knowledge, scientific reasoning and scientific literacy

All case studies included activities to assess content knowledge, *scientific reasoning* and *scientific literacy*. In **CS2 Turkey** the skills of observation, classification, making comparisons and building relationships with daily life were assessed by the teacher. The teacher assessed the students according to the following criteria:

- Whether or not the groups of the students answered correctly questions asked by the teacher
- Whether or not measurements were correctly obtained from pH scale
- Whether or not the students correctly categorised samples as acids, bases or salts.
- Whether or not the students made the inference that acids change pH paper to red and matter that bases change pH paper to blue.
- Whether or not the student gave some examples that are related to daily life.

The criteria were not shared with the students before the lesson. The teacher observed the groups to decide whether the groups had demonstrated those criteria or not. While the teacher was guiding the students, the teacher was observing their notes. If the teacher noticed any problem on the notes, the teacher gave feedback. Two examples of such feedback were "How did you categorise that?" and "Why did you choose that method?"

In **CS1 Greece**, Activity G: Everyday applications was completed in full. First, each group answered questions related to acids and bases found in everyday life. To do this, they were free to consult their worksheets and textbooks. Peer-assessment was used to assess the accuracy and completeness of students' answers. The teacher then chaired a whole-class discussion to facilitate the final correction of the answers. Finally, the teacher set a test, which contained matching questions, fill in the blank questions and short answer questions, in order to assess students' individual performance.

In **CS3**, **CS4** and **CS5** (all Slovakia), *scientific literacy* (explaining phenomena scientifically) was assessed at the end of the inquiry-based activity, by students' completion of self-assessment cards (Table 12). In **CS3 Slovakia**, students were asked to rate their ability to carry out a number of tasks on a scale of very well/with some deficiencies/I can't do this, as shown in Table 13. In **CS5 Slovakia**, students were asked to self-reflect on several of the topics learned during the lesson (Table 13).

Table 12: Self-assessment card for the assessment of scientific literacy

Self-assessment card
1. I understand the classification of substances based on the solution of red cabbage extract...
2. I was able to get information from the internet and encyclopaedia...
3. I was able to suggest procedure how to prepare the indicator from red cabbage...
4. I managed to get indicator from red cabbage...
5. I was able to sort out substances into acid and alkaline based on the values of pH...
6. I was able to explain the term indicator...
7. I was able to explain why water and kitchen salt solutions were not acidic or alkaline solutions...

In **CS4 Slovakia** the evaluation of understanding of the observed phenomena was achieved by assessing students' ability to explain the following:

- The indicator did not change its colour in solutions of powdered chalk and kitchen salt
- Mixing of an alkaline and acidic solution creates a neutral solution

Understanding based on metacognition

A further interesting self-assessment was carried out in **CS5 Slovakia**, in which identification of success in achieving learning outcomes was assessed by metacognition. After the lesson, students filled in a questionnaire where they responded to the following questions:

- What did I have trouble with during the lesson?
- What did I learn in the lesson?
- What else would I like to learn?
- What do I remember well?
- Where can I use what I did at the lesson?

This was an opportunity for students to reflect on the learning process, and to identify gaps in their newly acquired knowledge.

Table 13: Example of a self-assessment card after learning the topic "Acids"

Topic: Acids	I can't do this	With some deficiencies	Very well
1. I can name... ... three acids used at home, and ...three acids used in a laboratory			
2. I can explain... ...what indicators are			
3. I can describe... ...the first aid after an acid-spill			
4. I know the principle of... ...how to dilute acids with water			
5. I can write down... ...the chemical formulas of three acids			
6. I can determine... ...if an unknown solution is acid or not			

INQUIRY AND ASSESSMENT UNIT

ELECTRICITY

Electric current – lighting up the darkness!

Dagmara Sokolowska

ELECTRICITY

ELECTRIC CURRENT – LIGHTING UP THE DARKNESS!

Overview

KEY CONTENT/CONCEPTS

- Introduction to conductivity and electric circuits
- Simple electric circuit
- Conductivity of different materials

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 (identifying connections between concepts; choosing components for and electrical circuit)
- Scientific literacy (searching for information; using scientific terminology; explaining concepts scientifically)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials (mind maps, documentation of inquiry, drawings of electric circuits)
- Other assessment items (post-activity test)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – ELECTRICITY

The **Electricity** SAILS inquiry and assessment unit provides an introduction to electrical conductivity and electric circuits and is recommended to be implemented after students have studied electrostatics. This topic is usually included in the lower second level science curricula across Europe. Three activities are presented and use a guided inquiry-based approach. The classroom implementation of this unit is typically over two lessons (~ 90 minutes).

Activity A introduces the students to the topic through a whole class brainstorming activity, and students construct a mind map of the topic based on their prior knowledge. In Activity B, the students design and assemble a simple working electric circuit. Students then use their circuits for planning and carrying out an investigation on the conductivity of every-day objects and materials (Activity C). As a further challenge, students can propose an experiment to show lightning in the classroom without the use of any device plugged into the mains. This unit presents opportunities for assessment of several inquiry skills, in particular *planning investigations* and *working collaboratively*, as well as improving students' *scientific reasoning* capabilities and *scientific literacy*.

The assessment methods described in the unit include teacher observation, group brainstorming and use of student artefacts.

This unit was trialled in Slovakia, Ireland, Turkey and Poland (five case studies, 17 classes, 333 students). *Planning investigations* and *scientific reasoning* were the main skills assessed; although in Ireland *working collaboratively* (debating with peers) was assessed. One teacher in Turkey added an activity on *developing hypotheses* to the unit, and provided oral feedback to the students on this skill.

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 **Electricity** SAILS inquiry and assessment unit were developed by the FP7 Fibonacci project [1] and adapted for use in the SAILS project by the team in Jagiellonian University. The unit comprises three activities, which are recommended for use with lower second level students, aged 12-15 years. The topic is first introduced through a whole class brainstorming activity and individual/small group construction of a mind map based on their prior knowledge (Activity A). In the second activity, the students design and assemble a simple working electric circuit (Activity B). They then use this circuit for planning and executing an investigation on the conductivity of every-day objects and materials (Activity C). Students are facilitated to improve their skills in *developing hypotheses* through peer discussion on the conductivity properties of these materials. Everyday contexts are included and students are facilitated to develop skills in *scientific literacy* and searching for information, e.g. how lightning is formed during a thunderstorm and what is the conductivity of air?

Teachers should be aware that the materials listed below will be needed during the implementation of this unit, but should not be given to the students until after their planning has been completed.

- Torch bulb (one per group)
- Two separate wires (per group), not connected to the bulb, but prepared for an easy adjustment (plastic coating removed at both ends of each wire)
- Two crocodile clips (optional)
- Plasticine or insulating tape
- 4.5 V battery (one per group)
- Everyday objects made out of different materials (at least 2 objects of each): wood, different kinds of metal, plastic, rubber, textile, glass, paper (at least 16 objects per group); one piece of graphite

Students will require access to the internet or other resource materials (books, films, etc.) about meteorology, electricity, formation of lightning, etc.

Activity A: Introduction to electricity

Concept focus	Connecting the concept of electricity to everyday life
Inquiry skill focus	Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (making scientific connections) Scientific literacy (explain concepts scientifically)
Assessment methods	Classroom dialogue Worksheets Student devised materials

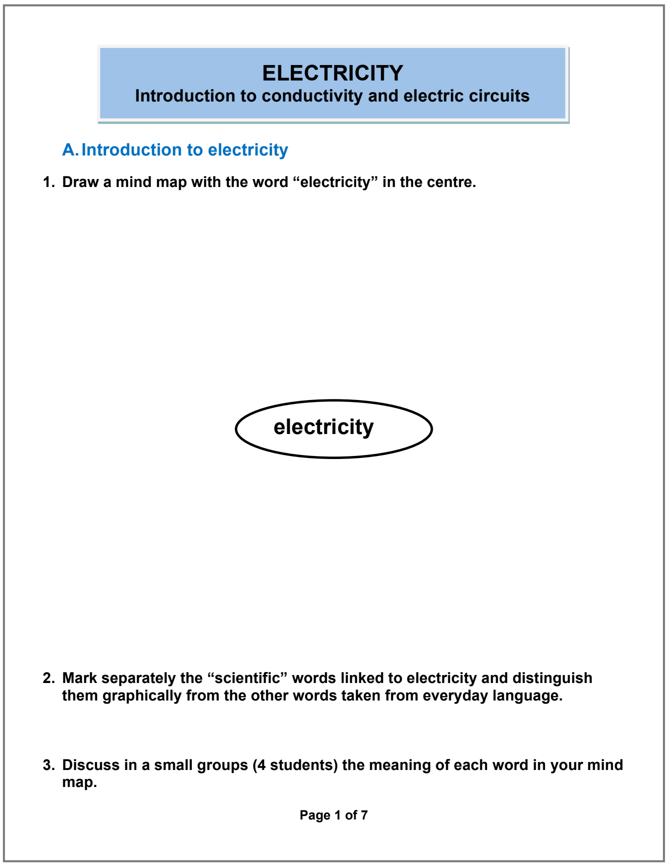
Rationale

In this activity, students are asked to draw a mind map starting with the word electricity in the centre of a page. This approach should encourage students to recall their prior knowledge of the topic. Students should then discuss the words used, identify scientific terms and distinguish them from everyday words. Through this task, students strengthen their *scientific literacy* and make scientific connections.

Suggested lesson sequence

1. At the start of the lesson, the teacher can encourage the students to brainstorm, by asking questions that relate to the use of electricity in their everyday life, for example:
   a. What do we need to be able to see?
   b. Are there any other ways that help us to see, e.g. moving around when one is not able to see? Do you know any respective adaptations of animals?
   c. We live in a world of day and night. When and where in the world does a human being lack sunlight?
   d. How did people in the past adapt to living in darkness?
   e. How do people do that today?
   f. What caused this change and when did this occur?
2. Once the students have identified electricity as an answer to the latter questions, they are provided with a worksheet (Figure 1).
3. Students individually construct a mind map on the first page of their worksheet.
4. The teacher can ask some prompt questions during this task, e.g.
   a. What is the possible origin of the word "electricity"?
   b. What are the other small elements of matter?
   c. What does "electric current" mean?
   d. What do you think happens when an electric current flows?
   e. What is a general term for materials that conduct an electric current?
   f. What is the general name used to denote materials that do not conduct an electric current?
5. After completing their mind maps, students distinguish between the scientific terms and everyday words.
6. Students form groups (up to 4 student per group) and debate the words on their mind maps.

[1] Fibonacci Electricity unit, http://www2.if.uj.edu.pl/fibonacci/class3.html [accessed October 2015]


ELECTRICITY
Introduction to conductivity and electric circuits

A. Introduction to electricity

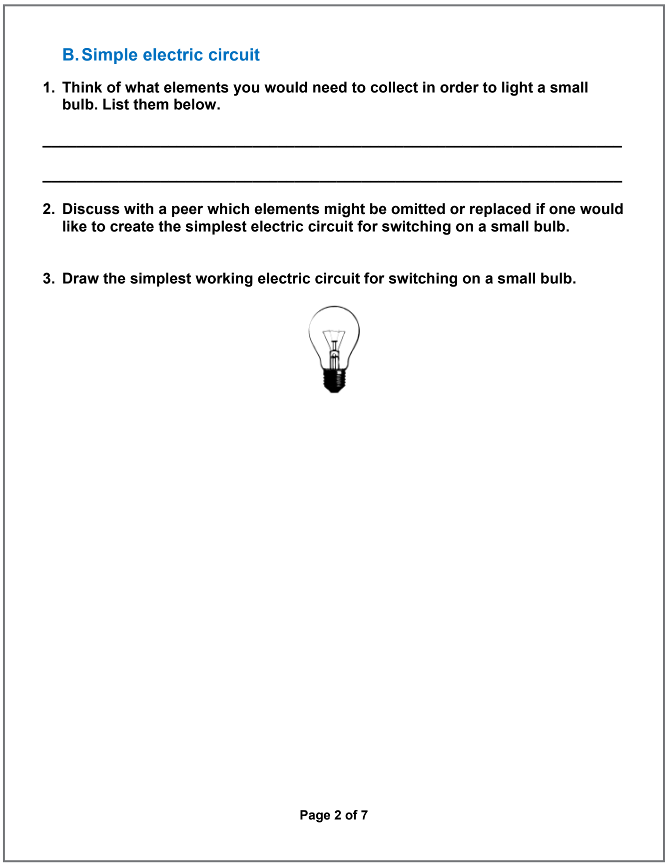
1. Draw a mind map with the word "electricity" in the centre.

electricity

2. Mark separately the "scientific" words linked to electricity and distinguish them graphically from the other words taken from everyday language.

3. Discuss in a small groups (4 students) the meaning of each word in your mind map.

Page 1 of 7


B. Simple electric circuit

1. Think of what elements you would need to collect in order to light a small bulb. List them below.

2. Discuss with a peer which elements might be omitted or replaced if one would like to create the simplest electric circuit for switching on a small bulb.

3. Draw the simplest working electric circuit for switching on a small bulb.

Page 2 of 7

Figure 1: Student worksheet, pages 1 and 2 – activities A and B

Activity B: Simple electric circuits

Concept focus	Building a simple electric circuit
Inquiry skill focus	Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (choosing components for electric circuit) Scientific literacy (critiquing a method; explaining electric current scientifically)
Assessment methods	Classroom dialogue Worksheets

Rationale

In this activity, students are asked to identify the components needed to construct a simple electric circuit. They engage in peer discussion and distinguish between items that are necessary and those that are not needed, before drawing a sketch of their proposed electric circuit. This activity allows the students to develop their skills in *planning investigations*, critiquing experimental design, and *working collaboratively*. Opportunities exist for strengthening *scientific literacy* and *scientific reasoning* capabilities.

Suggested lesson sequence

1. In this activity, students think of the elements (components) needed to form a simple electric circuit.
2. The students work in pairs or small groups and discuss the chosen components. Through this discussion, they decide which components are necessary for their simple circuit.
3. Students draw the simple electric circuit in their worksheet (Figure 1, page 2).

C. Conductivity of different objects.

1. Plan the experiment to check conductivity of different objects, using the electric circuit with a single electric bulb. Include the list of possible objects you could investigate in the classroom. Write down the plan below.

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2. Draw the simplest working electric circuit enabling investigation of conducting properties of an object.

Page 3 of 7

3. Put forward the hypothesis of conducting properties of selected objects. In the table below, in column "hypothesis" next to each selected object, write down your hypothesis on how well the particular object conducts an electric current, using expressions: "well", "poorly", "not at all". Whenever you investigate a solution (e.g. salt in water), in the first column include the relevant information about the amount of substance used (concentration).

Conductivity table.

object/ material	hypothesis	experimental result			general type
		well	poorly	not at all	

4. Perform the experiment finding out conducting properties of the selected objects. You can add more objects in the course of experiment. Always put forward the hypothesis first and write it down in the table before conducting the experiment. After each part of experiment check the right box in section "experimental results" in the table above. Leave the column "general type" empty.

Page 4 of 7

5. In science, technology and engineering, people use schematics rather than pictorial drawings. E.g. an electric circuit can be represented by an electrical diagram (electronic schematic). To do so, one needs to know abstract, graphic symbols denoting particular objects. In an electrical diagram the following symbols are usually utilized:

a bulb/lamp | a battery | a piece of wire | an object connected to the circuit

Using the symbols listed above, draw in the boxes below two simple electrical diagrams representing the electric circuits used by you in section B.3 and C.2 of the worksheet.

6. Write down your opinion, answering the question:
Is conductivity an inherent property of an object, or a property of a material the object is made of? Explain your answer.

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Page 5 of 7

7. After a brainstorming with your peers about the common names of conducting and non-conducting materials, complete the two sentences below.
   a. Solid materials, like …………………………, conducting an electric current are called …………………………
   b. Materials not conducting an electric current, like …………………………, are called …………………………
8. Fill out the last column of the conductivity table on page 4, ("general type"), indicating the common names of a relevant material/object in relation to its conducting/non-conducting properties.
9. Discuss with your peer if the air can or cannot conduct an electric current. Write down 1-2 sentences summing up your discussion.

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10. Check with an appropriate experiment if the air in the classroom conducts an electric current. Describe experimental setup and your observation.

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Page 6 of 7

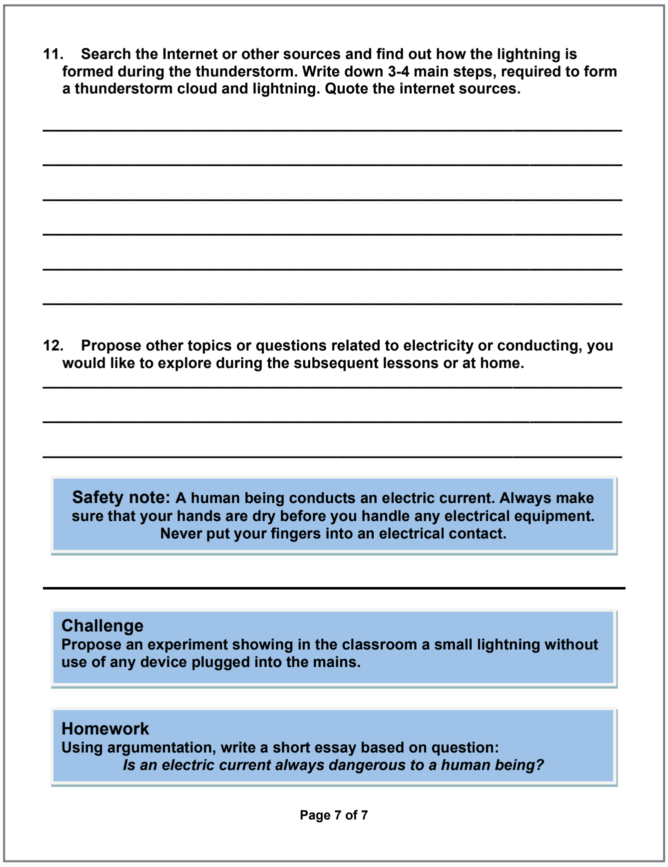
Figure 2: Student worksheet, pages 3-6, for Activity C: Conductivity of different objects

Activity C: Conductivity of different materials

Concept focus	Conductivity – conductors, insulators
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (making predictions) Scientific literacy (searching for information; explaining conductivity scientifically)
Assessment methods	Worksheets

Rationale

In this activity, students are asked to plan an investigation to check the conductivity of different materials, using an electrical circuit with a single bulb. They first develop a hypothesis about various materials, plan an investigation to investigate their research question, observe and record the results and draw conclusions. During this activity, students develop their *scientific literacy* through introduction to the symbols used for representation of an electric circuit, enrich their *scientific reasoning* and skills of *developing hypotheses*, drawing conclusions and *planning investigations*.



11. Search the Internet or other sources and find out how the lightning is formed during the thunderstorm. Write down 3-4 main steps, required to form a thunderstorm cloud and lightning. Quote the internet sources.

12. Propose other topics or questions related to electricity or conducting, you would like to explore during the subsequent lessons or at home.

Safety note: A human being conducts an electric current. Always make sure that your hands are dry before you handle any electrical equipment. Never put your fingers into an electrical contact.

Challenge
Propose an experiment showing in the classroom a small lightning without use of any device plugged into the mains.

Homework
Using argumentation, write a short essay based on question:
Is an electric current always dangerous to a human being?

Page 7 of 7

Figure 3: Student worksheet, page 7 – end of Activity C, challenge and homework

Suggested lesson sequence

1. In this activity, students complete the third section of the student worksheet (Activity C: Conductivity of different materials, Figure 2). They suggest materials with which they would investigate conductivity, and propose a circuit that can be used to test the materials.
2. The students develop their hypotheses for each of the materials, and record these hypotheses in the table provided in the worksheet.
3. Students carry out the investigation using the simple circuit and their chosen materials, and record the outcomes in their table.
4. Students are introduced to the electrical symbols used in drawing circuit diagrams. They investigate these through reproducing the diagrams that they had already drawn and using these scientific symbols.
5. The teacher facilitates a class/group brainstorming session, in which students discuss conductivity. Questions to support the session include:
   a. Is conductivity an inherent property of an object, or a property of a material the object is made of?
   b. What is a general name for materials that conduct electricity?
   c. What is a general name for materials that do not conduct electricity?
6. The brainstorming session should move to discussion of everyday experiences of electricity, in particular “Can air conduct an electric current?”
7. Students are encouraged to search for scientific information; using the internet or other sources to find out how lightning is formed. They should summarise their findings in their worksheet, and provide details of their sources (Figure 3, worksheet page 7).
8. At the end of the session, self-assessment and peer-assessment evaluations can be conducted.
9. A further challenge is provided to encourage further inquiry, “Propose an experiment to show lightning in the classroom without the use of any device plugged into the mains”, and a homework question, “Is the electric current always dangerous to a human being?” These can be used for the assessment of individual *scientific literacy* and *scientific reasoning* capabilities.

2.2 Assessment of activities for inquiry teaching & learning

There are opportunities identified throughout this unit for the development and assessment of inquiry skills. Evidence of skill development can be collected in the form of student artefacts (worksheets or student devised materials, such as mind maps), through teacher observation or peer- and self-assessment. While some assessment tools are described within this unit, there is also flexibility for the teacher to devise and implement their own assessment instruments. Suggested skills to be assessed during implementation of this unit include *developing hypotheses, planning investigations* and development of *scientific literacy*, in particular, explaining electrical current and electrical conductivity using scientific terminology.

Assessment of Activity A: Introduction to electricity

In this activity, the brainstorming task offers opportunities for the assessment of *scientific literacy, working collaboratively* and *scientific reasoning*:

- *Scientific literacy* (prior knowledge from everyday life and other sources)
- *Working collaboratively* (student engagement in brainstorming)
- *Scientific reasoning* ("creativity" during brainstorming, i.e. clearing explaining their choice of terms and words)

Prior to the activities the teacher chooses a group of students to assess during each brainstorming session throughout these lessons. It is suggested that this should not exceed six students. During each brainstorm the teacher checks an appropriate box in the table below to record the frequency and type of selected students' contributions (Table 1). It is also possible to indicate cases where disrespect is shown to the peers' opinions expressed during the brainstorming, e.g. by marking (R).

Table 1: Assessment of individual student's contributions during a brainstorming activity

Student name	Context – history, everyday life			Scientific words, meaning			Scientific symbols, circuits	
	Prior knowledge	Engagement	Creativity	Engagement	Prior knowledge	Creativity	Engagement	Prior knowledge
Name 1								
Name 2								
Name 3								

In addition, depending on the teacher's and students' experience in using a mind map as a teaching/learning tool, a rubric can be used to assess students' skills in drawing a mind map (Table 2). The teacher can use this 4-level rubric for the assessment all of the students' mind maps after the lesson is completed.

Table 2: Rubric for the assessment of the skill of drawing a mind map

Assessed skill	Emerging	Developing	Consolidating	Extending
Drawing a mind map	The student's mind map is empty or full of words unrelated to the concept of electricity	The student draws a mind map containing only a few words and/ or the words are listed with no relation to each other	The student draws a mind map with more than 10 words, both scientific and belonging to everyday language, but the visualisation of relationships and categories is poor	The student draws a mind map with more than 10 words, both scientific and belonging to a common language, with a good visualisation of the relationships and categories

Assessment of Activity B: Simple electric circuits

In this activity, teachers can assess *planning investigations*, *scientific literacy*, *working collaboratively* and *scientific reasoning* based on the students' responses on their worksheets. A suggested 4-level rubric for the assessment of *scientific literacy* (drawing an electrical circuit) is shown in Table 3.

Table 3: Rubric for the assessment of students' ability to draw an electric circuit

Assessed skill	Emerging	Developing	Consolidating	Extending
Drawing an electric circuit	The student… … chooses a set of adequate objects: a bulb, two wires and a battery but does not draw any pictures	The student… … chooses a set of four adequate elements and draws a schematic drawing that is not completely correct	The student… … chooses a set of four adequate elements and draws a completely correct schematic drawing of a simple circuit, but does not draw a circuit with additional materials	The student… … chooses a set of four adequate elements and draws two schematic drawings completely correctly

Assessment of Activity C: Conductivity of different materials

In this activity, inquiry skills *planning investigations*, *forming coherent arguments* and *working collaboratively* may be assessed, as well as *scientific literacy* and *scientific reasoning*. The student drawings on their worksheets can be evaluated for this assessment. The suggested rubric for the assessment of drawing an electrical circuit, shown in Table 3 and used in Activity B, can be used to assess students' *scientific literacy*.

In order to assess the inquiry skill *planning investigations*, a 4-level rubric can be utilised (Table 4). The rubric can be used to evaluate the work of a number of students, selected prior to the lesson, for this particular assessment. For each assessment intervention, the teacher can choose the same or different group of students.

Table 4: Rubric for the assessment of planning investigations

Assessed skill	Emerging	Developing	Consolidating	Extending
Planning investigation of conducting properties of different materials	The student… … lists a limited number of objects made of 1-2 different kinds of materials but does not write the plan at all or the investigation plan is incomplete	The student… … lists a limited number of objects made of 1-4 different kinds of materials and the investigation plan is almost correct	The student… … lists a limited number of objects made of over 4 different kinds of materials and the investigation plan is almost correct	The student… … lists a limited number of objects made of over 4 different kinds of materials and the investigation plan is complete

In order to assess the skill of searching for information, the following 4-level rubric can be used (Table 5). The rubric should be used to evaluate the work of a number of students, selected prior to the lesson for this particular assessment.

Table 5: Rubric for the assessment of searching for information

Assessed skill	Emerging	Developing	Consolidating	Extending
Searching for information	The student… … finds information from 1-2 sources, but does not pay attention to the independence of the sources; summary is incorrect or incomplete and does not quote the source	The student… … finds consistent information from 1-2 sources, but does not pay attention to the independence of the sources; summary is almost correct, but does not quote the source	The student… … finds consistent information from at least two substantially different sources; summarises it in 3-4 almost correct sentences, quotes all or almost all sources of information	The student… … finds consistent information from at least two substantially different sources; summarises it in 3-4 correct sentences, quotes all sources of information

In order to assess the development of the skill of *working collaboratively*, a self-assessment tool is proposed for use at the end of the unit. This allows the students to reflect on their involvement in group work during the lesson. Using the scale 0 (not at all) to 6 (very much), students score their own engagement, according to the statements listed in Table 6.

Table 6: Self-assessment tool for assessing the skill of working collaboratively

Self-assessment card	0 (not at all)	1	2	3	4	5	6 (very much)
1. I was involved in planning the experiment							
2. I carried out the given tasks							
3. I helped colleagues							
4. I was involved in collection of data							
5. I was active in performing the experiment							
6. I communicated properly with the others							

A similar peer-assessment tool is shown in Table 7. This allows the student to reflect on the involvement of their peers in group work during the lesson. Using the scale 0 (not at all) to 6 (very much), students score their peers' engagement, according to the statements listed.

Table 7: Peer-assessment card for the assessment of working collaboratively

Peer-assessment card	Peer 1	Peer 2	Peer 3
1. Did your colleague take part in planning the experiment?			
2. Did your colleague take part in carrying out the given tasks?			
3. Did your colleague help the group?			
4. Did your colleague engage in data collection?			
5. Did your colleague take part in performing the experiment?			
6. Did your colleague communicate properly in the group?			

3. SYNTHESIS OF CASE STUDIES

The **Electricity** SAILS inquiry and assessment unit was trialled in four countries, producing five case studies of its implementation – **CS1 Slovakia**, **CS2 Ireland**, **CS3 Turkey**, **CS4 Poland** and **CS5 Poland**. The case studies were conducted by 14 different science teachers in a total of 17 classes and with 333 students.

The activities have been carried out with lower second level students from mixed ability classes; **CS1 Slovakia** combines the classroom experiences of 10 teachers in 11 classes, **CS2 Ireland** reports on one teacher's implementation with two different class groups (all girls, aged 14 years) and **CS4 Poland** describes one teacher's implementation with one class of 14 year old students. **CS3 Turkey** and **CS5 Poland** present the experiences of teachers implementing this unit at upper second level, with students aged 15-16 years and one of the teachers in **CS1 Slovakia** also trialled this unit with this age group.

The key inquiry skill evaluated was *planning investigations*, while most case studies also reported on collecting evidence of *scientific reasoning* and *scientific literacy*. The identified assessment opportunities included students' contribution during brainstorming, students' construction of mind maps, students' abilities to draw electrical circuits and develop investigation plans. The assessment methods used include classroom dialogue, students' worksheets and other devised materials, such as mind maps, and peer-/self-assessment tools.

3.1 Teaching approach

Inquiry approach used

The inquiry approach used in all the case studies was that of *guided inquiry*, as outlined in the unit description. In two case studies – **CS2 Ireland** and **CS3 Turkey** – students did not have lessons on electricity prior to the implementation of this unit, while in all other classes the activities of this **Electricity** SAILS inquiry and assessment unit were used for revision purposes. The purpose of this unit was particularly important in student's construction of mind maps in Activity A: Introduction to electricity. If students had no prior knowledge of the topic electricity, the mind map was used to set the everyday context. If electricity was introduced beforehand, the mind map was utilised as a revision exercise. In one class (**CS2 Ireland**) the mind map was used for comparison at the beginning and at the end of the unit. The unit was usually adopted as outlined, however in some cases (**CS2 Ireland** and **CS5 Poland**) the final challenge was partially or entirely skipped during the implementation.

Implementation

Implementation of the unit took 45-90 minutes, depending on the country. This corresponds to only one lesson (45 min) in some classes (Slovakia) and two lessons (~90 min) in all other cases. Students worked in groups of 2-3 students of mixed abilities in **CS2 Ireland**; of 4 students in **CS4 Poland**; in pairs in **CS5 Poland**; of 4 students in each class in **CS1 Slovakia**; and as a whole class comprising of 16 students in **CS3 Turkey** (due to the shortage of appropriate equipment). Each student was given one worksheet and completed it individually, except in **CS5 Poland** where it was not possible for the teacher to provide photocopies for all students (34); so instead, the students took their notes on separate pieces of papers.

Table 8: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Slovakia	Activities A-C	Mainly two lessons (45 min each)	• Groups of 3-4 students (12 classes in total) • Mixed ability; some single gender groups
CS2 Ireland	Activities A-C	One or two lessons (80 min total)	• Groups of 2-3 students (2 classes in total) • Mixed ability; single gender (all-girl school)
CS3 Turkey	Activities A-C	Two lessons (40 min each)	• Participated individually (16 students in total) • Mixed ability and gender class
CS4 Poland	Activities A-C	Two lessons (45 min each)	• Groups of 4 students (20 students in total) • Mixed ability and gender
CS5 Poland	Activities A-C	One lesson (45 min)	• Groups of 2-3 students (34 students in total) • Mixed ability and gender

Adaptations of the unit

The teachers that implemented the unit shared the opinion that it was appropriate for two lessons. Slight modifications were proposed by some of the teachers, namely the assessment of generating research questions (**CS3 Turkey**), use of a mind map both at the beginning and at the end of a unit (**CS2 Ireland**, both class groups), construction of a model of an electric circuit (**CS2 Ireland**) and omissions or shortcuts in latter sections (**CS2 Ireland** and **CS5 Poland**).

3.2 Assessment strategies

In the **Electricity** SAILS inquiry and assessment unit, several assessment opportunities were identified. No one teacher that implemented this unit used all of the opportunities or tools for assessment that were provided, and instead they focused on particular skills for development and assessment, as detailed in Table 9.

Table 9: Inquiry skills identified by teachers in the case studies

CS1 Slovakia	• Planning investigations • Scientific literacy (searching for information; explaining lightning scientifically)
CS2 Ireland	• Planning investigations • Working collaboratively • Scientific literacy (searching for information; use of scientific language, explaining electrical conduction scientifically)
CS3 Turkey	• Developing hypotheses • Forming coherent arguments • Scientific literacy (explaining electrical conductivity scientifically)
CS4 Poland	• Planning investigations • Scientific reasoning (identifying connections) • Scientific literacy (explaining the principles of electricity scientifically)
CS5 Poland	• Planning investigations • Working collaboratively • Scientific reasoning (choosing components for an electrical circuit)•Scientific literacy (ability to explain electrical conductivity scientifically)

Three key skills identified in the activities for teaching and learning were highlighted for assessment during implementation in the classroom. *Scientific literacy* and *scientific reasoning* about electricity could be evaluated four times – during brainstorming in activities A and C, using mind maps in Activity A and using graphical and schematic representations of working electric circuits (activities B and C). The assessment of *planning investigations* was suggested in Activity C and could be used as part of a group work assessment. A task involving searching for information was proposed at the end of the unit and could be offered as a homework exercise.

In addition to these, three other assessment opportunities were realised by the teachers that implemented this unit in their classrooms and are included in their case studies, together with new assessment tools. The assessment of "constructing a model of an electric circuit" was added by a teacher in **CS2 Ireland** and a 4-level rubric was proposed for this purpose (Table 10). *Working collaboratively* (engagement in group work) was assessed by one of the Polish teachers (**CS5 Poland**) and *developing hypotheses* (generating a research question) was evaluated by a teacher in **CS3 Turkey**.

Table 10: Rubric for the assessment of circuit drawing/models proposed in CS2 Ireland

Assessed Skill	Level 1	Level 2	Level 3	Level 4
Scientific literacy: circuit model/ drawing	Circuit symbols drawn and connected correctly	...and includes reference to flow of electrons/direction of current	... and indicates that electrons already present throughout the wires, etc., begin to move as soon as switch goes on and some explanation as to why they begin to move (reference to battery/ potential difference, etc.)	...and an explanation of energy conversion, i.e. electrical energy – light energy in the bulb and/or reference to how kinetic energy of electrons does not change

Assessment tools

At different stages, the unit offers different assessment methods for assessing the skill of *working collaboratively*, namely a tool for assessing engagement in collaboration, a tool for the assessment of brainstorming and a tool for self- and peer-assessment. In the assessment of teaching and learning activities second of this unit, rubrics are proposed for the assessment of four activities – twice for the assessment of *scientific literacy* and *scientific reasoning* (drawing a mind map and use of graphical and schematic representations of working electric circuit), once for the assessment of *planning investigations* and once for *searching for information*. All rubrics are based on four levels of student development of the particular skill. These rubrics were implemented without changes, except in the case of **CS4 Poland**, where the teacher extended three of these rubrics from four to six levels (Table 11). A six-level scale is used for traditional grading in Poland and the teacher was used to this format in her teaching practice. Additionally a new rubric for the assessment of a student's ability to construct a model of an electric circuit was proposed by the teacher in **CS2 Ireland** (Table 10).

Brainstorming is utilised twice in the **Electricity** SAILS inquiry and assessment unit, as an assessment method for evaluation of *scientific reasoning* and *scientific literacy*, and at times when all students take part in whole class discussion. Self- and peer-assessment tools were not included in the resources provided to the teachers trialling this unit, but were added by one of the teachers in **CS4 Poland** for evaluation of *working collaboratively* (engagement in group work). These have been subsequently been incorporated into the final **Electricity** SAILS inquiry and assessment unit (Tables 6 and 7).

Table 11: Rubric for the assessment of inquiry skills in CS4 Poland

Task	1	2	3	4	5	6
Drawing a mind map	Student doesn't draw mind map or draws it putting words not connected to topic (can't explain the connection to the topic).	Student draws a mind map containing 5 words connected to the topic, but there is a lack of connections and relations between them.	Student draws a mind map containing more than 5 words connected to the topic and the majority of the words are from common language. There is a lack of connections and relations between words.	Student draws a mind map with more than 8 words connected to the topic (majority of words are from common language). Student draws the connections between some words.	Student draws a mind map with more than 10 words connected to the topic (most of words are from common language). Student draws connections between words but the structure is not expanded very much.	Student draws a mind map with more than 10 words connected to the topic and most of words are scientific. Student draws proper relations and connections between words.
Drawing circuits	Student chooses proper components of circuits to light a bulb (B.1) but doesn't draw the scheme or draws it incorrectly (B.3). S/he doesn't draw a proper circuit (C.2) or schemes of circuits (C.5)	Student chooses proper components of circuits to light a bulb (B.1) and draws this circuit (B.3). S/he doesn't draw a circuit or does it incorrectly (C.2). S/he doesn't draw schemes of circuits (C.5)	Student chooses proper components of circuits to light a bulb (B.1) and draws this circuit (B.3). Student draws a circuit (C.2) but doesn't correctly draw the schemes of circuits (C.5).	Student chooses proper components of circuits to light a bulb (B.1) and draws one of the circuits B.3 or C.2, but doesn't correctly draw the schemes of circuits (C.5).	Student chooses proper components of circuit to light a bulb (B.1) and draws circuits B.3 and C.2. Student makes mistakes in drawing one of the schemes of circuits (C.5).	Student chooses proper components of circuit to light a bulb (B.1) and draws circuits B.3 and C.2. Student draws schemes of both circuits (C.5).
Planning investigations	Student doesn't list things made of different materials for measurement and doesn't write down an experiment plan.	Student lists 2-3 things made of different materials for measurement but doesn't write down an experiment plan.	Student lists 4-5 things made of different materials for measurement and writes down an incorrect experiment plan.	Student lists 4-5 things made of different materials for measurement and writes down an almost correct experiment plan.	Student lists 6-7 things made of different materials for measurement and writes down an almost correct experiment plan.	Student lists more than 7 things made of different materials for measurement and writes down a correct experiment plan.

Implementation and evidence

Students working with the **Electricity** SAILS inquiry and assessment unit were assessed both as they worked during the lessons and afterwards, on the basis of student worksheets. Solely in **CS1 Slovakia** all teachers used only the latter strategy of assessment. In addition, most teachers posed questions and gave formative feedback orally during the lessons (**CS2-CS5**), but this was not documented. As can be observed from the case studies, individual teachers showed preferences for different assessment tools.

The assessment of the mind map activity using rubrics was utilised only in **CS4/CS5 Poland** and **CS2 Ireland**, although in the latter it was utilised twice – at the beginning and at the end of unit implementation – and in this case the rubrics for the assessment of a mind map were changed accordingly. Evaluation of *planning investigations* with use of rubrics was introduced in **CS4**, **CS5 Poland** and **CS1 Slovakia**. The searching for information activity was given as homework only in **CS1 Slovakia** and was assessed with rubrics. Group work engagement was evaluated by self- and peer-assessment tool only by one teacher in **CS5 Poland**, who added these tools to the unit (Table 6 and Table 7). Constructing a model of an electric circuit was assessed only in **CS2 Ireland**, since rubrics for this activity was an original contribution of an Irish teacher to the unit (Table 10). Evaluation of generating a research question was implemented by only one teacher in **CS3 Turkey**, who did not propose any specific assessment tool for this activity but gave feedback based on her own judgements.

Problems encountered

The teachers in **CS1 Slovakia** considered the assessment based on observing students during their brainstorming activity (assessing pre-knowledge, activity and creativity) and drawing a concept map rather problematic. Thus they utilised only the rubrics. At the same time the teacher in **CS3 Turkey** liked to use the brainstorming chart, but reported substantial problems with the use of rubrics during the lesson and would prefer to utilise this tool for evaluation of student worksheets, after the lesson. The teachers in **CS2 Ireland**, **CS4** and **CS5** (both Poland) did not mention any problems in implementation of the assessment strategies proposed for this unit.

Proposed adaptations

From the case studies, a number of adaptations were proposed in this unit, which seek to expand the opportunities to develop inquiry skills and to assess students' performance.

1. The rubric tools proposed in the unit are composed of four levels of skill development – emerging/developing/consolidating/extending. A teacher in **CS4 Poland** found that composition of six levels provided more clarity (Table 11). This can be taken into consideration by teachers who need a more fine-grained structure of rubrics and shows the flexibility in the adaption of the provided assessment tools for use in different curricula and context.
2. One teacher utilised a mind-map before and after the unit (**CS2 Ireland**). Students were assessed on what changes they made to the mind-map, which gave the teacher a clearer measure of the students' ideas of what it means for something to be a conductor of electricity).
3. In **CS5 Poland**, the tool for the assessment of drawing the mind map on electricity was extended by including an additional rubric for evaluation of engagement in peer-discussion in pairs (Table 12).
4. The teacher in **CS2 Ireland** suggests an extension to the task of drawing a simple electric unit, asking students to draw what they think is happening inside the wires (Table 10).
5. It was suggested by one of the teachers that for the conductivity table in the student worksheet, it would be better to get students to explain why they made the prediction. This would help the teacher assess argumentation and justification skills and means that students who just guess correctly are not assessed as being at the higher end of an assessment scale (**CS2 Ireland**).
6. Formulation of the inquiry research question has been added by a teacher from **CS3 Turkey** to the unit just after activity with a mind map, and a simple three-point scale for the assessment is proposed:
   - Point 1: Students cannot formulate a good hypothesis.
   - Point 2: Student formulates a hypothesis but with an inappropriate statement
   - Point 3: Student formulates an appropriate hypothesis and states it appropriately

Table 12: Rubric for assessment of student mind maps used in CS5 Poland

Assessed Skill	Emerging	Developing	Consolidating	Extending
Drawing a mind map	Student's mind map is empty or full of inadequate words, for which the student cannot describe a relation to electricity	Student draws a mind map containing only a few words and/or the words are listed with no relation to each other	Student draws a mind map with more than 10 words, both scientific and belonging to a common language, but the visualisation of the relationships and categories is poor	Student draws a mind map with more than 10 words, both scientific and belonging to a common language, with a good visualisation of the relationships and categories
Discussion with peers	Student does not take part in the discussion	Discussion between the students is limited to reading words from own mind maps and checking the neighbour's terms	Student detects differences between two mind maps and compares them (e.g. tries to judge which one is better)	Student points out significant differences and compares both mind maps; considers scientific value of scientific terms in both maps and argues, why one of them is better that the other

INQUIRY AND ASSESSMENT UNIT

LIGHT

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

Eilish McLoughlin

LIGHT

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

Overview

KEY CONTENT/CONCEPTS

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

LEVEL

- Lower second level
- Upper second level

INQUIRY SKILLS ASSESSED

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

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

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

ASSESSMENT METHODS

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

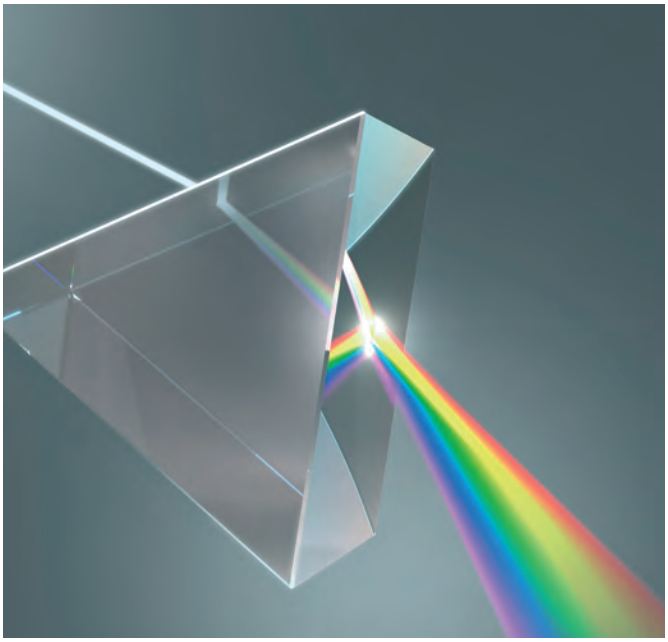
Classroom materials for this Inquiry and Assessment Unit are available at WWW.SAILS-PROJECT.EU

INQUIRY AND ASSESSMENT UNIT OUTLINE – LIGHT

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

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

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



2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

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

Activity A: What are sources of light?

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

Rationale

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

Suggested lesson sequence

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

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

Possible teacher questions

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

Activity B: How does light travel?

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

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

Worksheet 1 What are sources of light?

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

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

....

....

....

....

....

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

....

....

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

....

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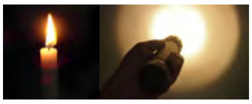


4. What are the differences between the candle and torch in terms of their physical properties?

....

....

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

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

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

....

....

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

....

....

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

....

....

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

Rationale

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

Suggested lesson sequence

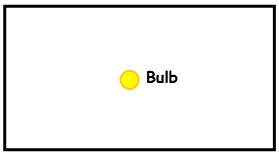
Materials: *cardboard box with a hole cut in one side, incandescent light bulb (~40 W), overhead projector/acetate or whiteboard/marker*

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

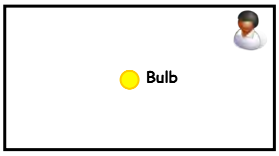
Worksheet 2 How does light travel?

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

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



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



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

....

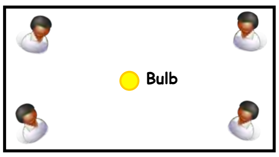
On the diagram, draw in the path that light takes from the bulb to the person.

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

....

....

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



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

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

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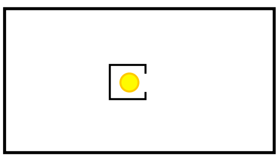
....

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



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

....

....

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

Possible teacher questions

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

Activity C: Understanding shadows

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

Rationale

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

Suggested lesson sequence

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

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

Worksheet 3 Understanding shadows

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

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

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

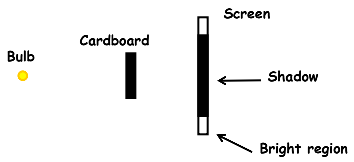
4. Is there another way of the making the shadow larger? (Hint: What did you move in order to answer Question 3? Is this the only part of your set up you can change?)

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

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

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

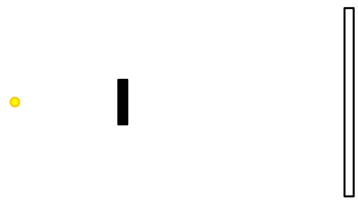
7. The diagram below shows the relative positions of the bulb, cardboard piece, and paper screen.



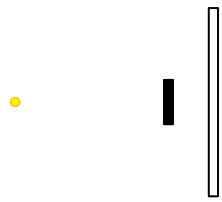
(i) Draw in the path that light travels from the bulb to the cardboard piece. Does this light reach the screen? Explain.

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

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



(i)



(ii)

(iii)

Figure 3: Worksheet for Activity C: Understanding shadows

Possible teacher questions

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

Activity D: Exploring white light and filters

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

Rationale

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

Suggested lesson sequence

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

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

Possible teacher questions

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

Activity E: Exploring primary colours

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

Rationale

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

Suggested lesson sequence

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

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

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

Worksheet 4 Exploring white light and filters

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

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

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

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

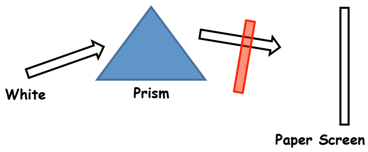
   (a) The prism changes white light into different colours

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

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

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

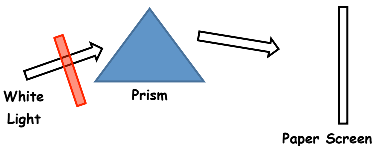
3. Take a coloured filter and place it in the path of the light leaving the prism.



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

   Explain how you think the filter affects the light.

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



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

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

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

Worksheet 5 Exploring primary colours

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

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

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

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

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

Additional investigation:

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

Possible teacher questions

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

Activity F: Exploring plane mirrors

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

Rationale

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

Suggested lesson sequence

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

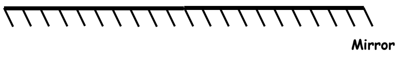
1. The activity begins with students being posed a question, such as, "If you look through a straw at an object, what direction must the light travel from the object to your eye in order for you to see it?"
2. The students are then asked to consider the same question but for two straws forming a V-shape.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

Possible teacher questions

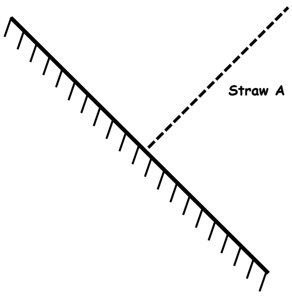
- Do you notice anything about the angles at which the straws have to be in order for light to pass from one to the other?
- Does this relationship hold when the mirror is angled?
- What would happen to light at different points on the mirror if the surface of the mirror was curved inwards or outwards?

Worksheet 6 Exploring plane mirrors

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



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



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

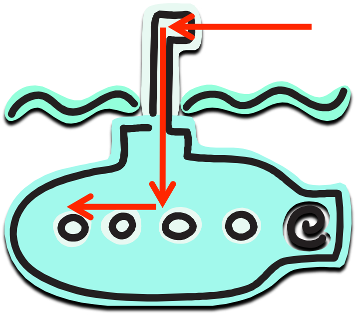


Figure 5: Worksheet for Activity F: Exploring plane mirrors

Activity G: Exploring refraction

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

Rationale

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

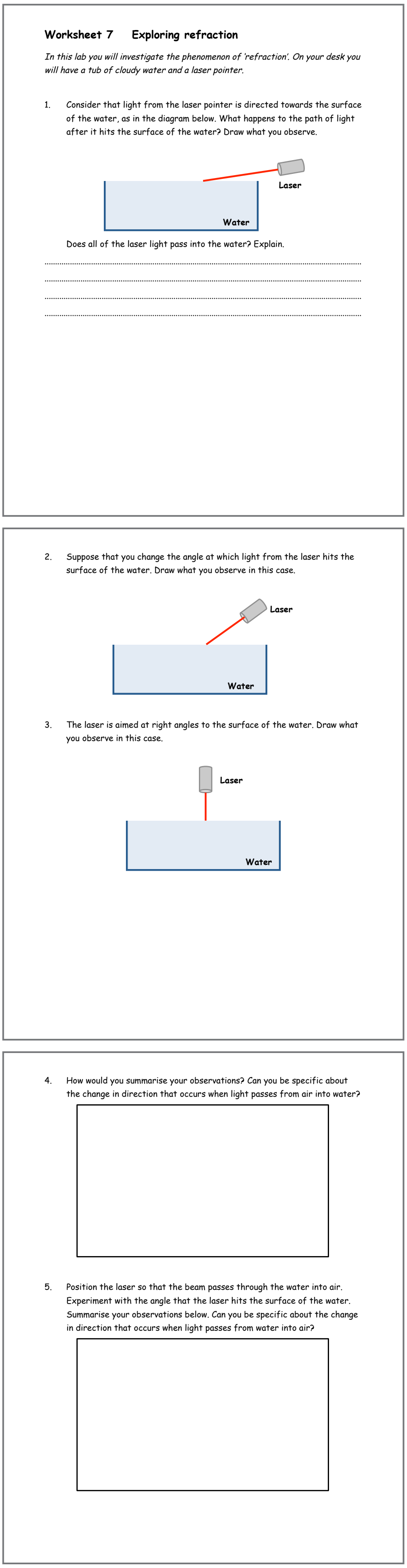
Suggested lesson sequence

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

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

Possible teacher questions

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


Worksheet 7 Exploring refraction

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

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

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

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

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

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

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

Figure 6: Worksheet for Activity G: Exploring refraction

Activity H: Exploring lenses

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

Rationale

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

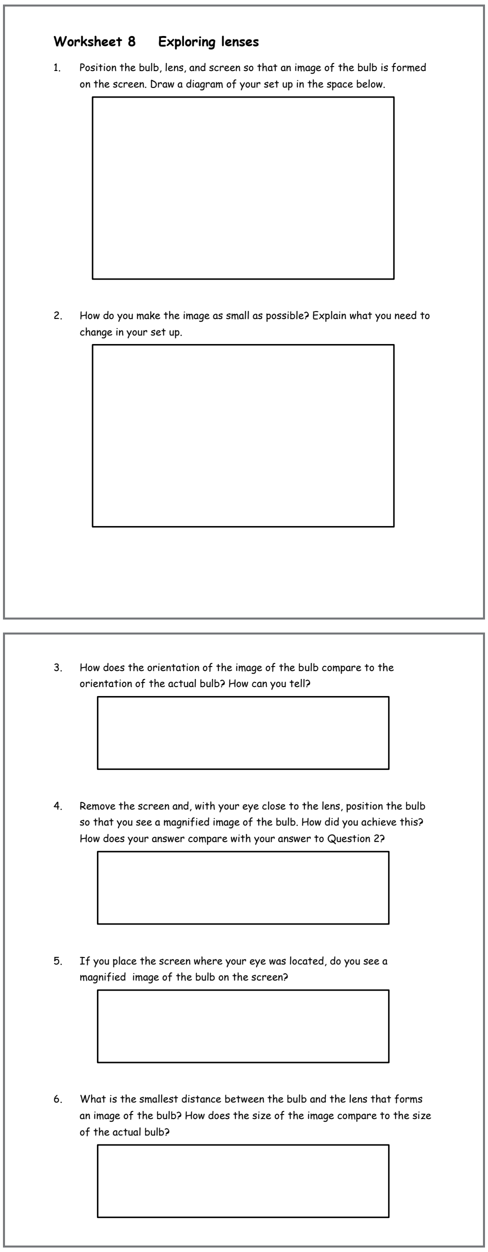
Suggested lesson sequence

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

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

Possible teacher questions

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


Worksheet 8 Exploring lenses

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

Figure 7: Worksheet for Activity H: Exploring lenses

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

2.2 Assessment of activities for inquiry teaching & learning

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

Asking questions

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

Teacher questions to guide the students include:

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

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

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

Developing hypotheses

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

Teacher questions to aid students in developing their hypotheses include:

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

Table 2: Teacher rubric for the assessment of developing hypotheses

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

Planning investigations

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

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

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

Table 3: Teacher rubric for the assessment of planning investigations

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

Carrying out an investigation

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

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

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

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

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

Interpreting results and drawing conclusions (scientific reasoning)

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

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

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

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

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

Observations (scientific reasoning)

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

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

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

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

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

3. SYNTHESIS OF CASE STUDIES

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

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

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

3.1 Teaching approach

Inquiry approach used

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

Implementation

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

Adaptations of the unit

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

Table 7: Summary of case studies

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

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

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

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

3.2 Assessment strategies

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

Forming coherent arguments

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

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

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

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

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

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

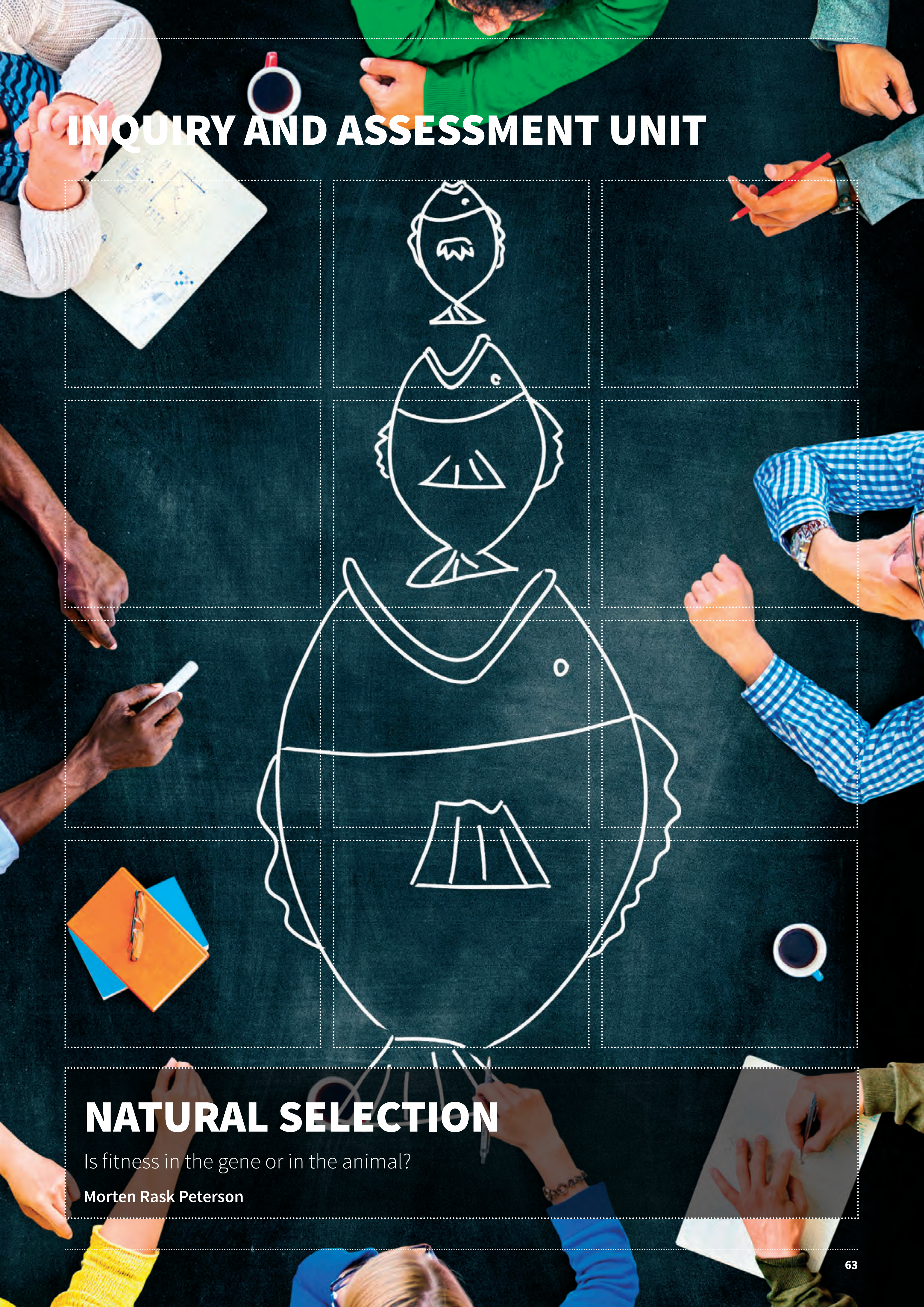
Developing hypotheses
CS1 Ireland used the criteria from the 3-level rubric proposed in the assessment of teaching and learning section of the unit for making judgements on the skill of *developing hypotheses* (Table 2), based on written responses to questions 7 and 8 in Activity C: Understanding shadows.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

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

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

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

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



INQUIRY AND ASSESSMENT UNIT

NATURAL SELECTION

Is fitness in the gene or in the animal?

Morten Rask Peterson

NATURAL SELECTION

IS FITNESS IN THE GENE OR IN THE ANIMAL?

Overview

KEY CONTENT/CONCEPTS

- Visualising evolution
- Natural selection
- Genetic drift
- Fitness

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 and observation skills; organisation and interpretation of data)
- Scientific literacy (using physical models to understand adaptation by natural selection; analysis of data and presentation of scientific results)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Worksheets
- Student devised materials (report)
- Other assessment items (pre/post test)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – NATURAL SELECTION

The **Natural selection** SAILS inquiry and assessment unit focuses on natural selection and the Darwinian theory of evolution, which is part of the biology curriculum at upper second level in most European countries. The topic is addressed in a structured, hands-on activity, during which students simulate a gene pool and the random selection of alleles. They assemble model organisms, called Legorgs, out of Lego® bricks, and measure their fitness. They use this physical simulation to grasp the underpinning concepts of adaptation by natural selection.

The skills developed in this unit include *planning investigations, forming coherent arguments* and *working collaboratively*. Skills in *scientific reasoning*, such as collecting data, drawing conclusions are enhanced and students' *scientific literacy* is enriched through comparisons between the physical simulation and the real world. This activity is recommended for implementation at upper second level, where students have sufficient mathematical knowledge to numerically analyse a large quantity of data, and have conceptual understanding of the biology involved. The assessment methods described in the unit include teacher observation, use of student artefacts and classroom dialogue.

This unit was trialled by teachers in Poland, Hungary, Denmark and Sweden – producing five case studies. In all cases, the teaching approach was *guided inquiry*, although teachers also allowed open inquiry where feasible. Students were aged 14-19 years, with those in Poland and Sweden at lower second level. Skills assessed included *planning investigations, working collaboratively, scientific reasoning* and *scientific literacy*.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The **Natural** selection SAILS inquiry and assessment unit details a hands-on simulation activity on natural selection, designed for students aged 15-18 years, in which they investigate multiple genes in Lego® animals (Legorgs). The teaching and learning activities described in this unit were developed by Christensen-Dalsgaard and Kanneworf[1] and adapted for use in the SAILS project. Materials related to the unit activities, including instructional videos, are available online.[2]

Concept focus	Visualising evolution
Inquiry skill focus	Planning investigations Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (data entry and observation skills; organisation and interpretation of data) Scientific literacy (using physical models to understand adaptation by natural selection; analysis of data and presentation of scientific results)
Assessment methods	Classroom dialogue Teacher observation Worksheets Student devised materials Other assessment items (pre/post test)

Rationale

The title of a very famous article on evolution compressed summarises the importance of this topic in a simple statement: "Nothing in biology makes sense except seen in the light of evolution."x[3] Evolution and natural selection are only evident over many generations and so it can be difficult to adopt an inquiry approach to teaching this topic. Computer simulations are often used in classes; however, these can limit students' understanding of the topic, as they are able to take input and get output, without knowledge of the in-between processes. In this unit the topic is addressed in a hands-on activity, which eliminates this gap in knowledge and describes an inquiry learning activity where students can gain a deeper understanding of the underlying biological concepts, while practicing inquiry skills and competencies at the same time.

Model organisms, called Legorgs, are assembled by the students. The Legorgs consists of six segments – one foot and five segments indicated by different colours of the bricks, representing a gene code with five alleles. Each allele specifies a morphogenetic rule for how the segments (bricks) are placed on the previous segment. This means that the students are working with a physical model including multiple genes making it easier to access concepts like "fitness," "natural selection" and "genetic drift." As in every model there are limits and restrictions in the usage and the comparison with the real world. In this particular activity one of the main limitations is that the measurement of "fitness" relies only on one parameter, namely the moving length of the Legorg when falling.

In this activity, three specific concepts are addressed:

- The concept of **natural selection** is the overall conceptual theme of the activity. From this activity, the students can understand that natural selection occurs on the basis of differences between the individuals of a generation. In this activity, random accident, predator-prey, and other negative effects on selection are not addressed. The only parameter for selection is the "fitness" of the individual animal.
- The concept of **fitness** is presented to the students so that they will be able to see that fitness is a concept attached to the whole organism and not to single genes. The students will have the opportunity to see that there is no such thing as a good gene or a bad gene but there are good combinations of genes and bad combinations of genes.
- Students are also introduced to the concept of **genetic drift**, in that they will see genes drifting out of the population and not returning due to the small cohorts in the activity.

Suggested lesson sequence

At the beginning of the lesson, the teacher can provide an introduction to the task that will be performed. This is an opportunity to introduce the scientific terms that will be used in the activity (gene, allele) and demonstrate the connection between the model system (Legorgs) and evolution.

Students are provided with a worksheet, which provides an introduction to the Legorgs and the concept of "fitness" (Figure 1), as well as a table outlining the morphogenetic rules that will be used for assembling the Legorgs (Figure 2). Students may be given some time to become familiar with these rules, and understand how the Legorgs will be assembled.

Once the students are familiar with the task, and how the Legorgs are assembled, they are provided with a workflow diagram and a student worksheet that details how to prepare the first and subsequent generations of Legorgs (Figure 3 and Figure 4).

[1] Evolution in Lego®: A Physical Simulation of Adaptation by Natural Selection, Jakob Christensen-Dalsgaard and Morten Kanneworff, Evolution: Education and Outreach, **2009**, 2, 518-526. Available from Springer Link, http://link.springer.com/article/10.1007%2Fs12052-008-0099-7 [accessed October 2015]

[2] Home of the Legorgs, http://www.jcd.biology.sdu.dk/ [accessed October 2015]

[3] Nothing in biology makes sense except in the light of evolution, T. Dobzhansky, The American Biology Teacher, **1973**, 35, 125-129.

Evolution of Legorgs: a physical simulation of adaptation by natural selection

This activity illustrates adaptation by natural selection for a trait, in this case motility of animals with genetically specified morphology, assembled from six Lego® bricks. The animals are called Legorgs, (short for leg-organisms) since they only consist of a leg.

The individual Legorgs are constructed by random draw from the gene pool of five 8x2 Lego® bricks, each representing a body segment. Each of the bricks can have five colours (alleles), and each colour specifies a morphogenetic rule. The morphogenetic rule specifies how to place the brick on the previous brick (therefore, it is necessary to specify a foot segment, which we by convention always select as black. The motility of the animal is the distance it can move under controlled conditions (see below). We assume that fitness is proportional to the motility, and that individuals transmit genes to the next generation proportional to their fitness. The experiment is to measure the fitness of animals and their descendants through five generations. Our prediction is that in general, fitness should increase with generation.

Fig. 1 Fifth-generation Legorgs, with on average 30 mm motility

Scoring fitness.
Legorgs are built from five genes, specifying five segments placed on a foot (Figure 1). The animals are drawn randomly from the gene pools, described below. Each allele (colour) corresponds to a morphogenetic rule, specifying how to place the brick on the previous one, as detailed in the "Morphogenetic rules for assembly of Legorgs." Therefore, the genetic structure will build Legorgs with different morphology. Fitness is scored by assembling the Legorgs (segment 1 is placed on the black foot-segment) and righting them on the foot. When released, the animal may tip and fall, and when righted again it will have moved a certain distance on the surface. The distance moved by a corner of the foot is marked and measured. The average of five measurements is the fitness of the Legorg and is entered in the "Generation of Legorgs" table. For best results let the Legorgs move on a hard, smooth surface such as a glass or whiteboard plate. Here, it is convenient to mark the corner of the foot segment with a whiteboard marker.

Figure 1: Student worksheet – introduction to the **Natural selection** SAILS unit tasks

Morphogenetic rules for assembly of Legorgs

The morphogenetic rules for assembly of Legorgs are shown below. Legorgs are assembled from segment 1, "counter-clockwise" i.e. the previous segment (grey) is turned counter-clockwise to orient it up-down as in the figures. Segment 1 is placed on the foot that is always black.

Allele/Colour	Description	
Red	Staggered, ahead	
Blue	Just on top	
White	Traverse, right	
Black	Traverse, left	
Yellow	Traverse, middle	

Figure 2: Student worksheet detailing the morphogenetic rules for assembly of Legorgs

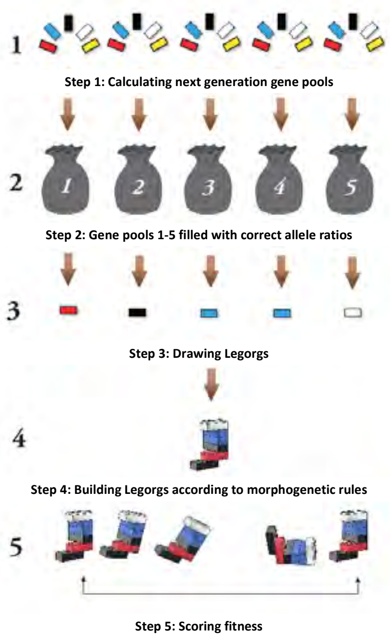


Figure 3: Student worksheet showing the workflow for creating each generation of Legorgs

First generation
For the first generation Legorgs, use the "Generation of Legorgs" table to record the alleles for each Legorg. Each Legorg consists of five genes (bricks) placed on a foot; each of the genes can be one of five alleles (colours).

- Five opaque plastic bags are filled with 5 bricks (1 of each colour in each bag). Each of these bags simulates the gene pool for one of the five genes (in the following generations it is desirable to have 100 bricks in each bag, but it is not necessary in the first generation with equal distribution of alleles).
- Shake bags to ensure randomised draw. Draw a brick from each bag (the sequence is important). Note the sequence of colours drawn on the "Generation of Legorgs" table. When bricks from the five bags are drawn, the animal is specified genetically. Do not construct the animal now, so put the bricks back into the bags (NB!) and select again for the next Legorg.
- Repeat this until you have the genetic structure of 10-20 Legorgs noted on the "Generation of Legorgs" table.
- Now build the Legorgs using the "Morphogenetic rules for assembly of Legorgs," score their fitness and enter fitness value in the final column of the "Generation of Legorgs" table. Calculate and enter the sum and average for fitness for the Legorgs.

Next, the contribution of each individual gene (position of brick with respect to foot) to the overall fitness of the Legorg can be calculated. Each gene is detailed on a copy of the "Gene pool table" – one per gene per generation, i.e. there will be five "Gene pool tables" for the first generation.

- The allele of each Legorg is weighed by their fitness. This is done by entering the fitness of the Legorg (obtained previously) in the table at the position of the allele (colour) for that gene (particular position of the segment relative to the foot).
- Calculate the sum of fitness (Σ fitness) for all Legorgs and the sum of fitness for each allele (Σ colour weight).
- Calculate fitness for each allele relative to the total fitness in percent (rounded to nearest whole number), using the formula $\frac{\Sigma \text{ colour weight}}{\Sigma \text{ fitness}} \times 100$
- The percentage of each allele is simply the number of bricks of each colour needed to fill the gene pool (assuming 100 bricks for the next generation gene pool bag).

Second to fifth generation

- Fill the opaque bags with coloured bricks, according to the calculation from the last generation gene pool table.
- Mutations can be simulated by changing one brick in each of the bags with a brick of another (randomly chosen) colour. This corresponds to an unnaturally high mutation rate, (0,01 against normally 10^{-4} to 10^{-7}), but can probably show effects of mutations during the few generations used here.

As previously, draw the genetic structure of 10 or 20 Legorgs, build, determine fitness and note them in the "Generation of Legorgs" table. After determining fitness of all the Legorgs, transfer the values to the corresponding "Gene pool table" and calculate the next generation gene pools, as performed previously.

Figure 4: Student worksheet detailing the procedure for creating the first and subsequent generations of Legorgs

They are then assigned their first task, to prepare a set of first generation Legorgs (10-20 individuals recommended, although can be adapted based on available resources). They record the alleles for each gene in the first "Generation of Legorgs" table (Figure 5). Students then measure the fitness score for each of the first generation Legorgs, and record the value in the table.

Once the first generation of Legorgs are assembled, and their fitness measured, students need to interpret their results to determine the gene pool for the next generation of Legorgs (Figure 6). Each gene from the previous generation must be assessed individually; therefore students use one gene pool table per gene per generation. Upon analysis of the results, students can calculate the relative fitness (% of allele) and determine the ratio of each allele in the next generation gene pool.

The students should prepare several generations of Legorgs (up to five generations is recommended), as this will allow for sufficient data to be obtained to demonstrate "evolution" of the Legorgs.

If students are engaging well with the task, and understand the correlation between the models and real-world system, it may be interesting to simulate a mutation. This is achieved by replacing one brick in the gene pool bag with another different colour brick. This is an artificially high rate of mutation (1%), but is useful for demonstrating the effect of mutation in the small number of generations prepared in this activity.

Once students have assembled and measured the fitness for five generations of Legorgs, they will have generated a very large quantity of data (5 generation tables and 25 gene pool tables). To aid them in interpreting this data, and relating their results to the topic of natural selection and evolution, a worksheet can be provided (Figure 7).

To further assess students' understanding of the relationship between the model Legorg system and natural selection a post-implementation test is proposed, such as that shown in Figure 8.

2.2 Assessment of activities for inquiry teaching & learning

In this section we identify some opportunities for the assessment of inquiry skills. Some tools for formative assessment are proposed, aimed at verifying the development of inquiry skills of *planning investigations* and *forming coherent arguments*. This unit also provides a key opportunity to strengthen students' scientific reasoning capabilities and enrich their *scientific literacy*. Several assessment opportunities have been identified, and some criteria for the assessment are detailed for these skills.

Planning investigations, scientific reasoning, scientific literacy

Throughout this activity, students need to collect meaningful data, organise large volumes of data and analyse data accurately and precisely. The amount of data in this unit is large and the students work with multiple schemes and tables to keep

Generation of Legorgs

Generation No.	

	Note allele (colour) for each of the 5 genes in the Legorg and measure fitness					
Legorg no.	**Gene 1**	**Gene 2**	**Gene 3**	**Gene 4**	**Gene 5**	**Fitness**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
				Sum of fitness:		
				Average fitness:		

Figure 5: Student worksheet – table for recording each generation of Legorgs

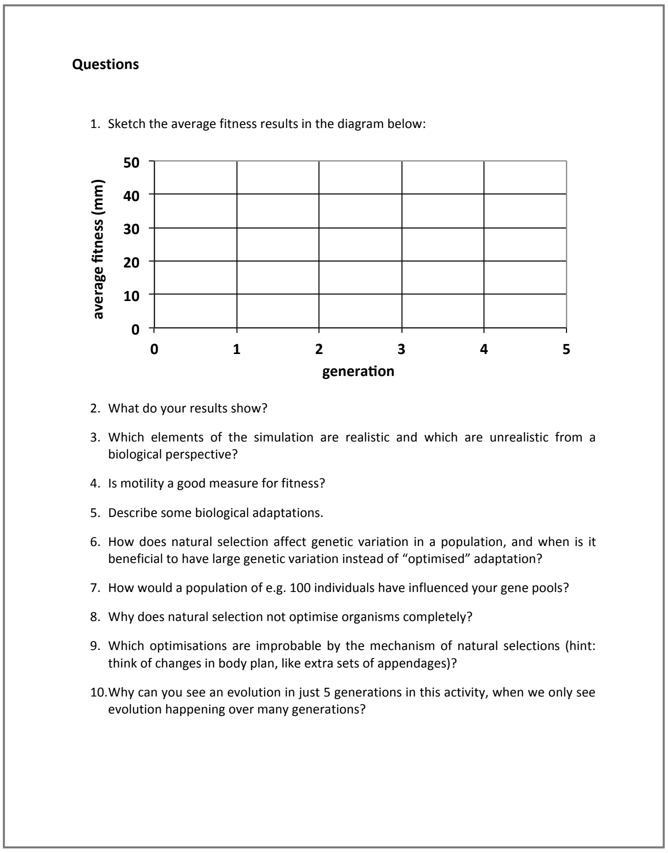
Gene pool table

Each individual Legorg can be described within a gene pool table, as shown below. There should be one table per gene per generation.

Generation No.		**Alleles**				
Gene No.		Note Legorg's fitness in column of the animal's allele (colour)				
Legorg No.	Fitness	Yellow	Red	Black	Blue	White
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
Σ fitness		Σ yellow weight	Σ red weight	Σ black weight	Σ blue weight	Σ white weight
Relative fitness % of each allele $\frac{\Sigma \text{ colour weight}}{\Sigma \text{ fitness}} \times 100$						

Note: The sum of fitness (Σ fitness) is calculated from the total fitness values, regardless of colour of the allele. The sum of the weight for each colour (Σ colour weight) is calculated from the sum of each of the entries for that colour's column

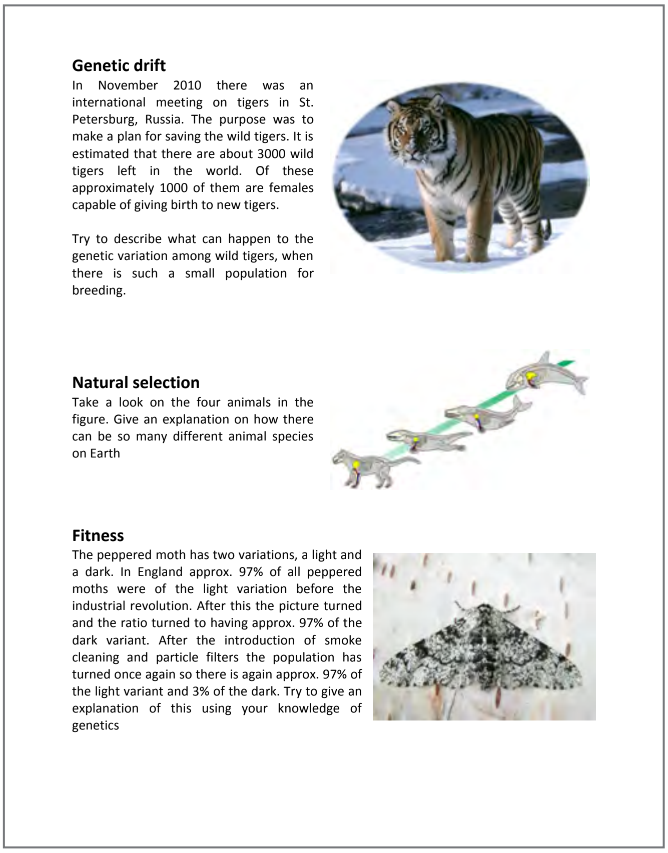
Figure 6: Student worksheet: Gene pool table


Questions

1. Sketch the average fitness results in the diagram below:

2. What do your results show?
3. Which elements of the simulation are realistic and which are unrealistic from a biological perspective?
4. Is motility a good measure for fitness?
5. Describe some biological adaptations.
6. How does natural selection affect genetic variation in a population, and when is it beneficial to have large genetic variation instead of "optimised" adaptation?
7. How would a population of e.g. 100 individuals have influenced your gene pools?
8. Why does natural selection not optimise organisms completely?
9. Which optimisations are improbable by the mechanism of natural selections (hint: think of changes in body plan, like extra sets of appendages)?
10. Why can you see an evolution in just 5 generations in this activity, when we only see evolution happening over many generations?

Figure 7: Student worksheet: Questions to aid interpretation of data


Genetic drift

In November 2010 there was an international meeting on tigers in St. Petersburg, Russia. The purpose was to make a plan for saving the wild tigers. It is estimated that there are about 3000 wild tigers left in the world. Of these approximately 1000 of them are females capable of giving birth to new tigers.

Try to describe what can happen to the genetic variation among wild tigers, when there is such a small population for breeding.

Natural selection

Take a look on the four animals in the figure. Give an explanation on how there can be so many different animal species on Earth

Fitness

The peppered moth has two variations, a light and a dark. In England approx. 97% of all peppered moths were of the light variation before the industrial revolution. After this the picture turned and the ratio turned to having approx. 97% of the dark variant. After the introduction of smoke cleaning and particle filters the population has turned once again so there is again approx. 97% of the light variant and 3% of the dark. Try to give an explanation of this using your knowledge of genetics

Figure 8: Pre- and post-implementation test

track of their experiments. This requires them to organise their data management and data analysis to come to a meaningful result at the end of the activity. Teachers can assess this skill by observing how the students manage to structure their data collection. These processes can be described through written work or documented through work diagrams and flowcharts made by the students. Some criteria for the assessment of this skill are to consider:

- Is there a joint discussion and decision on how to organise this or is it the "leader" of the group that does this in an authoritative way?
- Is the data collection systemised and are the students capable of keeping track of the different schemes and the large amount of similar data?

Forming coherent arguments, scientific reasoning and scientific literacy

There are two key opportunities for evaluation of student skills in *forming coherent arguments* (an aspect of *scientific reasoning*) and *scientific literacy* – forming conclusions and explaining unexpected results.

When forming conclusions, the students' interpretation should be assessed both at the individual level (the Legorg) and at the generation level (the gene pool). There are a lot of calculations involved in getting the results needed to continue and complete the activity. During data collection, students will be aware of the accuracy in taking measurements and the need to repeat measurements in order to improve accuracy. In the same way, they have the possibility of seeing the individual differences in a generation and the expression of a generation mean.

The students complete a large number of tables and calculate the mean for many individual Legorgs during this activity. These results should be interpreted, perhaps through plotting a graph of the mean fitness score for each generation. Students should be able to explain their interpretation of results for both individual Legorgs and for each generation. The teacher can evaluate student skill by considering the following criteria:

- Do the students understand why they have to calculate means of both the individuals and the generations?
- Is there a discussion on the validity of the measurements?
- Do the students discuss uncertainties in the graphical representation of their data analysis?

A sample 3-level rubric for assessing students' skills in *forming coherent arguments* is provided in Table 1. The teacher can use these performance levels to assess the group's work. If the teacher observes that a group is at a certain level and do not progress s/he can interact with the group to bring them to a higher level. A top-performing student is capable of generating the necessary data in a consistent manner and can discuss uncertainty of the measurements.

Table 1: Rubric for the assessment of the skill of forming coherent arguments

Inquiry skill	Level 1	Level 2	Level 3
Forming coherent arguments	They do the measurements but are not consistent in how they do this for each measurement.	They do the measurements and they take care to do them in the same way throughout the activity.	They do the measurements in the same way throughout the activity and they discuss the validity of and uncertainty associated with the measurements.

A second opportunity for the assessment of students' skill in *forming coherent arguments* is their ability to explain any unexpected results. The students will naturally encounter unexpected results during this activity. The concept of genetic drift is not outlined in the instructions and typically it is not outlined in either the textbooks or in the biology lessons. This means that for most students realising that genes can disappear from a population simply because of natural selection is a new discovery. This new discovery calls for an explanation, and experience with the activity tells us that this is a common start for a discussion of the conceptual understanding of the Darwinian theory.

- Do the students notice the genetic drift of some of the genes?
- Does this lead to any discussions on what happens?
- What explanations do the students give for this?
- Are these explanations discussed in the group for validity?

These questions arise during their work, but the assessment of the students' explanation can be carried out though in-class discussion or evaluation of a student artefact after the lesson.

Scientific literacy

In this unit, students have many opportunities to develop their *scientific literacy*. They can engage in reflective thinking to better understand the processes that they have used, develop their conceptual understanding of the topic of natural selection and transfer the knowledge gained in the model system to real-world situations. At the end of the implementation, students are asked to prepare a final report, which can be used for both formative and summative assessment purposes.

The students can be given a set of questions to answer in their written report, such as those provided in the student worksheet (Figure 7). This report can be an opportunity for reflection on the processes involved in the task, rather than the overall results. The feedback questions for the students' written work should reflect this approach and thereby give the students room for reflection

The students' conceptual understanding could be assessed with a paper and pencil pre- and post-test (Figure 8). The questions in this example are open-ended, meaning that the teachers will have to do a qualitative analysis of the development in conceptual understanding as a result of this inquiry activity. As outlined in the introduction to this unit, the thinking behind natural selection and evolutionary theory is fundamental concept in biology. Understanding this theory therefore opens up for a better understanding of other topics within biology and in interdisciplinary contexts.

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in four countries, producing five case studies of its implementation – **CS1 Poland**, **CS2 Hungary**, **CS3 Denmark**, **CS4 Sweden** and **CS5 Hungary**. In all of the case studies, the teachers had some previous experience of teaching through inquiry. However, the students involved had varying levels of experience of being taught through inquiry.

This unit was recommended for implementation at upper second level, however teachers in **CS1 Poland** and **CS4 Sweden** implemented this with lower second level students, aged 14-16 years. The students in the described case studies were of mixed ability and mixed gender. In **CS1 Poland**, **CS3 Denmark** and **CS4 Sweden**, the students were organised into groups of 4-5 students. In **CS2 Hungary**, the specific study group size is not reported, but the class consisted of five groups of mixed gender and students with dyscalculia were placed in a teacher assigned group. In **CS5 Hungary**, the class consisted of 15 students, but again, group size is not specified. In **CS3 Denmark**, the activity was implemented in either one 180-minute lesson or two 90-minute lessons, while in all other case studies the task was allotted 4-5 lessons of 45-minute duration.

The key skills assessed in the case studies were *forming coherent arguments, planning investigations* and *working collaboratively*, while opportunities for the assessment of *scientific reasoning* and *scientific literacy* were also identified. The key assessment method was provision of formative feedback through classroom dialogue, as well as evaluation of student worksheets or student-devised materials.

3.1 Teaching approach

Inquiry approach used

In all cases the inquiry approach used was *guided inquiry*, as detailed in the teaching and learning activities. All groups worked with the same research question and the same methodology, using the worksheets from the unit or online resources. However, due to the in-built randomness of the task the students got different results from their investigations. Teachers have noted that this activity is quite structured, as the process is outlined step by step in the unit, but that implementation is open as the students have many opportunities to engage in open questioning and interpretation.

Implementation

There were variations in how the unit was delivered in the different contexts. In general, students had received lessons in the biological concepts of natural selection, genetic drift and fitness beforehand. However, in **CS4 Sweden**, the unit was adapted for lower second level students and focused only on natural selection, omitting the concepts of fitness and genetic drift. To commence the lesson, the students watched a video (in Swedish) about evolution.

In all case studies, the students worked in randomly organised or student-selected groups, except for a teacher assigned group of students with dyscalculia in **CS2 Hungary**. There were some differences recorded in terms of group size and how they were organised (Table 2). The group sizes ranged from 3-6 students.

In order to start the activity, the students in **CS1 Poland** started out with translating the material from English to Polish, while using the instructional videos as support for this translation. The teacher reported that this was an opportunity for the students to engage in interdisciplinary studies, as they were learning about scientific concepts in a foreign language. It was also beneficial for the groups to work together in preparation for implementation of the unit.

Table 2: Summary of case studies

Case Study	Duration	Group composition
CS1 Poland	Four lessons (45 min each)	• Groups of 4-5 students (29 students) • Randomly formed; mixed genders
CS2 Hungary	Five lessons (45 min each)	• Mixed ability and gender • One group with students with dyscalculia
CS3 Denmark	One or two lessons (180 min total)	• Groups of 4-5 students (three separate classes) • Teacher assigned; mixed gender and ability
CS4 Sweden	One lesson (60 min)	• Three separate classes (aged 14-16) • Groups of 4-5; students worked individually in one class
CS5 Hungary	Five lessons (45 min each)	• Groups of 3-4 students • Student selected; mixed and single genders

In both **CS1 Poland** and **CS3 Denmark** there was a conceptual pre and post-test on the biological concepts of natural selection, genetic drift and fitness, as suggested in the teaching and learning activities. In **CS1 Poland**, these tests were used in the overall assessment of the students. In **CS3 Denmark** the tests were analysed through a Darwinian landscape model and students who showed positive changes in their understanding of either one of the concepts were invited to a follow-up interview.

In **CS5 Hungary**, the teacher described linking this activity to concepts studied a year earlier (natural selection), and that the activity was incorporated as an aspect of classification of living organisms, that was on the syllabus for the current school year.

In **CS1 Poland**, the teacher described that the students may have had difficulties, as their skill in mathematics was not sufficiently developed at lower second level. In addition, the students in this case study had no prior experience in inquiry-based learning.

Adaptations of the unit

In all case studies, except in **CS3 Denmark** (where the unit was developed), there was a lack of both time and Lego® bricks to carry out the full activity. This resulted in the students investigating fewer than the five generations recommended in the instructions. In **CS1 Poland**, the students worked with cohorts of 3-5 Legorgs, instead of 10-20 individuals per generation as the unit suggests. In this case study, students investigated only one generation (or in rare cases, two generations) of Legorgs.

In **CS2** and **CS5** (both **Hungary**), to overcome the lack of Lego® bricks, coloured cardboard pieces were used when drawing the gene pools for the second and third generations. Again, further generations were not investigated due to lack of resources and time.

In **CS4 Sweden**, the students selected coloured objects from a jar, instead of using Lego® blocks, and inputted the results as colour charts in the original tables from the unit. In one class, they did not assemble Legorgs using Lego® or measure fitness in any way; instead they focused on the selection process. Using this method, students investigated five generations of Legorgs. In another implementation, the students assembled Legorgs and developed a fitness rating scale of “stability” instead of focusing on movement (1 = cannot stand by itself; 5 = stands steady). Students in **CS4 Sweden** also included a computer simulation of the same exercise, using more generations (25) and larger populations. This allowed the study to compare and critique the two model systems.

3.2 Assessment strategies

In the five case studies, many focused on *planning investigations* and *working collaboratively*, as well as *forming coherent arguments* and enhancing *scientific literacy* and *scientific reasoning* capabilities (Table 3). There was a common understanding across all case studies that this activity is particularly good for developing skills in *working collaboratively* and *forming coherent arguments*, although this is only possible if students are given time to work through the activity.

In all case studies, the teachers conducted formative assessment in-class, carrying out on-the-fly evaluations of student performance. In **CS5 Hungary**, the teacher noted that in the initial phase of the activity there was not a lot of time to assess the students, but in the later phase there was time for observation and assessment.

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

CS1 Poland	• Planning investigations • Forming coherent arguments • Scientific reasoning (data entry, drawing conclusions) • Scientific literacy (understand how the model Legorgs relate to evolution; analysis of data and presentation of scientific results)
CS2 Hungary	• Planning investigations • Forming coherent arguments • Scientific reasoning (organisation and interpretation of data)
CS3 Denmark	• Forming coherent arguments • Working collaboratively
CS4 Sweden	• Planning investigations • Scientific reasoning (data entry and observation skills)
CS5 Hungary	• Planning investigations • Forming coherent arguments • Working collaboratively (debating with peers)

In **CS1 Poland**, the teacher made use of 3-level rubrics for the assessment of *planning investigations* and carrying out an investigation (Table 4). In addition, the emphasis in the assessment was on *scientific literacy*, which was assessed using an observation sheet to evaluate each student's actions (Table 5). The teacher reviewed how students analysed their data, in particular through use of numerical and statistical methods to obtain well-documented results in order to make judgements on their skills. A total of 15 points were assigned to *scientific literacy*, from a maximum of 30 points. To assess students' skill in *forming coherent arguments*, the teacher assessed their conclusions to ensure that random processes (genetic drift), natural selection and identifying the correlation between the results obtained and real evolutionary processes were all included.

Table 4: Rubric for assessment of inquiry skills in CS1 Poland

Inquiry skill	2 points level	4 points level	6 points level
Adapting the methodology	Student presents the consecutive steps of the natural selection simulation, but without details.	Student creates an action plan of the natural selection simulation with Legorgs, with some guidance from the teacher.	Student creates detailed instructions for the experiment based on the English language instruction films, with a properly detailed description of the consecutive phases, without help from others.
Carrying out an investigation	Group performs measurements, but not always consistently.	Group performs measurements using the same methods sensibly and consistently throughout the activity.	Group performs measurements consistently throughout the activity and can discuss the degree of their reliability and precision.

Table 5: Observation sheet for assessment of students' skill in analysing data

Students' actions	Yes	No	Points
1. Students discuss the experimental layout and data collection method.	X		1
2. The leader decides on his/her solution and does not listen to other group members' ideas.		X	1
3. Students collect data systematically.	X		1
4. The first generation table (illustrating Legorgs gene configuration and their fitness) is laid out properly.	X		1
5. Students adequately fill in the data into the first generation table.	X		2
6. The first generation first gene pool table is laid out properly.	X		1
7. Students adequately fill in the data into the first generation first gene pool table.	X		2
8. The first generation 2nd to 5th gene pool tables are laid out properly.	X		2
9. Students adequately fill in the data into the first generation 2nd to 5th gene pool tables.	X		2
10. Students collect and analyse data for following generations using the same process as the first one.	X		*
11. A graphical representation of results is created.	X		2
* up to 5 bonus points to be earned for active students for this task	**Total**		**15 pts**

In **CS2** and **CS5** (both **Hungary**), data collection and data analysis (graphical representation) were the key aspects evaluated for assessment purposes. The teachers provided oral formative assessment in class. In **CS2**, due to a shortage of time, students submitted their responses to a post-implementation questionnaire electronically. The teacher in **CS2** used a 3-level rubric for the assessment of *planning investigations, scientific reasoning* and *forming coherent arguments* (Table 6). In **CS5** the teacher used an expanded 4-level rubric to assess *planning investigations, forming coherent arguments* and *working collaboratively* (Table 7).

Table 6: Assessment scale used in CS2 Hungary

Assessed skill	Emerging	Developing	Consolidating
Planning investigations **Carrying out an investigation**	Cannot interpret the tasks without help but manages to do the measurement with some help although not always accurately.	Can interpret the tasks without help, carries out the measurements making sure that they measure in exactly the same way every time.	Quickly understands the tasks, is consistent with measurements and discusses the validity and problems of measurements.
Scientific reasoning (analysis and interpretation)	Identifies sources of error in analysis. Cannot draw conclusions without help.	Identifies sources of error in analysis. Can draw conclusions.	Identifies sources of error in analysis, discusses their effects on results. Formulates conclusions with accuracy and in great detail.
Forming coherent arguments (communication)	Spots unexpected events but cannot account for them.	Spots unexpected events and tries to find an explanation.	Spots unexpected events and can offer an explanation.

Table 7: Assessment scale used in CS5 Hungary

Assessed skill	Emerging	Developing	Consolidating	Extending
Planning investigations **Carrying out an investigation**	Cannot interpret the task on their own but participates in the planning process and in the implementation with the help of peers. Appreciates the goal and significance of individual steps but cannot properly interpret the activity as a whole. Shows insecurity in measurement, does not notice possible sources of error.	Takes an active role in the planning and implementing process of the task and rectifies mistakes without help. Has a job in the implementation. Understands the goal and procedure of the activity in rough terms but correctly. Spots possible sources of error and attempts to avoid them with some success.	Takes an active role in the planning and implementing process of the task and helps peers when needed. Persistently and reliably works on the implementation. Strives to carry out instructions quickly and accurately. Incorporates measurement error avoidance strategies in the experimental design and works according to the specified protocol.	Quickly and precisely understands the goal and procedure of the activity. Helps and guides peers in planning and implementing process. Can suggest alternatives in order to achieve success. Can create their own alternative protocol if needed to avoid measurement errors.
Forming coherent arguments	Produces data and arguments that are not sufficiently coherent and reliable. Cannot draw conclusions and arguments without help.	Collects and represents data appropriately, can draw conclusions and arguments from them, but the conclusions are not sufficiently coherent.	Collects and represents data appropriately and draws conclusions and arguments coherently and shows precision reflecting on prior knowledge.	Draws conclusions and arguments coherently, in sufficient depth and precision and attempts to find an explanation for unexpected or contradictory results.
Debating with peers	Participates in group work but works with interruptions. Generally participates in group debates as a passive observer.	Participates in group work without interruptions but with varying intensity. Expresses opinions in debates but does not present coherent or persuasive arguments.	Participates in group work actively and without interruption. Actively participates in debates and supports opinions with arguments.	Efficiently organises and assists work and debate of peers. Brings up persuasive arguments for their position in debates, is able to appreciate others' points of views and can be convinced to change their mind if presented with persuasive arguments.

In **CS3 Denmark**, the students handed in a written report based on the follow-up questions in the teaching and learning sequence (Figure 7). During the activity, the teacher gave oral feedback, mainly by posing questions back to the students rather than simply giving them answers. The teachers also used a pre- and post- implementation test (Figure 8) to evaluate the increase in students' understanding of natural selection and evolution after carrying out the inquiry activity. Collected evidence was the students' written reports, interviews with selected students, and video analysis of these students behaviour during the activity and interview with the teacher.

Students in **CS4 Sweden** developed their skills in *planning investigations* and *scientific reasoning* (data entry and observation). The teachers made their judgements based on observations during the activity, listening to student presentations of results, and evaluation of submitted data tables. The teachers conducted purely formative assessment, as informal feedback was provided during the activity and through whole-class class discussions after the activity. The assessment data was not used for summative purposes

3.3 Further developments/extensions

As pointed out in many of the case studies this activity is very time demanding and in all cases was run over several lessons. In one of the case studies it is suggested that the activity could be run in e.g. a volunteer after-school course where the students have the possibility of staying within the activity without having to unpack and pack materials from lesson to lesson and thereby getting a more continuous flow in motivation, knowledge and skills during the activity.

Another extension could be to incorporate the digital simulation more after having run the activity. This would give the possibility for further discussion the impact of the different biological concepts. This discussion could contribute in the development of the skills of debating with peers and *forming coherent arguments*.

INQUIRY AND ASSESSMENT UNIT

POLYMERS

Are all plastics the same?

Mária Ganajová

POLYMERS

ARE ALL PLASTICS THE SAME?

Overview

KEY CONTENT/CONCEPTS

- Determining density of plastic materials by comparing with water density
- Thermal stability and thermal conductivity of plastic materials
- Combustion of plastic materials
- Electrical conductivity of plastic materials

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 (collecting and recording data, problem-solving, argumentation, forming conclusions)
- Scientific literacy (understanding properties of plastics and how they are utilised in everyday life)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials (final summary)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – POLYMERS

The **Polymers** SAILS inquiry and assessment unit focuses on studying properties of plastic materials (density, thermal and electrical conductivity, combustibility) through experimentation. Students develop hypotheses about expected properties based on their previous knowledge and verify them subsequently by experimentation. This unit is recommended for implementation at upper second level and the unit activities are presented as a *guided inquiry*.

Activity A introduces the determination of density of plastic materials by comparing with water density, while Activity B looks at combustion properties of plastic materials. Further activities look at their thermal stability and thermal conductivity (Activity C) and electrical conductivity (Activity D).

This unit can be used for development of many inquiry skills, in particular *developing hypotheses* and *planning investigations*. In addition, students can develop their skills *working collaboratively*, and enhance their *scientific reasoning* and *scientific literacy*. The assessment methods described include teacher observation, use of student artefacts and self-assessment.

This unit was trialled by teachers in Ireland, Poland, Slovakia and Turkey – producing five case studies of implementation (four case studies with students aged 14-16 years and a Turkish case study with pre-service teachers). *Working collaboratively* and *planning investigations* were assessed in most case studies, while the assessment of *developing hypotheses*, *forming coherent arguments* and *scientific reasoning* is also reported. The assessment methods described include classroom dialogue, self-assessment and evaluation of students' worksheets.

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 **Polymers** SAILS inquiry and assessment unit were developed by the FP7 ESTABLISH project[1] and adapted for use in the SAILS project. The unit is designed for implementation with students aged 14-17 years, and develops in four parts (activities A-D), in which students are introduced to properties of plastic. Due to its properties, plastic has a wide range of use in all spheres of human activities. In comparison to traditional materials such as metals, polymers have many advantages such as easy processing, low density and a convenient ratio of utility qualities and price. Students acquire knowledge of plastic from everyday life and they will deepen it in this unit. They will verify different properties of plastic by experiment.

In the unit activities, students have the opportunity to study various polymers, looking at their physical and chemical properties. Then, on the basis of acquired experience, students estimate their practical and industrial utilisation, considering both existing and potential applications. Students should think of polymers occurring in their surroundings and consider the reasons for application of the given polymer based on its properties, for example why PVC was used for a particular toy. Furthermore, they will analyse the properties of plastics using several tests (flame test, polymer density) and propose the applications of polymers tested.

Students will be stimulated to formulate their own questions (*developing hypotheses*) and design adequate experimental settings to perform them (*planning investigations*). Thereafter students develop their *scientific reasoning* and *scientific literacy* through reporting and interpreting their results.

Suggested learning sequence

Before commencing the practical aspects of the lesson, students can discuss the following questions in groups:

- Are plastics useful?
- Which are the properties that have enabled their widespread use?
- Do all plastic materials have the same properties?
- Does plastic undergo changes with time?
- Which properties of plastic would you like to study in more detail?
- Does plastic have negative properties as well as positive properties?

This serves to review prior knowledge and is an opportunity to identify any misconceptions or confusion about the topic. The teacher then introduces the problem for students to investigate, where the experiment chosen to investigate the problem can be proposed by the students or by the teacher. Students learn about the combustibility of plastic materials, their thermal and electric conductivity, reactions with acids, alkalis and solutions of salts. Students should carry out their experiments using different types of plastic – polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC) – and record their findings step by step. These tasks develop their skills in collecting and recording data, data processing, carrying out experiments and *developing* hypotheses. Students discuss their results and observations in groups, for example measuring the conductivity of plastic materials and comparing the findings with that of other substances.

Finally, students prove their ability to apply the knowledge acquired in practice (e.g. electric non-conductivity of plastic materials makes them believe that plastic materials can be used as insulators). They complete a table in which they summarise different properties of the examined plastic materials and next to each plastic they write suggestions of where in everyday life its qualities could be used. The teacher can ask questions to enhance creative thinking in students:

- How can this property be used in practice?
- Where is this plastic material used?
- Have you come across this phenomenon in everyday life?

The **Polymers** SAILS inquiry and assessment unit develops students' skills in searching for information on the internet, *developing hypotheses, planning investigations*, recording data and observations and formulating conclusions. The activities are designed in such a way that students work in groups to discuss, reason and propose solutions to the problems, thus developing their *scientific reasoning* capabilities and skill in *working collaboratively*.

[1] Establish Plastic and plastic waste, http://www.establish-fp7.eu/resources/units/plastic-and-plastic-waste [accessed October 2015]. The teaching and learning activities have also been described in the following publications: a) Plastic and Plastic waste by Hana Čtrnáctová, Mária Ganajová, Peter Šmejkal in *Chemistry: ESTABLISH IBSE Teaching & Learning Units*, vol. 2, Dublin City University, 2014, ISBN 9781873769225, pp. 143-195; b) *Inquiry-based versus project-based method of teaching the topic Plastic* by Petra Lechová, Mária Ganajová, Milena Kristofová in the Book of Abstracts from Science and Mathematics Education Conference: Teaching at the heart of learning, 7-9 June 2012, Dublin (Ireland), 2012, pp. 210-213; c) *Formative assessment of inquiry-based science education of the properties of plastics* by Mária Ganajová, Milena Kristofová; reviewers Martin Bílek, Hana Čtrnáctová, Ryszard Gmoch et al., in *Science and Technology Education for the 21st Century: proceedings of the 9th IOSTE Symposium for Central and Eastern Europe*, 15-17 September 2014, Hradec Králové (Czech Republic), 2014, ISBN 9788074354168, pp. 249-259.

Activity A: Determining density of plastic materials by comparing with water density

Concept focus	Determination of density of selected plastics
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (addressing problem through logic and use of evidence, making comparisons) Scientific literacy (explain phenomena scientifically)
Assessment methods	Classroom dialogue Teacher observation Worksheets

Rationale

In this activity, students evaluate the density of samples of plastics in comparison to the density of water. They develop hypotheses regarding what they expect to observe for the density of each sample, based on physical investigation of the material and using their prior knowledge. Students then plan an investigation to determine the density, and implement their experimental plan. Finally, they evaluate their results and draw conclusions based on their observations.

Suggested lesson sequence

1. The teacher distributes samples of plastics (PE, PP, PS, PVC) to students.
2. Students observe them and develop hypotheses about their density in comparison to water. They record their expectations in their worksheets (Figure 1).
3. Students plan an investigation to determine the exact density of selected plastics.
4. Students are provided with materials to carry out their investigations, and they record their observations in their worksheet.

Possible teacher questions

- What is density? What is the unit of density?
- How can the density of substances be determined?
- What is the density of water?
- Compare the density of water and metal objects.

Activity A: Determining density of plastic materials by comparing with water density.

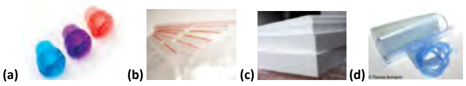


Figure 1. Examples of plastics. (a) polyethylene (PE), (b) polypropylene (PP), (c) polystyrene (PS) and (d) polyvinyl chloride (PVC)

Materials: Glass beaker of 250 cm^3, samples of different plastic materials (PE, PP, PS, PVC)

Procedure: Study the plastic objects and formulate hypotheses about their density in comparison with that of water. Write down your hypotheses.

Hypotheses:...

Propose a procedure by which you can verify and compare the density of the above plastic materials with that of water. You can look up water density in the chemical tables. Describe the procedure in words.

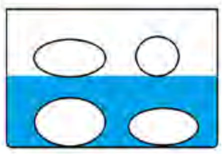
Procedure:...

Problem solving task: Devise a procedure for the exact determination of density of selected plastic materials.

....

Findings:

1. In the picture below, there is the result of the experiment to determine density of different plastic materials of PE, PP, PVC, PS. Write the names of the materials into the bubbles in such a way that it complies with the findings of the experiment.

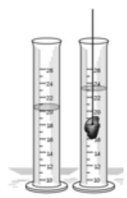


2. Complete the text with the following expressions:

floats on water • falls to the bottom of the beaker • bigger • smaller

The density of water is _______ g/cm^3. Polyethylene _______________, therefore its density is _______________ than that of water. Polystyrene _______________, therefore its density is _______________ than that of water. Polyvinyl chloride _______________, therefore its density is _______________ than that of water. Polypropylene _______________, therefore its density is _______________ than that of water.

3. How can we find out the volume of an irregularly shaped object (sample of plastic)? The picture below can inspire you.



How do we calculate density of the object? ρ = ———

Compare the calculated density with the one in the tables.

Figure 1: Worksheet for Activity A: Determining density of plastic materials

Activity B: Combustion of plastic materials

Concept focus	Examine the properties of individual types of plastics during combustion: Prove the presence of chlorine in PVC by the flame test.
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (addressing problem through logic and use of evidence, making comparisons) Scientific literacy (explain phenomena scientifically)
Assessment methods	Classroom dialogue Teacher observation Worksheets

Rationale

In this activity, students investigate the combustion of plastics. They record their observations during the combustion of each sample, in particular the colour of the flame, smoke production and smell, as well as carry out analysis of the residue after combustion using indicator paper. Finally, they evaluate their results and draw conclusions based on their observations.

Suggested lesson sequence

1. Students engage in a whole-class or small group discussion, based on the question "Are plastics combustible?" Afterwards, students should develop a hypothesis to be investigated.
2. The teacher distributes samples of plastics to the students. Students carry out an experiment, in which they verify the flammability of selected plastics and they describe the combustion of plastics. In particular, students should note the colour of the flame, smoke production and smell during combustion on their worksheet (Figure 2).
3. After combustion, students investigate the character of the residue after burning, using universal indicator paper (acidic or basic).
4. In the next part of the lesson, students perform Beilstein's test for halogens. The teacher must warn students about laboratory safety rules and perform the experiment in a fume hood. Students ignite a copper wire in the flame of burner. With this wire, they take a sample of plastic and put it back into the flame. When halogens are present, the flame turns green (molten copper forms highly volatile cupric halides in presence of halogens, which colour the flame green).
5. Students record their observations in their worksheets.

Activity B: Combustion of plastic materials.

Figure 1. Combustion of a plastic bottle.
Source: http://andyarthur.org/topics/places/country-life/fire/photos-fire-aug-15-2010.html

Materials: burner, scissors, incombustible mat, tongs, copper wire, samples of different plastic materials (PE, PP, PS, PVC)

a) Combustion of plastic materials polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC).
You know from your everyday life that paper and wood will burn down. In groups, discuss properties of plastic materials. Are they combustible? Do they produce any odour when burning? Write down your hypotheses.

Hypotheses:..
....
....
....

Procedure: Carry out an experiment to test combustibility of plastic materials. Observe and describe the changes in phases of the materials during the process of burning, describe the flame – its colour, smoke production, and odour. Identify the character of fumes by means of universal indicator paper at the end of the test.
Describe the experiment in words.
....
....
....
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....
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....
....

Findings:
The findings can be summarised in the following table:

Type of plastic	polyethylene (PE)	polypropylene (PP)	polystyrene (PS)	polyvinyl chloride (PVC)
Burning of plastic				
Odour of plastic during burning				
Belstein's test for halogens				

Match the plastic materials on the left with the properties on the right, e.g. 2A

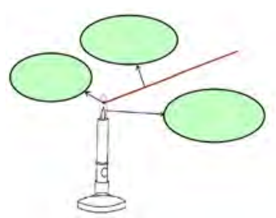
1. Polyethylene
2. Polypropylene
3. Polystyrene
4. Polyvinyl chloride

A drops when burning
B. does not drop when burning
C. burns without soot
D. burns with a yellow flame
E. produces soot when burning
F. burns with a green flame
G. gases smell of paraffin
H. gases have sweet odour
I. gases have acrid odour

b) Beilstein's test for halogens.
Friedrich Konrad Beilstein (1838 – 1906)

Procedure:
Ignite a copper wire in the flame of the burner. Use the wire to take a sample of a plastic and put it again into the flame of the burner. If halogens are present, the flame will become green. The essence of Beilstein's test is the fact that molten copper in the presence of halogens produces easily volatile cupric halides that cause the green colour of a flame.

Describe the following picture to describe the essence of Beilstein's test.



Notes:
The test must be carried out in the presence of fresh air because of the production of poisonous dioxin. Dioxins ($C_{12}H_4Cl_4O_2$) are currently considered the most toxic chemical compounds accumulating in tissues of organisms. They comprise 210 chemical substances of the groups polychlorodibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF).

The test of combustibility of plastic materials requires skill and care. Do not carry out the test of combustibility of PVC plastic in closed rooms!

Disposal of waste:
Collect the used plastic in collecting receptacles.

Findings:
Write your findings into the last line of the table for question a).

Figure 2: Worksheet for Activity B: Combustion of plastic materials

Possible teacher questions

- What is combustion?
- Which substances can burn?
- Will plastics burn? If yes, why?
- What elements are in the compound PVC? Find information about PVC on the internet.
- What is the colour of chlorine?

Activity C: Thermal stability and thermal conductivity of plastic materials

Concept focus	Explore the influence of heat on the behaviour of plastics Comparison of the thermal conductivity of plastics and metals
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (addressing problem through logic and use of evidence, making comparisons) Scientific literacy (explain phenomena scientifically)
Assessment methods	Classroom dialogue Teacher observation Worksheets

Rationale

In this activity, students investigate the thermal properties of plastics, evaluating both stability and conductivity. They compare plastic and metallic materials, and identify the relative advantages and disadvantages of these materials.

Suggested lesson sequence

1. Students carry out an experiment, in which they observe how plastics, metals and other materials behave in boiling water.
2. Students plan and implement an experiment, in which they verify and compare the thermal conductivity of plastics and metals.

Possible teacher questions

- Describe the behaviour of solids in lukewarm and boiling water.
- What substances are soluble in water?
- What are handles on pots made of? Why?
- Why are ladles made of wood, and not plastic or metal?

Activity C: Thermal stability and conductivity of plastic materials.

Part 1: Thermal stability of plastic materials

Thermoplastic (plastomers) are plastic materials that become soft and plastic (soluble by heat) when exposed to heat. Polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC), polystyrene (PS) belong to this group.

Materials: Beaker, burner, matches, cotton, metal, wood, samples of different plastic materials (PE, PP, PS, PVC)

Procedure: Carry out an experiment in which you will observe the change of shape of thermoplastic in boiling water. Compare the change with that of selected natural materials. Put the appropriate plastic, cotton, metal and wood into boiling water and close the container. Take them out of water some minutes later and write your findings into the table.

Findings: Complete the following table with your findings

Materials	Structural change in boiling water	Materials	Structural change in boiling water
Polyethylene (PE)		Cotton	
Polypropylene (PP)		Metal	
Polystyrene (PS)		Wood	
Polyvinyl chloride (PVC)			

1. Which plastic materials used in everyday life cannot be exposed to high temperatures? Justify your answers

....

....

....

2. Have you come across "melting" of a plastic product in everyday life?

....

....

....

Part 2: Thermal conductivity of plastic materials

Imagine the following situation. Your mum was cooking soup in two pots. She stirred the soup in one pot with a metallic ladle and the one in the other pot with a plastic ladle. She left both ladles in the hot soup and left. She returned half an hour later and wanted to take the ladles out of the pots. Something went wrong, however. She got burnt by one of the ladles. Do you know by which one? Carry out an experiment using a beaker, burner, metallic and plastic spoon. Compare chemical composition of metals and plastic materials and based on that prove or contradict your hypothesis on the thermal conductivity of the materials.

Hypotheses:...

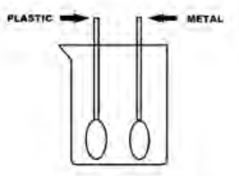
....

....

....

Materials: Beaker, burner, plastic spoon, metallic spoon

Procedure: Devise and carry out an experiment to test thermal conductivity of plastic materials. The picture below may help you with that:



Findings:

State 1 minute later: ____________________

State 2 minutes later: ____________________

State 3 minutes later: ____________________

State 5 minutes later: ____________________

What could you say about thermal conductivity of plastic materials?

Figure 3: Worksheet for Activity C: Thermal stability and conductivity of plastic materials

Activity D: Electrical conductivity of plastic materials

Concept focus	Investigate electrical conductivity of plastics Compare electrical conductivity of plastics with that of other materials Investigate static electricity
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (addressing problem through logic and use of evidence, making comparisons) Scientific literacy (explain phenomena scientifically)
Assessment methods	Classroom dialogue Teacher observation Worksheets Other assessment items (homework task)

Rationale

In this activity, students investigate the electrical properties of plastics, evaluating both stability and conductivity. They compare plastic and metallic materials, and identify the relative advantages and disadvantages of these materials.

Suggested lesson sequence

1. To investigate the electrical conductivity of plastic materials, students first engage in a group discussion about electrical conductivity of plastics and natural substances (cotton, wood, metal). They develop hypotheses about conductivity and they write down their expectations in their worksheets (Figure 4).
2. Students then suggest a suitable experiment to verify electrical conductivity of plastics. They prepare a simple electric circuit, in which they connect the plastic, cotton, metal and wood. They write down the observations into the table in the worksheet.
3. A suggested homework assignment is for students to search for information on the internet about use of plastic materials as electrical conductors/insulators.
4. To investigate static electricity, students again engage in a group discussion, during which they discuss "sparks" caused by static electricity. The aim of this task is to name and explain this phenomenon.
5. Students simulate the creation of static electricity using a plastic spoon, a piece of wool fabric and polystyrene balls. They write down the procedure and the observed results into their worksheet.

Activity C: Thermal stability and conductivity of plastic materials.

Part 1: Thermal stability of plastic materials

Thermoplastic (plastomers) are plastic materials that become soft and plastic (soluble by heat) when exposed to heat. Polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC), polystyrene (PS) belong to this group.

Materials: Beaker, burner, matches, cotton, metal, wood, samples of different plastic materials (PE, PP, PS, PVC)

Procedure: Carry out an experiment in which you will observe the change of shape of thermoplastic in boiling water. Compare the change with that of selected natural materials. Put the appropriate plastic, cotton, metal and wood into boiling water and close the container. Take them out of water some minutes later and write your findings into the table.

Findings: Complete the following table with your findings

Materials	Structural change in boiling water	Materials	Structural change in boiling water
Polyethylene (PE)		Cotton	
Polypropylene (PP)		Metal	
Polystyrene (PS)		Wood	
Polyvinyl chloride (PVC)			

1. Which plastic materials used in everyday life cannot be exposed to high temperatures? Justify your answers

....

....

....

2. Have you come across "melting" of a plastic product in everyday life?

....

....

....

Part 2: Thermal conductivity of plastic materials

Imagine the following situation. Your mum was cooking soup in two pots. She stirred the soup in one pot with a metallic ladle and the one in the other pot with a plastic ladle. She left both ladles in the hot soup and left. She returned half an hour later and wanted to take the ladles out of the pots. Something went wrong, however. She got burnt by one of the ladles. Do you know by which one? Carry out an experiment using a beaker, burner, metallic and plastic spoon. Compare chemical composition of metals and plastic materials and based on that prove or contradict your hypothesis on the thermal conductivity of the materials.

Hypotheses:...

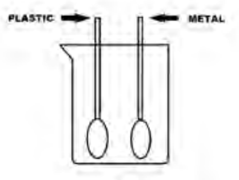
....

....

....

Materials: Beaker, burner, plastic spoon, metallic spoon

Procedure: Devise and carry out an experiment to test thermal conductivity of plastic materials. The picture below may help you with that:



Findings:

State 1 minute later: ___________________

State 2 minutes later: ___________________

State 3 minutes later: ___________________

State 5 minutes later: ___________________

What could you say about thermal conductivity of plastic materials?

Figure 4: Worksheet for Activity D: Electrical conductivity of plastic materials

Possible teacher questions

- Which substances are electrically conductible?
- Why are metals conductive?
- How can we verify conductivity of substances?
- How is static electricity created?

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, forming coherent arguments* and *working collaboratively*. Several assessment opportunities have been identified, and assessment methods include self-assessment, peer-assessment and assessment by the teacher through observation, discussion or evaluation of written materials.

Working collaboratively

In this unit, it is recommended that the teacher divide students into small groups, who work together to carry out inquiry-based activities.

A self-assessment tool utilising "smileys" can be used for evaluation of *working collaboratively* (Table 1). The questionnaire focuses on students' self-assessment of their ability to work in a group, their cooperation with other members and students' mutual cooperation. After completing the activity, students should fill out the questionnaire.

Table 1: Questionnaire for the self-assessment of working collaboratively

	Very good	Good	I have to get better
1. How did I help during group work?			
2. How did the other members of the group help me?			
3. Did I make group work harder?			
4. How did I manage to fulfil the goal of the lesson?			
5. How did other members of the group manage to fulfil the goal of the lesson?			

Students can also engage in self-assessment of their groups' ability to achieve the lesson's goals (Table 2), using a ranking of 1: almost never, 2: rarely, 3: sometimes, 4: often or 5: always. After the lesson, students can complete a group-work questionnaire, assessing their cooperation with other members of the group during discussion, suggesting procedures and forming conclusions.

Table 2: Questionnaire for the self-assessment of working collaboratively (group work)

	Assessment criteria	1	2	3	4	5
Communicative skills, planning investigations	1. We discussed procedures for solving the given tasks together					
	2. I suggested procedures and the others agreed					
	3. The others suggested procedures and I agreed					
Formulation of conclusions	4. We formulated conclusions together					
	5. I explained to the others how to formulate conclusions					
	6. Other classmates explained to me how to formulate conclusions					
Creation of answers to questions	7. We formulated answers together					
	8. I answered questions and justified them					

Scientific literacy (understanding properties of plastics, explaining phenomena scientifically and understanding the role of plastics in everyday life)

To assess students' understanding of the topics that they had been introduced to during the inquiry-based activities, some self-assessment tools are proposed. For example, students can self-assess their understanding of "What have I learnt about density of plastics with inquiry-based method?" on the basis of metacognition. After the lesson, students can fill out a questionnaire, in which they answer the following questions:

- What did we do?
- Why did we do it?
- What have I learnt today?
- How can I use it?
- What questions do I still have about the topic?

The teacher can assess students' understanding through dialogue in class or evaluation of student worksheets. In particular, student answers to the following questions on their worksheets can be used for the assessment of students' understanding of the concepts under investigation:

- What do we prove with Beilstein's test?
- How would you determine the density of plastics?
- What new information have you learnt about plastics?

In a similar self-assessment questionnaire, students can list the following:

- Things I have learned today:
- Things that were interesting:
- Questions that I still have:

Forming coherent arguments (argumentation)

Students should be assessed on the basis of their ability to form coherent arguments. For the assessment, the teacher can consider what types of arguments prevail (guessing, factual or logical ones) and whether the arguments lead to the correct solution.

For example, a three-point scale for the assessment of argumentation can be:

- 1 point: The student cannot give arguments; the student is guessing.
- 2 points: The student tries to give arguments, but makes mistakes.
- 3 points: The student's arguments are scientifically correct.

A selected activity that is suitable for the assessment of *forming coherent arguments* is part 1 of Activity D: Electrical conductivity of plastics, in which students are asked to develop hypotheses about electrical conductivity of plastics, and compare these with their experimental results. A proposed 3-point rubric for the assessment of students' ability to form coherent arguments is shown in Table 3.

Table 3: Rubric for the assessment of forming coherent arguments in part 1 of Activity D

1 point	2 points	3 points
The student guesses the answers and cannot justify why plastics, wood and cotton wool are non-conductive.	The student answers that plastics, wood and cotton wool are non-conductive on the basis of experiences, observations and knowledge from everyday life (wooden electric poles, plastics in electronics, insulators, plastic carpet in chemical laboratories etc.) The student describes the phenomenon and the realised experiment (the connection of substances into the electrical circuit). However, the student cannot scientifically justify it.	The student understands the essence of conductivity of substances and understands the essence of metallic bonding. The student scientifically justifies why metals conduct the electric current – the reason is free motion of electrons – and why plastics do not conduct the electric current – the reason is non-existence of free electrons.

Planning investigations

Several opportunities for evaluation of the skill of *planning investigations* are detailed in the **Polymers** SAILS inquiry and assessment unit. For example, during Activity A: Determining density of plastics by comparing to water density, students are asked to describe a procedure to verify and compare densities of selected plastics (Figure 1). For the assessment of this skill, the teachers may use a 3-level rubric, as shown in Table 4.

Table 4: Rubric for the assessment of planning investigations in Activity A

1 point	2 points	3 points
The student understands the task, but does not know what the density is. S/he does not independently plan the experiment.	The student knows what density is and suggests a procedure to determine density of plastics in comparison to water, but s/he does not scientifically justify the suggested procedure.	The student defines density, suggests a procedure to determine density of plastics in comparison to water and scientifically justifies the suggested procedure.

Developing hypotheses

Several opportunities for evaluation of the skill of *developing hypotheses* are detailed in the unit. For example, during Activity B: Combustion of plastics, students are asked to discuss in groups to form hypotheses about the combustibility of plastics (Figure 2). A suggested rubric for the assessment of this task is shown in Table 5. The three levels of ability can be summarised as:

- 1 point: The student forms an incoherent hypothesis.
- 2 points: The student forms a hypothesis, which can be verified only with the teacher's help.
- 3 points: The student can form a hypothesis, suggests its verification and verifies the hypothesis without help from others.

Table 5: Rubric for the assessment of the skill of developing hypotheses in Activity B

1 point	2 points	3 points
The student assumes that plastics do not burn and does not consider other contexts.	The student assumes that some plastics burn and lists some specific examples. With the teacher's help, the student is able to carry out the experiment and verify the hypothesis.	The student assumes that plastics burn, lists specific examples and suggests an experiment without the help of the teacher, in which s/he takes a small sample of plastic and with tongs s/he inserts the plastic into flame of the burner and therefore verifies the hypothesis.

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in four countries, producing five case studies of its implementation – **CS1 Ireland**, **CS2 Poland**, **CS3 Slovakia**, **CS4 Slovakia** and **CS5 Turkey**. The activities were carried out with lower second level students in four of the case studies (**CS1-4**), while **CS5 Turkey** details implementation with pre-service teachers (aged 20 years) who had limited experience of inquiry. The unit was implemented in full in **CS2 Poland** and **CS5 Turkey**, while **CS1 Ireland** omitted Activity D. In **CS3 Slovakia**, implementation focused on Activity C and **CS4 Slovakia** trialled activities A and B.

Classes were of mixed gender, and students were aged 14 years in **CS1 Ireland**, **CS3 Slovakia** and **CS4 Slovakia**, and aged 16 in **CS2 Poland**. In **CS4 Slovakia**, the class was one that normally achieves lower grades. In all case studies, the students involved had little or limited experience of inquiry learning, with the exception of those in **CS1 Ireland** and **CS5 Turkey**.

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 second level students and pre-service teachers. 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

The teachers working in different contexts modified the implementation of the unit. However the use of a *guided inquiry* approach was predominate in each case study. There was some variation in the level of openness of the guided approaches used at various stages in the activities. For example in **CS1 Ireland** the students first engaged in an *open inquiry* investigation for Activity A, but activities B and C were implemented using a *guided inquiry* approach and worksheets were provided to aid in guiding the process. In all case studies examples of students being led by multiple teacher questions and completion of worksheets were documented.

Implementation

There were variations in how the unit was delivered in the different contexts. In all case studies some whole class discussions were used but the majority of the activities were carried out in small groups. There were some differences recorded in terms of group size and how they were organised (Table 6). The group sizes ranged from pairs to groups of six. In most case studies, groups were formed by the students, but in **CS3 Slovakia** the teacher selected the groups. This arrangement was based on students' previous results and organised so that students with similar results where not in the same group. It was indicated that in **CS4 Slovakia** the group leader was picked on the basis of previous good results, organisation skills and the trust of their peers. In addition, the students chose to further divide themselves based on gender, three of the groups were all female and the remaining group was made up of males. In the other case studies there was a mixture of mixed gender and single sex groupings.

In all case studies, the lessons started with a teacher introduction that then moved on to discussing plastics and their everyday use. This was mostly followed by student discussion leading to teacher instigated *guided inquiry* investigations. In all case studies, the teachers used student worksheets from the units to help guide and record student work and thinking. All teachers used the worksheets as in the unit except in **CS2 Poland** where Activity A was slightly modified as noted in the case study. The teachers implemented the unit over different time periods. In **CS4 Slovakia** and **CS5 Turkey**, one lesson was spent on the inquiry activity. In **CS2 Poland** and **CS3 Slovakia**, two lessons were used and in **CS1 Ireland**, four lessons were allocated to the unit delivery.

Table 6: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Ireland	Activities A-C	Four lessons (240 min in total)	• Groups of 2, 3 or 4 students • Student selected; mixed genders
CS2 Poland	Activities A-D	Two lessons (45 min each)	• Groups of 2-3 students • Student selected; mixed and single sex
CS3 Slovakia	Activity C	Two lessons (60 min each)	• Groups of 5-6 students • Teacher assigned; mixed genders
CS4 Slovakia	Activities A-B	One lesson (60 min)	• Groups of 4 students • Student selected; single sex
CS5 Turkey	Activities A-D	Two lessons (90 min each)	• Groups of 4 students • Student selected; mixed and single sex

Adaptations of the unit

As detailed previously, the unit is divided into four key activities:

- Activity A: Determining density of plastic materials by comparing with water density
- Activity B: Combustion of plastic materials
- Activity C: Thermal stability and thermal conductivity of plastic materials
- Activity D: Electrical conductivity of plastic materials

The teachers had the option to implement the unit in full, or to choose particular activities. In **CS2 Poland** and **CS5 Turkey** the teachers attempted to implement all four activities. In **CS5 Turkey**, the teacher chose to change the order of the activities where Activity B was completed last, so that the students would not have to remain in the classroom after the combustion fumes were released. This activity was also implemented as a teacher demonstration as opposed to a student activity. In **CS2 Poland**, the teacher chose not to conduct the Beilstein's test due to concerns about the emissions, and as a result of time pressures did not get to complete Activity D as intended. Similarly, in **CS1 Ireland**, Activity D was not completed. This teacher also chose to alter the sequence where Activity B was completed last. In **CS3 Slovakia**, the teacher decided to focus solely on Activity C and in **CS4 Slovakia**, the teacher concentrated their implementation on activities A and B.

An interesting adaptation in **CS1 Ireland** was the inclusion of unknown plastic samples. Students were encouraged to gather and bring to class a personal collection of plastics, of which they did not know the plastic composition. These unknown samples were analysed as part of the unit procedures, and compared to the results for the known samples. This adaptation added extra interest for students and allowed them to see the value and use of their experimental data.

3.2 Assessment strategies

Within the five 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. Teacher and student rubrics were used in many of the case studies to help the teacher 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. In some of the case studies the teachers chose to focus on specific skills to assess, for example in **CS3 Slovakia** the teacher solely assessed *working collaboratively* and in **CS2 Poland** the teacher focused on assessing *working collaboratively* and *planning investigations* (including data collection). The inquiry skills and features that were assessed are summarised in Table 7.

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

CS1 Ireland	• Developing hypotheses • Planning investigations (including data collection) • Forming coherent arguments • Working collaboratively • Scientific reasoning (problem-solving, argumentation, forming conclusions) • Scientific literacy (understanding properties of plastics and how they are utilised in everyday life)
CS2 Poland	• Planning investigations (including data collection) • Working collaboratively
CS3 Slovakia	• Working collaboratively
CS4 Slovakia	• Forming coherent arguments • Scientific reasoning (forming conclusions) • Scientific literacy (explain phenomena scientifically, understanding properties of plastics and how they are utilised in everyday life)
CS5 Turkey	• Planning investigations (including data collection) • Developing hypotheses • Working collaboratively

The assessment was carried out at different levels in the various case studies. In some case studies the teacher assessed at a group level e.g. **CS5 Turkey**, and in others the assessment level related to the skill being assessed e.g. in **CS1 Ireland**, the teacher assessed *working collaboratively* at the group level and *scientific literacy* at an individual level. In assessing the skills the teachers used many rubrics and indeed adapted and developed new rubrics to assess the various skills. While they found the rubrics of useful, some of them found them challenging to implement.

The teacher in **CS2 Poland** found it difficult to listen to student discussions while simultaneously trying to record observations on students' performance in *working collaboratively*. Similarly in **CS1 Ireland**, the teacher was unable to observe as much as intended, as he was restricted to helping the students at the fume hood. Interesting, the teacher in **CS5 Turkey** chose not to utilise a rubric during the class, as it was too difficult when trying to engage with the students. He instead focused on using rubrics when evaluating students' reports. In many of the case studies, the teachers used worksheets as assessment data. Interestingly in **CS2 Poland** the teacher noted that the tables that the students were required to complete were a little ambiguous. This meant that they were unclear what to fill out and as a result they were difficult to assess at times. Finally, all of the case studies, with the exception of **CS5 Turkey**, reported using student self-assessment tools as assessment data. The teachers appeared to find these beneficial, for example in **CS3 Slovakia** the teacher noted they would use the strategy again and found it useful for discussing how to improve the quality of group work.

Planning investigations

In **CS1 Ireland**, the teacher used questioning and observation strategies to formatively assess *planning investigations*. The teacher used the planning rubric from the unit to help formulate these questions and make judgements (Table 4). Based on student responses, in certain cases the teacher provided students with additional challenges to help them further demonstrate and develop their skills. In **CS2 Poland**, the assessment of *planning investigations* included evaluation of students' skill in data collection and was assessed through analysis of student worksheets and self-assessment questionnaires. The teacher adapted the proposed rubric for assessing *planning investigations* to include a fourth level (student is able to list the limitations of the method). In addition, the teacher developed a further 4-level rubric for assessing data collection (Table 8).

Table 8: Rubric for the assessment of data collection in CS2 Poland

1 point	2 points	3 points	4 points
Missing or incorrect data in the table	The data for four substances completed correctly in the table	The data for five substances completed correctly in the table An attempt to describe the structure of substance after taking it out of water	All data in the table completed correctly Described by more than one word, and all data that can be observed is completed

In **CS5 Turkey**, the teacher used observations and completed worksheets to assess the students. He also developed his own 3-level rubric, which was used to assess the four skills he focused on – *developing hypotheses, planning investigations* (designing experiment), recording observations and data and *working collaboratively* (discussing with peers) – as shown in Table 9.

Table 9: Rubric for the assessment of inquiry skills in CS5 Turkey

Inquiry skill	Poor	Needs improvement	Good
Developing hypotheses	The hypothesis is not testable or does not include variables	The hypothesis is testable but too general	The hypothesis is testable, contains sufficient detail, variables are evident
Planning investigations (designing experiments)	The suggested procedures are not clear, required materials are not specified clearly	The suggested procedures are clear but lack some details	The suggested procedures are clear and include details about how to make accurate measurements
Recording observations and data	The observations and data are not recorded or recorded in an unclear, untimely, and untidy way	The observations and data are recorded timely with some unclear statements	The observations and data are recorded timely and clearly
Working collaboratively (discussing with peers)	Does not participate in discussions does not express opinions or does not listen to others' opinions	Expresses opinions in a timid way, participates in discussions occasionally	Participates in discussions, listens to others, expresses opinions clearly and respects others

Developing hypotheses

This skill was assessed in both **CS1 Ireland** and **CS5 Turkey**. In both of these case studies the teacher carried out their assessment in-class, based on observation of group discussions and through posing questions to students. In **CS1 Ireland** the teacher solely focused on formative assessment whereas in **CS5 Turkey** the teacher also used the worksheets to assess the students. Rubrics were used to inform the teachers' judgements in both case studies; in **CS1 Ireland** the unit rubric was used (Table 5), whereas in **CS5 Turkey** the teacher used an adapted rubric (Table 9).

Forming coherent arguments

In **CS1 Ireland**, the teacher used observation and questioning to assess the students' skill in *forming coherent arguments* at an individual and group level. The teacher based his judgements on the ideas noted in the rubric provided within the unit, but adapted it for the context of when he assessed the skill (activities B and C). In **CS4 Slovakia**, the teacher assessed students based on their answers to questions in the worksheet. The teacher noted that students were not used to forming arguments and conclusions and that the assessment was useful for finding out about students' understanding.

Working collaboratively

This skill was assessed in all case studies, except **CS4 Slovakia**. In **CS1 Ireland**, the teacher assessed this skill through observation and through analysis of students' completion of the self-assessment tool provided within the unit (Tables 1 and 2). He noted that students added further statements to the self-assessment tool that gave even more information on their skill development. In **CS2 Poland**, the teacher also used observation and analysis of student self-assessment questionnaires as methods for collecting data. An observation card was developed to aid with recording engagement and scientific accuracy during discussions (Table 10). Additionally, the teacher evaluated students' ideas that were noted during discussions. The teacher developed a new 4-level rubric to assess this skill (Table 11). In **CS3 Slovakia** the assessment was focused on student self-assessment and used the questionnaire provided in the unit as the criteria for judgements (Table 1). Finally in **CS5 Turkey**, teacher observation in conjunction with a teacher-developed rubric was employed to judge student skill level (Table 9).

Table 10: Observation card for the assessment of working collaboratively in CS2 Poland

Student name	Number of times s/he took part in the discussion	Did s/he do it herself/himself or was s/he asked to do it?	Factual correctness of statements	S/he provided interesting suggestions	Other notes (the ideas sheet)	Scoring

Table 11: Assessment of working collaboratively in CS2 Poland

1 point	2 points	3 points	4 points
The student rarely takes part in the discussion The student does not listen to the other members of the group The student is not interested in the discussion (e.g. s/he does something else)	The student takes part in the discussion but only at the request of the person moderating the discussion The student's statements are not always factually correct The student listens to other students' statements	The student occasionally takes part in the discussion The student's suggestions are correct The student respects the opinions of other people, but s/he is not always able to notice incorrect (irrational) statements	The student often takes part in the discussion without the teacher's encouragement The student provides suggestions that may be used by the group The student provides correct substantive justifications The student can notice erroneous statements made by other discussion participants and s/he is able to correct them

Scientific reasoning

The skill of *scientific reasoning* (problem-solving) was formatively assessed in **CS1 Ireland** where the teacher used questioning and observations to evaluate the students. The teacher indicated that the assessment was targeted at the individual and group level. The teacher provided the students with task-orientated feedback and used challenging questions to steer and develop students' reasoning. The teacher asked questions such as "Are there any other pieces of equipment that would work as well, better or worse? How could you ensure it is a fair test? What do you think would happen if…?"

Scientific literacy

In **CS1 Ireland** the teacher assessed *scientific literacy* through a final report, after the lesson was completed. The students were asked to write a summary of what they had discovered during the inquiry activities. The question was deliberately open-ended, allowing students to draw on prior knowledge and experiences, as well as newly acquired information from the inquiry activities. The assessment was summative; the teacher used students' final reports as the assessment data. In addition, students used a self-assessment tool to reflect on their learning as a homework exercise, suggested in the unit, in which they were asked to list the following:

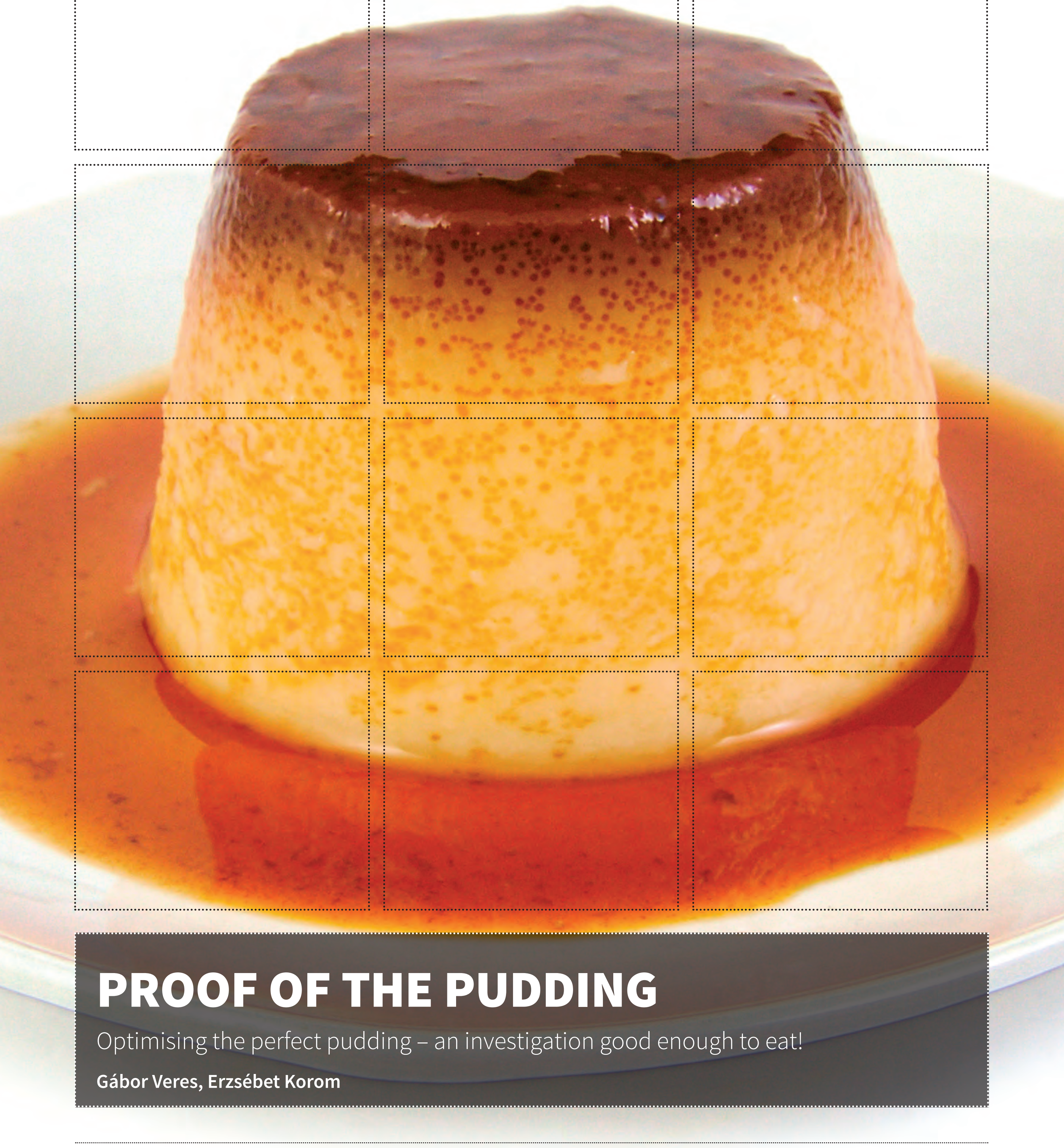
- Things I have learned today
- Things that were interesting
- Questions that I still have

In **CS4 Slovakia** the students completed the metacognition questionnaire from the unit, in which they answered the following:

- What did we do?
- Why did we do it?
- What have I learnt today?
- How can I use it?
- What questions do I still have about the topic?

The teacher used this as assessment data to evaluate their *scientific literacy*. The teacher found this a useful strategy and indicated a desire to continue using it.

INQUIRY AND ASSESSMENT UNIT



PROOF OF THE PUDDING

Optimising the perfect pudding – an investigation good enough to eat!

Gábor Veres, Erzsébet Korom

PROOF OF THE PUDDING

OPTIMISING THE PERFECT PUDDING – AN INVESTIGATION GOOD ENOUGH TO EAT!

Overview

KEY CONTENT/CONCEPTS

- Groups of nutrients
- Colloidal systems
- Health nutrition
- Attitudes towards healthy nutrition and lifestyle

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; argumentation; observation; making comparisons; drawing conclusions; identifying variables; transfer of knowledge from model to real system)
- Scientific literacy (understanding the scientific concepts under investigation)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials (pudding, final report)
- 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 – PROOF OF THE PUDDING

The **Proof of the Pudding** SAILS inquiry and assessment unit outlines an inquiry activity in which the students (plan to) prepare a "good" pudding. This can focus on biological aspects – nutrition, energy content of foods, quality of nutrients, healthy lifestyles – and chemical concepts – groups of organic compounds, colloid systems, and sol gels. The close connection with everyday life and learning based on hands-on activities raise the students' interest. The three activities first introduce the topic, develop into planning and implementing an investigation and end with reflection on new knowledge. These activities can be implemented in two lessons (~90 minutes), but preparation of the pudding takes more time and may be assigned as homework.

Through this activity, students develop their inquiry skills in *planning investigations* by distinguishing alternatives and constructing models, as well as skills in *developing hypotheses, forming coherent arguments* – setting variables, handling quantities, making comparisons, making judgements and decisions, analysing and critiquing experiments – and *working collaboratively*. The assessment opportunities described include student observation, group discussion or presentation and evaluation of student artefacts.

The unit was trialled by teachers in Ireland, Slovakia, Greece and Hungary, with students aged 14-18 years, in five classes in total. The teaching approach in the case studies was generally that of *guided inquiry* (*open inquiry* for one Hungarian class). The assessment of *planning investigations* was carried out in all case studies. In Ireland, Slovakia and Greece, the assessment of *forming coherent arguments* and *working collaboratively* is also described.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The **Proof of the Pudding** SAILS inquiry and assessment unit was developed as part of the FP7 PRIMAS project[1], and adapted for use in the SAILS project by the team at the University of Szeged. In this unit, students are tasked with the preparation of a "good" pudding. The unit comprises three activities; in the first activity the theoretical concepts underlying the activity are introduced, in the second activity students plan an experiment to test their hypotheses of what makes a good pudding and, finally, the students reflect on what has been learned through the activities.

The depth of prior knowledge for implementing the unit depends on the focus of development. For lower second level, the goal for development can be developing research skills. For upper second level students, an inquiry into the colloid state and systems based on knowledge in the field of chemistry and physics, or considering nutrients and the healthy diet is appropriate. It is not a problem if the group does not have prior knowledge of the topic, as searching for information can be a part of the task. However, in all cases, it is important that the students are able to anchor and link the newly acquired information to their existing knowledge and increase their understanding.

Activity A: Preparation of inquiry

Concept focus	Introduction of background theory Features of carbohydrates, proteins, fats and minerals Nutrition
Inquiry skill focus	Developing hypotheses Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (identifying problems, making reasoned decisions) Scientific literacy (explaining scientific concepts)
Assessment methods	Classroom dialogue

Rationale

This activity introduces the concept of the inquiry – preparation of a good pudding – and allows the students to review their prior knowledge and consider the problem for investigation. This warm-up activity raises students' interest and enthusiasm about the task, while also providing a theoretical introduction. This ensures that the students can identify appropriate content knowledge and enables the teacher to introduce complementary conceptual knowledge connected to the task, which is necessary to solve the problem.

Suggested lesson sequence

1. Students divide into groups of 3-4 (can be self-selected or teacher assigned)
2. As a warm-up activity, the teacher offers some supportive questions, such as
   a. What aspects could you use to compare an industrial pudding with a homemade one?
   b. What makes a pudding "good" or "bad"? What positive features or quality problems can you define?
   c. Which pudding can be made more easily?
3. Once these questions have been discussed, the teacher can ask further questions to build on the conceptual knowledge connected to the task, such as:
   a. What kind of basic nutrient groups do you know?
   b. What are the advantages and disadvantages of those nutrient groups?
   c. From which food groups/categories would you choose the main nutrients for a "good" pudding?
4. The teacher then chairs a whole-class discussion to define the problem (how is a good pudding made) and to focus the aim of the inquiry (jelly state or nutrition)

Activity B: Planning investigations & carrying out the inquiry

Concept focus	Model system for the jelly state Planning preparation of a "good" pudding
Inquiry skill focus	Developing hypotheses Planning investigations Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (making reasoned decisions) Scientific literacy (explain colloid state and sol/gel transformation)
Assessment methods	Classroom dialogue Worksheets Student devised materials

[1] Promoting inquiry in mathematics and science education across Europe (PRIMAS), http://www.primas-project.eu [accessed October 2015]; PRIMAS guide of supporting actions for teachers in promoting inquiry-based learning, http://www.primas-project.eu/servlet/supportBinaryFiles?referenceId=2&supportId=1301 [accessed October 2015]

Rationale

In this activity, students plan their investigations, considering both the model system and ingredients for a real pudding.

a) Planning a model system – setting the jelly state

- Simplification of the end product, construction of a model system that enables the formulation of the desired state
- Compiling the experimental model system, carrying out the investigation
- Collecting data using the model, defining the appropriate dilution rate.

This part of the activity encourages comparison and analogical thinking and gets the students to make judgements and decisions. They work towards developing a hypothesis and plan their investigation of the model system (construct models, distinguish alternatives, setting variables). This is an opportunity to work collaboratively and share knowledge.

b) Preparing the end product – planning the ingredients of a real 500 g pudding

In the latter half of this activity, the students further develop their hypotheses and planning. They should look for connections, distinguish between alternatives and make decisions based on the evidence obtained in part a):

- The choice of further ingredients of the planned jelly on the basis of the model system
- Formulating quality aspects and planning the content accordingly
- Preparing the final product

This part of the activity encourages analytical thinking, ranking on the basis of quality aspects, looking for connections, distinguishing alternatives and use of systematic thinking, considering the effect of ingredients and connections between quantity and quality.

Suggested lesson sequence

1. Students divide into groups of 3-4 (can be self-selected or teacher assigned)
2. The teacher asks the students to "Plan an experiment to model the jelly state of a pudding," in which they address each of the following aspects:
    a. Clearly formulate hypotheses related to your question.
    b. Present arguments that support your hypothesis, based on correct and relevant scientific knowledge.
    c. Plan an investigation that allows you to analyse your hypotheses.
    d. Describe in detail all the steps, including the variables you want to study, variables you have to control and all the equipment and materials necessary to its realisation.
3. The teacher may ask some prompt questions while the groups plan their investigations:
    a. Do you know materials of similar states?
    b. How would you define when the pudding is in an appropriate state?
    c. Which compounds could lead to the condensed state of the solution?
    d. What aspects and methods could you find in order to define the differences between the condenser materials?
    e. What is the simplest model you could use for the jelly state of the pudding?
    f. How could you find out the ratio of compounds for the model system?
4. Students discuss their investigation plans with the teacher and if necessary reformulate it, before carrying out their investigation of the model system
5. The teacher now asks the students to consider a real pudding
    a. Define the quality aspects of the end product
    b. Qualify and choose further components
    c. Plan the final content
    d. Prepare the final product, if feasible

Activity C: Evaluation and feedback

Concept focus	Reflection on acquired knowledge
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (drawing conclusions) Scientific literacy (presenting scientific data)
Assessment methods	Classroom dialogue Worksheets Student devised materials

Rationale

In the final part of the unit, each student reflects on what they have learned in carrying out the activity. This is an opportunity to form conclusions, present their final product and argue its merits, thus consolidating their content knowledge. They should exhibit critical thinking, coherent argumentation and reflective thinking.

Suggested lesson sequence

1. Student groups present their results from Activity B: Planning investigations & carrying out the inquiry to the class
2. The teacher chairs a whole-class discussion, considering the results as a whole. The teacher can ask some prompt questions:
    a. What criteria did you use to evaluate the end product?
    b. On what basis can you argue for your product?
    c. What critical arguments could you formulate against other products?
    d. How can you evaluate your own and the groups' work? What were your strengths and weaknesses?

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. The students can be assessed, either as groups or as individuals, through the use of discussion and provision of oral formative feedback during the lesson. During assessment, the teachers can consider student's concept knowledge, inquiry skills and *scientific literacy*. In addition, self- and peer-assessment may be carried out. For each of the activities, some suggested skills for assessment and criteria for success are outlined.

Assessment of skills in Activity A: Preparation of inquiry

Concept knowledge

- Can the students identify the most important features of carbohydrates, proteins, fats, minerals and vitamins?
- Do the students understand the importance of these compounds in the physiology of nutrition

Inquiry skills – planning investigations, forming coherent arguments

- Are students able to distinguish the different ingredients of products?
- Are they able to formulate the main features of the jelly states?
- Are they able to argue their opinions appropriately?

Scientific reasoning and scientific literacy

- Can students distinguish between closed and open thinking?
- Do they display evidence-based reasoning?
- Can they engage in critical thinking (e.g. in connection with media advertisements)?
- Do they demonstrate consumer awareness?

Assessment of skills in Activity B: Planning investigations & carrying out the inquiry

Concept knowledge

- Can the students identify the physical features of the jelly states and the conditions of its formulation?
- Do the students know the chemical structure, origin and solubility of flour, starch and gelatine in water?
- Do students understand the colloid state/system, sol/gel transformation?

Planning investigations

- Are the students able to recognise and justify the role and importance of the model system?
- Are they able to plan a suitable order of dilution?
- Are they able to appropriately observe the results (physical states and changes in the model systems)?

Scientific reasoning and scientific literacy

- Drawing conclusions on the basis of the model system and applying them to the end product
- Distinguishing variables (content, temperature)

Assessment of skills in Activity C: Evaluation and feedback

Forming coherent arguments, scientific reasoning, scientific literacy

- Do students engage in critical thinking while debating with peers?
- Can the students present a coherent argument when assessing their own and others' work?
- Do the students engage in reflective thinking?

2.3 Further developments/extensions

The suggested two lesson periods allocated to cover the unit (approximately 90 minutes) are not sufficient to exploit all the possibilities inherent in the task. Students can manage to finish the preparation of the designed end product with sufficient support, but designing them along multiple design aspects and critical analysis of each other's end products requires more time. Thus, it is suggested that one more period be attached to the unit where possible. This time could be allocated to more detailed analysis (e.g. energy content, composition of nutrients) or a more thorough development of research skills, as well as observation, support and assessment.

3. SYNTHESIS OF CASE STUDIES

The **Proof of the Pudding** SAILS inquiry and assessment unit was trialled in four countries, producing four case studies of its implementation – **CS1 Ireland**, **CS2 Slovakia**, **CS3 Greece** and **CS4 Hungary**. 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 Greece**.

The ages of the students involved in the case studies were 15-16 years old in **CS1 Ireland**, **CS2 Slovakia** and **CS3 Greece**, while in **CS4 Hungary** the unit was trialled with two classes – one science class of 14-15 year olds and one biology class of 17-18 year olds (Table 1). In all case studies the students were of mixed ability; **CS1 Ireland** was the only case study with a single-sex class (all female).

The case studies focus on developing students' skills in *planning investigations, forming coherent arguments* and *working collaboratively*. *Scientific reasoning* capabilities and *scientific literacy* were also assessed, in particular evaluating skill in forming arguments and transferring knowledge from the model to the real system. A wealth of assessment methods are detailed, in particular classroom dialogue, evaluation of student devised materials – the pudding – and peer- or self-assessment.

3.1 Teaching approach

Implementation

The case studies show that, taking the main problem raised by the unit and the teaching recommendations into consideration, the range of applications can be expanded, which is partly due to the multidisciplinary nature of the content. This way, emphasis can be put on either the chemistry or biology parts. The main focus was on biological aspects in **CS3 Greece** and chemical aspects in **CS4 Hungary**. The analysis of the problem can be separated into construction of a model and the actual adaptation of the model. Dealing with the first part of the problem develops theoretical and proportional thinking mostly, whereas the second part helps in practical adaptation and encourages combinative and critical thinking. The latter can be used more effectively with groups of students at a higher age. Each case study places a strong emphasis on eliciting students' preliminary knowledge and focuses them on the task, strengthening their motivation as well as their independent research skills in the process. Each trial was based on group work (or pair work in case of **CS2 Slovakia**), but these were complemented with homework assignments (**CS1 Ireland**) and individual research opportunities as well.

In **CS1 Ireland**, states of matter, gelatine structure and the nature of science were addressed. The teacher introduced the inquiry task question: "What makes a good pudding?" In the planning phase of the investigation the students were guided by a worksheet. Tasks included class and group discussion, ranking and choosing variables, making predictions, and listing required materials and tools. The teacher assigned homework to investigate gelatine and to complete an individual plan for the investigations. In the phase of carrying out the inquiry, the students discussed their homework and they were given a more detailed recipe and noted what variable they were evaluating. They then revised their plan, implemented it and recorded notes during the experiment on their worksheets. The investigated variables were: gelatine type and concentration, liquid type (milk, soya milk, water, and various fruit juices) and temperature of liquid. During the evaluation and feedback phase, students completed presentations and answered teacher questions on their work, listened and took notes and judgements on other groups presentations.

In **CS2 Slovakia**, the teacher carried out a 15-minute discussion with the students on the previous biology lesson, to prepare them for their research. Students answered questions and after the discussion they formed pairs or groups of three members. With the teacher, they agreed on two tasks: (1) to plan and carry out an experiment to test the ratio of liquid and thickeners, and (2) to propose a homemade recipe for 500 g of the pudding. Students were asked to bring ingredients (starch, flour, gelatine or agar of their own choice) for the next lesson, cook their pudding at school and defend its composition in terms of nutritional value.

Table 1: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Ireland	Activities A-C	Three lessons (80 min each)	• Groups of 3 students
CS2 Slovakia	Activities A-C	One double lesson (90 min)	• Groups of 2-3 students • Single-sex groups
CS3 Greece	Activities A-C	Two lessons (1x90 min and 1x45 min)	• Groups of 3-4 students • Self-selected, mixed gender
CS4 Hungary	Activities A-C	Two lessons (45 min each)	• Trialled in two classes • Mixed gender, mixed ability

In **CS3 Greece**, the focus of the implementation was centred on biological aspects, in particular the topics of nutrients and healthy diets. The teacher prepared several worksheets to guide the inquiry and aid in assessment. The students started the lesson with a discussion of the inquiry question posed: “How can we make a really good cheesecake?” As a result, further research questions arose. The teacher observed them while at the same time setting more questions to guide them. The students described several viewpoints of the meaning of “good,” most of them relating to a healthy diet. The students described the main quality criteria of the industrial cheesecake as: cost, ease of manufacture, good taste, and appearance. Students were asked to analyse a given cheesecake recipe from different nutritional perspectives. The teacher gave the students two internet links in order to help students with their calculations and also explained to students how to use these tools. The students had to formulate hypotheses on how they could revise the original pudding recipe in order to increase nutritional value and decrease the energy content of the end product. Students were asked to draw two bar graphs to represent total content of nutrients – one for the original recipe and one for their suggested recipe. The teacher then explained to students the steps required to prepare a pudding and gave them feedback on their questions. During the final lesson, the teacher asked students to present and discuss their experience along with their findings to the class.

The **CS4 Hungary** implementation focused on groups of nutrients, colloidal systems, and healthy nutrition. In terms of IBSE skills, this case study focused on *planning investigations* (including constructing the model system), *developing hypotheses* and *scientific reasoning* (through searching for information, and several types of debating and thinking skills – comparing, classification, connecting, and analogical thinking). During the preparatory phase the students’ prior knowledge was determined and any deficiencies addressed. In this phase, teacher presentation dominated; the students answered the teacher’s questions and tuned in to the task, their interest increased and their conceptual knowledge was stimulated. In the second phase the students had to construct a model system to plan the jelly state of the pudding. They had to understand that before doing the real processes on a large scale it is practical to first test it using a model system to identify what works and how. In the third phase the groups presented their prior ideas and compared them with the features of the end product. Through evaluating each other’s work they gave critical comments.

Adaptations

The unit description is more of a framework than a set script. By interpreting the problem under inquiry and the learning goals correctly, there are many ways and possibilities to adapt it to the local requirements. The case studies describe adaptations and their rationale, which are typically connected to time required for the inquiry (**CS2 Slovakia**), the way it fits into the curriculum (**CS2 Slovakia** and **CS3 Greece**) and the lack of students’ research experience (**CS1 Ireland**). During adaptation, teachers prepared different supporting materials, such as student worksheets (**CS1 Ireland** and **CS3 Greece**) and introductory supporting materials (**CS4 Hungary**). The teachers selected the skills to be assessed based on the specific group’s needs and developmental goals. They identified aspects for assessment and determined skill levels that were correlated with the student activities and could be observed during specific tasks. Specific adaptations were:

- In **CS1 Ireland**, the adaptations were decided upon based on the short time available and students’ limited previous experience of inquiry and science. The teacher followed the general sequence outlined in the unit, but prepared worksheets to aid the lesson to run smoothly.
- In **CS2 Slovakia**, adaptation of the unit was necessary for two consecutive hours (biology and chemistry). It took place in a divided class (16 students) during two lessons (90 minutes). It was also necessary to tailor the topic to fit into the thematic units that are currently taught in biology and chemistry.

Table 2: Inquiry skills identified by teachers in the case studies

CS1 Ireland	• Planning investigations • Forming coherent arguments • Working collaboratively • Scientific reasoning (proportional reasoning)
CS2 Slovakia	• Planning investigations • Forming coherent arguments • Working collaboratively • Scientific reasoning (argumentation)
CS3 Greece	• Developing hypotheses • Planning investigations • Forming coherent arguments • Working collaboratively
CS4 Hungary	• Planning investigations • Scientific reasoning (drawing conclusions, identification of variables, transfer of knowledge from model to real system)

- In **CS3 Greece**, the teacher made adaptations to the suggested activities in order to fit with the State Curriculum and the background of the students at this level. The teacher assembled and provided five worksheets, which gave the students support to start working individually. The teacher could assess the achievements and the skill level based on the answers to the questions on the worksheets. In this trial, emphasis was put on the second part of the unit's task so the students dealt more with biology rather than chemistry topics.
- In **CS4 Hungary**, the plan of the unit was compiled on the basis of non-structured or half-structured problems. The teachers sought to find a topic that was interesting for students and encouraged them to engage in individual research.

Inquiry skills addressed

As outlined in the assessment of activities for inquiry teaching and learning section of the unit, the proposed activities could be used to assess a range of inquiry skills, such as *planning investigations, developing hypotheses, forming coherent arguments* and *working collaboratively*, as well as increasing *scientific reasoning* capabilities and *scientific literacy*. However, within the case studies, the teachers selected different inquiry skills for the assessment, as shown in Table 2.

3.2 Assessment strategies

No assessment tools are provided in the assessment of inquiry teaching and learning section of this unit, and each of the case studies developed their own strategies for evaluation of inquiry skills. In both **CS1 Ireland** and **CS3 Greece**, the teachers used rubrics to assess all of the inquiry skills and *scientific reasoning* and *literacy*. **CS2 Slovakia** and **CS4 Hungary** focused on specific inquiry skills and primarily utilised formative assessment through oral feedback during the lesson. Most case studies included some aspect of peer- or self-assessment, allowing students to engage in and understand the evaluation process.

In **CS1 Ireland**, the assessed skills were *planning investigations, developing hypotheses, working collaboratively, forming coherent*

Table 3: Rubric for planning investigations

Characteristic	I	II	III	IV	Least preferred
Initial idea					Nebulous non-focused
Making judgements or decisions					Indecisive
Developing hypotheses					No cause and effect identified
Working collaboratively					Working in isolation
Ranking					Indecisive
Refining					No refinement

Table 4: Student rubric from CS1 Ireland

Assessed Skill	Emerging	Developing	Consolidating	Extending
Planning an investigation	Goes for an initial idea.	Looks at different options and decides on one, but without careful consideration regarding relevance or testability.	Looks at many different options and ranks them on scientific relevance and testability. Justifies decision through critique or by scientific explanation.	Considers the evidence from trials and others' results or ideas. Refines their plan using results from experiments.
Carrying out an investigation	In need of continuous support and instruction. Using equipment unsafely or inappropriately.	Occasional support needed. Demonstrates the ability to use equipment safely and appropriately.	Able to run experiments confidently and relatively independently, in a well organised and time efficient manner.	Demonstrates the ability to continually run experiments independently and safely without need of assistance.
Recording and analysing results	Limited recording of results, or none.	Results recorded and presented appropriately.	Recording, presenting results appropriately. Some analysis of results demonstrated.	Recording, presenting, and analysing results appropriately, using critical thinking to evaluate and draw valid conclusions.

arguments and critiquing experimental design. The skills were assessed using teacher observation, questioning and review of documentation measured against pre-developed criteria. The teacher prepared a number of rubrics based on Kelly's repertory grids, which detail the characteristics desired for each level of achievement and are assigned a score from 1 to 5 (where 5 is the lowest). An example is shown in Table 3, used in the assessment of *planning investigations*, where the Roman numerals refer to the group number.

In **CS1 Ireland**, the teacher provided a student rubric (Table 4), which was displayed in the classroom during the lesson. This served as a brief instructional guide for the students and provided motivation. Each row was displayed at different points throughout the lesson sequence. When observing the classes the teacher circulated with a flip chart containing the appropriate rubrics and recorded a group grade. Formative assessment was used during the classroom activities (observation, questioning) and summative assessments were used when the teacher reviewed student worksheets and reports.

In **CS2 Slovakia**, the assessed skills were *planning investigations, working collaboratively* and *forming coherent arguments*. The teacher assessed them directly through dialogue with students, on the basis of the students' responses, how they planned the test and also on how they recorded their data. Furthermore they assessed students' *scientific reasoning* (argumentation) during preparation of the recipe for homemade pudding. The teachers watched how the members of groups collaborated as well. During the activity, the teachers provided oral formative feedback. During peer-assessed activities, students listened to their classmates' arguments. Evaluation rubrics were not used, but teachers monitored the way of students referred to their plans and evaluated correctness of the arguments.

In **CS3 Greece**, the assessment was based on teacher observation, student artefacts and peer-assessment. The following skills were assessed in this case study: *developing hypotheses, planning investigations* (testing a hypothesis), *forming coherent arguments, working collaboratively, scientific reasoning* (observing, making comparisons) and *scientific literacy* (understanding the concepts under investigation). In order to assess some of these skills the teacher used rubrics (Table 5). The students answered all the worksheet questions. The teacher asked students to present their answers in class in order to discuss these issues between them and take feedback (formative assessment). In one worksheet, students had to fill in the cells of a table that contained the nutritional value of the recipe ingredients as well as their energy value. The teacher used the students' worksheets and the related rubric in order to assess the skill *developing hypotheses*.

Table 5: Rubric used for the assessment of students' skills in CS3 Greece

Assessed skill	2 Acceptable	1 Needs improvement	0 Poor/NA	Evidence from... (context of assessment)
Forming hypothesis	Yes (no gaps)	Needs improvement (some gaps exist)	No	**Worksheet 2, Activity A** Description: Rewrite the recipe from worksheet 1, replacing as much ingredients as you can in order to reduce fats... Justify your answer.
Testing hypothesis	Yes (no gaps)	Needs improvement (some gaps exist)	No	**Worksheet 4, Step 3** Question: After all, is your recipe suitable for a tasty and well-textured cheesecake? If not could you suggest any changes for a better result?
Observing	The answer is correct (no gaps)	Needs improvement (some gaps exist)	Is irrelevant or incorrect	**Worksheet 4, Step 2** Question 1: Do you believe that the ingredients used instead of these of the initial recipe, affect the final texture of the cheesecake? If yes in which way? Question 2: How does the new cheesecake taste?
Making comparisons	The answer is correct (no gaps)	Needs improvement (some gaps exist)	Is irrelevant or incorrect	**Worksheet 3, Activity C, Compare** Question: Compare the results of the first and second bar graph.
Understanding	The answer is correct (no gaps)	Needs improvement (some gaps exist)	Is irrelevant or incorrect	**Worksheet 5** All questions

The students also carried out peer-assessment on the conclusion section of the worksheet using a rubric for *forming coherent arguments* (Table 6). The teacher discussed the criteria of the rubric with students and after that he asked them to perform the assessment. The teacher also assessed the students' observations and their final conclusions written in their worksheets. The teacher used the underlying question as evidence of how the groups managed to test their hypotheses.

Table 6: Rubric for the peer-assessment of forming coherent arguments in CS3 Greece

	1 – Poor	2 – Needs improvement	3 – Acceptable
Does the answer seem right?	No	Needs improvement (some gaps exist)	Yes (no gaps)
Do they use arguments in order to convince you?	No	Needs improvement (some gaps exist)	Yes (no gaps)
Is the argumentation being put forward complete?	No	Needs improvement (some gaps exist)	Yes (no gaps)
Does the argumentation put forward seem right?	No	Needs improvement (some gaps exist)	Yes (no gaps)

In **CS4 Hungary**, the main tool for formative assessment was the teacher's oral feedback, which was linked to student's activities. Different assessment tools were used with the different student groups. In a lower second level science class, a rubric method was utilised to represent student's achievement in two inquiry skills: *planning investigations* and *scientific reasoning* (Table 7). The assessment rubric linked directly to the lesson and could be used to help the students' further development from the existing skill level. The assessment was based on students' answers that were collected with the questionnaire.

During the preparatory phase the students' prior knowledge could be assessed. In the second phase, the group work was assessed through teacher observation and oral feedback. During the planning of the models, each group was visited by the teacher. In the third phase of the task the groups evaluated each other's work, and they expressed critical comments. Both self- and group assessment took place in this phase. In the fourth and final phase of the task, reflective thinking was evaluated; this focused on students' ability to recall and articulate their own thinking.

Table 7: Rubric used for the assessment of skills in science class in CS4 Hungary

Assessed Skill	Acceptable	Needs improvement	Poor/NA
Planning investigations	You are able to investigate a problem or to solve it and to formulate independent suggestions. On the basis of testing the suggested method you are able to revise your original ideas. You can independently recognise the variables even if they are not identified in the task. You are able to control the independent variable properly.	You can start investigating and solving the problem on the basis of given instructions but you are able to find solutions independently to emerging problems. You are not able to recognise the variables independently but on the basis of given instructions you are able to comprehend and control them.	You can hardly understand the purpose of investigating the problem but you can complete the given instructions. In the case of difficulties you need help. You are not able to recognise the variables independently, you can hardly understand them on the basis of the instruction, you often make mistakes while controlling them.
Scientific reasoning	You are able to draw conclusions on the basis of experimental results examining and measuring variables. You can transfer the results of experiment or model to real problems.	You record the results of the experiments properly but on the basis of them you are not able to draw conclusions. You can be led to the connection between the experiment, the model and real problems, but you are not able to recognise them independently.	You are not able to draw conclusions on the basis of experimental results and observations. You cannot transfer the results of experiment or model to real problems.
Experimenting	You are able to carry out the planned experiment by yourself, to recognise to causality, you can write/draw the process and results of an experiment exactly.	You are able to carry out experiments with somebody's help, mostly you can recognise the causality with somebody's help, you can write/draw the process and results of an experiment with only a few mistakes.	You cannot carry out experiment by yourself at all, you cannot recognise the causalities during the experiments, you are not able to write/draw the process and results of an experiment

INQUIRY AND ASSESSMENT UNIT

SPEED

How fast can I go? How far can I get? How long will it take me to get there?

Paul Black, Gunnar Friege

SPEED

HOW FAST CAN I GO? HOW FAR CAN I GET? HOW LONG WILL IT TAKE ME TO GET THERE?

Overview

KEY CONTENT/CONCEPTS

- Velocity, speed
- Measurement (accuracy of measurements)

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 (collection of scientific data; identifying variables)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Student devised materials (investigation report)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – SPEED

In the **Speed** SAILS inquiry and assessment unit, two activities are presented for introducing the concept of velocity. Kinematics is a topic found on both lower and upper level science curricula across Europe, and forms the basis for many advanced topics in physics. Velocity, and the term speed, are found in everyday life in relation to journeys and are of clear relevance to students. This unit is concerned with the physical concepts of distance, time, the absolute value of velocity and its distinction from the concept of speed. The concept acceleration can also be included. The activities are presented as a *bounded inquiry* and each activity is expected to take one 45-minute lesson.

This unit can be used for development of many inquiry skills, such as *planning investigations, developing hypotheses, forming coherent arguments* and *working collaboratively*. In addition, students develop their *scientific reasoning* and *scientific literacy*. Possible assessment opportunities include teacher observation and classroom dialogue, evaluation of student artefacts and self-assessment.

This unit was trialled by teachers in four countries – Turkey, Ireland, Portugal and Germany – producing four case studies (students aged 12-18; mixed ability and gender). The teaching approach was *bounded inquiry* in all cases. *Planning investigations* was assessed in all case studies, while skill in *forming coherent arguments* and *working collaboratively* were assessed in some case studies, along with *scientific reasoning* and *scientific literacy*. The assessment was primarily formative and achieved through 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 **Speed** SAILS inquiry and assessment unit was developed by the team at King's College London as part of the SAILS project. This unit is committed to an inquiry based learning approach with regard to the physical concepts distance and time, the absolute value of velocity and its distinction from the concept speed. Two activities are proposed; in the first students are asked to consider "How fast can you go?" and investigate the variables of time and distance. In the second activity, students consider the everyday example of their journey from home to school, and identify the distance, time and speeds involved in this journey. Several inquiry skills play a central role in the activities of this unit. The most important skill is *planning investigations*, as well as further skills like setting up the investigation/experiment, *scientific reasoning* (identifying variables, controlling variables), carrying out the investigation and collecting data or analysis of results.

Activity A: How fast can you go?

Concept focus	Introduction to concept of speed
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (identifying variables; forming conclusions)
Assessment methods	Classroom dialogue Student devised materials

Rationale

In this activity, students are introduced to the concept of speed. They plan two investigations, in which the variables change (measurement of time and distance). From these investigations, they are encouraged to consider their results and observations, and develop an understanding of the concept of speed.

Suggested lesson sequence

1. Students can be asked to make measurements to find out:
   a. How long does it take you to walk 5 metres, walking slowly, then walking quickly?
   b. How far you can walk in 5 seconds, walking slowly, then walking quickly?
2. Once they have obtained results, they are asked to interpret them:
   a. How can the time and the distance measurements be related to one another?
   b. What can you work out from the measurements?
3. In each case they could be asked to estimate the possible error in their result and then be asked, "Are your answers to the first two questions above consistent with one another?"

Activity B: Getting to school

Concept focus	Relationship between distance, time and speed
Inquiry skill focus	Planning investigations Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (graphical representation of data) Scientific literacy (interpretation of scientific data)
Assessment methods	Classroom dialogue Student devised materials

Rationale

Activity B encourages students to consider the everyday example of their journey from home to school, and to consider the distance, time and speeds involved in this journey. They build their skills in graphical representation of data by producing graphs to represent this journey by foot or in a car/bus.

Suggested lesson sequence

1. Students are asked to make a measurement of the length of their journey from home to school
   a. How long does your journey take?
   b. What can you calculate from these measurements?
   c. How does your result compare with the answers you worked out in Activity A?
2. Students are then asked to consider how changing mode of transport for the journey from home to school would affect their answers:

   "If you get to school in a car or in a bus, how long would it have taken you to walk…"
   a. at a comfortable speed, and
   b. at your fastest speed

   A similar question can be asked for those who come by bicycle, whilst those who walk can be asked to estimate how long it might take by car.
3. For any one of the results from parts 1 or 2 above, draw a graph of speed against time,
   a. Assuming uniform speed
   b. Representing what really happens

   What would a pair of graphs, one for walking and one for travelling by car or bus, have in common if both were drawn for the same journey? What does the area under each of these graphs represent?
4. For the graphs used in part 3, draw the corresponding pair of graphs of distance against time.

Rationale and implementation of unit in full

One possible way to implement this unit in full is to focus on a specific set of choices, as follows:

(a) Start with Activity A – students may be asked to start by working individually to plan to measure how far they can walk in 5 seconds, and how long it takes them to walk 5 metres. They might be asked to write down their plans. Then they do these two tasks, still working individually, and should record their two measurements and write about how they think the two are related. These records are indicators of *developing hypotheses* (identifying questions), *planning investigations* (and carrying out research) and *forming coherent arguments* (evaluating conclusions).

(b) Then the students are asked to work in small groups of 3-4 students each, to compare their methods and their results. In this phase, the skill *working collaboratively* (providing feedback to one another) may be developed. Each group should produce a report, dealing with several questions – did they think both results in (a) measured the speed of walking, how close were their different results for speeds, were the differences real or merely due to measurement inaccuracy? These reports can provide evidence of negotiation and achieving agreements.

(c) The next task could be chosen from Activity B, whereby each group can start by working together to produce a plan and organise mutual collaboration in obtaining measurements. A possible choice here would be to consider the issues of speeding up and slowing down. A first challenge might be to measure one another's average speed of running over 50 metres and over 100 metres, from a standing start. Would the latter be slower, because you get tired, or faster because a smaller proportion of the time is spent in accelerating to one's top to speed at the beginning? Students can discuss what their results show, and consider whether other results could help check their ideas. Then they choose instruments and collaborate in collecting data. In these activities, students might demonstrate skills in *planning investigations, forming coherent arguments* and *working collaboratively*.

A further challenge would be to measure more directly the time spent in speeding up, and then the time spent at top speed, and/or one's maximum speed after accelerating: these tasks would call for more careful planning and perhaps better instrumentation. Measurements could then be represented on a distance-time graph, leading to work on other related graphs. The reports that students might prepare during such activities could give evidence of planning investigations and carrying out research, and of forming coherent arguments (linking aims to criteria for success and evaluating and supporting conclusions).

For more experienced classes, another implementation could start with Activity B or use more challenging activities in the case of extensive pre-knowledge and skills.

2.2 Assessment of activities for inquiry teaching & learning

Assessment considerations

The sequence of activities described herein are one possible implementation. A teacher using this sequence might be interested in assessing each student's ability to tackle such problems on their own – hence task (a) with the requirement to produce individual records. Then collaboration is introduced for parts (b) and (c). However, in each of these activities, students might be asked to start by working on their own to think about and write down ideas about how to tackle the task, and then exchange these with one another in their group so that in they can build on these ideas to make the group's best plan.

In making these choices, the teacher may be influenced by several factors, e.g. which are more likely to interest the class, for which are adequate facilities available, which will link to other learning priorities, and which will make best use of the time available. A different type of priority will be to choose the activity that the teacher judges will create the best opportunity to develop the students' experience of inquiry, and to help ensure that it is an enjoyable and valuable experience for them.

Assessment opportunities

The **Speed** SAILS inquiry and assessment unit mainly addresses the inquiry skills *planning investigations* (including collection and interpretation of data and identifying variables) and *working collaboratively*. These skills could be seen as the points to be emphasised in the formative feedback to students as they work on the inquiry: such feedback can arise in oral discussion as students are doing the tasks, and as feedback on written reports if students are asked to produce written accounts of their work.

Student artefacts could include a report at the end by each individual, or in the form of an "activity diary" which would include, for example, reports of interim plans and ideas. For example, interim reports, such as those produced in (a), might form part of such a diary. Another part of the diary could be written at the end, by asking each student to describe what they had learnt from the experience, thus encouraging reflection and self-assessment. The various possibilities should be foreseen in planning the activity, as opportunities for both formative and summative assessment of the evidence of each student's learning.

Sample assessment tools

The materials provided to the teachers trialling this unit did not feature specific assessment tools. However, following implementation several assessment opportunities were identified for which rubrics may be used. The skill of *planning investigations* has been highlighted as a key skill that may be developed through implementation of this unit. The assessment may look at students' ability to devise an experiment to address a particular research question, implementation of the suggested procedure and interpretation of results, as detailed in Table 1. *Planning investigations* involves identifying appropriate equipment and detailing a functional design, which when implemented provides results that can be used for testing of a hypothesis. Additional skills that can be developed while planning and implementing investigations include learning to use scientific equipment, record data and interpret results to form conclusions based on evidence.

Table 1: Proposed rubric for the assessment of planning investigations

Inquiry skill	1	2	3
Plan an investigation to test a prediction	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.
Design and conduct 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 may handle 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 may be incomplete or lack in 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.
Interpret results and draw 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.

2.3 Further developments/extensions

The **Speed** SAILS inquiry and assessment unit was originally developed to consist of eight activities (activities A-H), however only activities A and B were implemented in the case studies, as these are most suited for beginning any inquiry about speed. In the following activities (C-H), further investigations are described. They can be used directly after activities A and B or independently in the case of an advanced physics class.

Activity C: Getting away from it all

Concept focus	Speed Free-fall under gravity
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning
Assessment methods	Classroom dialogue Student devised materials

Rationale

In this activity, students consider an airplane travelling from London to New York. They prepare a graphical representation of this journey, comparing speed and time. From this, they are encouraged to consider the values for acceleration at various stages of the journey. Finally, this can be an opportunity to discuss acceleration due to gravity (free fall).

Suggested lesson sequence

1. Find out some data to enable you to draw a graph of speed against time for an airplane journey from London to New York. Your graph should represent the journey as accurately as possible.
2. Compare the values of acceleration that you could estimate from your graphs for Activity B – how do these values compare with the acceleration for free fall under gravity?

Activity D: Fast and slow speeds

Concept focus	Speed
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning
Assessment methods	Classroom dialogue Student devised materials

Rationale

In this activity, students consider extremes of motion – particularly some motion that is so slow that it may not be noticeable.

Suggested lesson sequence

1. List some very slow speeds – you must give an approximate numerical value to every item listed. What is the slowest speed you, or others, can think of? Similarly, list some very fast speeds – again with numerical values. What is the fastest speed you can think of?
2. Some movements can be so slow that with a quick look you may not notice that there is any movement at all. Can you think of some examples? (Speed of growth of different plants, an object just heavy/dense enough to sink in a very viscous fluid, rate of growth of your own hair or finger-nails)
3. A possible experiment here is to place a drop of a very viscous liquid (a thick honey or syrup might be suitable) on the flat part of a plate, then slowly tip up the plate until the liquid just starts to move. Then the plate can be supported at an angle just below the angle at which there is perceptible movement, and left for some time to determine whether movement has occurred, and if so to measure the speed.

Activity E: Speeding up and slowing down

Concept focus	Speed and acceleration
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning
Assessment methods	Classroom dialogue Student devised materials

Rationale

In this activity, students are provided with graphs showing a velocity-time graph for a journey. They are asked to draw the corresponding acceleration-time graph. This can be a challenging task, as students must consider acceleration and deceleration and may need to convert units. Teacher questions (hints) are important for ensuring success of this inquiry activity.

Suggested lesson sequence

1. Provide students with a velocity-time graph for a driver's journey and ask them to draw the acceleration-time graph for this journey.
2. The area under the line in the velocity time graph represents the distance travelled. What does the area under the acceleration-time graph represent?

Suggestions for teachers

- Label the first graph in mph against minutes and then students have to choose a scale for acceleration, e.g. feet/sec ^{2}.
- Provide a graph with two periods of acceleration and one for the final deceleration, with all three having different gradients, and with stretches of uniform speed in-between. Then students have to distinguish the positive and negative accelerations. The first graph should be straight lines only, so all accelerations are uniform, then the second is a set of rectangular blocks, and if the journey ends with the driver having stopped, the net area will be zero. The question can be made easier by giving hints about these issues.

Activity F: Quick on the draw

Concept focus	Speed and reaction time Free-fall under gravity
Inquiry skill focus	Planning investigations
Scientific reasoning and literacy	Scientific reasoning Scientific literacy (real world context of velocity and speed)
Assessment methods	Classroom dialogue Student devised materials

Rationale

This activity uses the context of a cowboy drawing his gun to introduce the concept of reaction time. An experiment to investigate students' reaction times utilises free fall under gravity, thus is an opportunity to discuss this concept

Suggested lesson sequence

1. In Western films, the cowboy who can react the fastest wins the duel, but reaction times matter in many more everyday situations. So how can you measure your own reaction time? Can you think of a way to measure your own, or one another's reaction time, given that typical values are around 0.2 seconds?

2. After their group discussion, students are asked to work in pairs to measure their reaction times. One student holds a one-metre stick vertically; the other stands with her/his lower arms horizontal so that the hands hold the bottom end of the sick; then that student opens her/his grasp a little so that the stick can fall freely between the hands.

3. Then, without giving any warning, the first student lets go of the stick: the second student grasps the stick as quickly as she/he can to stop it falling, but because of the delay due to that student's reaction time, the stick will have fallen part of the way towards the floor. The students have to measure the distance fallen i.e. the distance from the bottom end of the stick to the point at which the hands grasped it to stop it falling. They can then be asked to work out how long it took to fall this distance – which gives the reaction time. Students will need to have the value of the acceleration for free fall under gravity: alternatively, the teacher may give them a table of values of distance against time for free fall, for example over 15 cm to 35 cm fall.

4. This work can be followed up by asking students to estimate how far they would travel on a bicycle between noticing a danger ahead and starting to swerve or apply the brakes: the same question can be asked about a car travelling at the speed limit on a busy town road.

Activity G: Too many g's ain't good for you

Concept focus	Speed and deceleration
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (searching for information) Scientific literacy (understanding g-forces)
Assessment methods	Classroom dialogue Student devised materials

Rationale

In this activity, students are urged to consider the impact of rapid deceleration on the body. This is an opportunity for them to search for scientific information and form coherent arguments. They will develop their *scientific reasoning* skills and *scientific literacy* by considering g-forces.

Suggested lesson sequence

An inventor claims that he has found a way to bring to rest a car travelling at 60 mph within half a second. Some say this can be dangerous, for even if his body does not hit anything, the driver's internal organs can be damaged by the rapid deceleration involved. Is this a valid objection? To find out, use the web to find out about deceleration dangers for pilots and astronauts.

Activity H: Straight or curved?

Concept focus	Distinguishing speed and velocity
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning Scientific literacy
Assessment methods	Classroom dialogue Student devised materials

Rationale

This activity serves as a summary of activities A-G, and offers the students an opportunity to consolidate their newly acquired knowledge. They can review concepts introduced, and apply them in a new context.

Suggested lesson sequence

1. There is a distinction between velocity, which is the rate of travel in a straight line, and speed, which is total distance travelled whether or not it was in a straight line. Which of your measurements or estimates in the above activities were about velocity, and which were about speed?

2. A driver travels from home to his friend's house and is accused of breaking the speed limit: he denies this, saying that he did not go the long way round, but went by a direct route. Is this a good argument?

3. The moon goes round the earth at an approximately constant speed, but not at a constant velocity. What difference would it make if it went at a constant velocity? Why doesn't it do so?

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in four countries, producing four case studies of its implementation – **CS1 Turkey**, **CS2 Ireland**, **CS3 Portugal** and **CS4 Germany**. All 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 (except in **CS3 Portugal**).

CS1 Turkey, **CS2 Ireland** and **CS4 Germany** involved lower second level students: **CS1 Turkey** was a class of 24 students working in groups of four, **CS2 Ireland** was a class of 24 students, who worked individually and then in pairs and **CS4 Germany** involved a mixed gender class of 30 students working in groups of three or four. **CS1 Turkey**, **CS2 Ireland** and **CS4 Germany** describe single lessons of 45 minutes, 80 minutes and 120 minutes duration, respectively. The students in **CS3 Portugal** were a class of 16 mixed ability and mixed gender upper second level students aged 15-18 years old, working in groups of two or three, and the case study describes two consecutive lessons for a total of 225 minutes.

The key skill identified for the assessment in all case studies was *planning investigations*, including implementation of the planned experiments and *scientific reasoning* associated with planning. This was achieved through classroom dialogue and teacher observation, as well as evaluation of student artefacts.

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. Students completed the activities working individually or in small groups (see Table 2) and peer discussion was encouraged and facilitated.

Implementation

In each of the case studies, distance and time served as an introduction to the concept of speed; students were not given prior formal teaching on these topics. With the exception of **CS3 Portugal**, the students worked in groups throughout the lessons with a group size between 2 and 3 students. In all cases the skill of *planning investigations* was addressed. Even though the teacher posed the questions to be investigated, students raised sub-questions, which often served for them to identify variables. In each case the students conducted their own investigations based on their plans. All teachers engaged in on-the-fly assessment and gave both oral and written feedback. Three of the teachers used rubrics to help them assess (**CS1 Turkey**, **CS2 Ireland** and **CS3 Portugal**). On-the-fly assessment was used mostly for formative group assessment. The teachers in **CS2 Ireland** and **CS3 Portugal** used individual summative assessment but with formative purposes.

Adaptations of the unit

Each of these implementations and their case studies have distinguishing characteristics. **CS1 Turkey** used a ready-made worksheet to make it easier for the students and teachers to go from cookbook experiments to inquiry-focused activities. In **CS2 Ireland** the teacher explicitly commented how both on-the-fly assessment and evaluation of the written evidence allowed her to differentiate and give more guidance to students where required (in this example, a student with dyspraxia). In **CS3 Portugal** the teacher introduced a narrative showing the speed concept and relating it to moving slowly or quickly. In the activity students considered trips by car and on foot, from home to school. In **CS4 Germany**, students were given a general introduction to movement (excluding circular motion) through watching a video of the cartoon Asterix, which involved lots of different movements including 3D. This led to a discussion concerning the word velocity conceptually (but not as a quantity) afterwards. The teacher then posed the questions suggested in the unit, asking students to design their own plans and experiments. **CS4 Germany** also emphasised how students documented their investigations using a prescribed protocol; they were given feedback on the quality of their investigations and their documentation. The inquiry skills identified by the teachers in each case study are detailed in Table 3.

Table 2: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Turkey	Activity A	One lesson (45 min)	• Groups of 4 students (24 students in total) • Mixed ability and gender
CS2 Ireland	Activity A	One lesson (80 min)	• Worked individually and in pairs (24 students in total) • Mixed ability and gender
CS3 Portugal	Activity B	Two lessons (225 min)	• Groups of 3-4 students (16 students in total) • Mixed ability and gender (10 boys, 6 girls)
CS4 Germany	Activity A	One lesson (120 min)	• Groups of 3-4 students (30 students in total) • Self-selected; mixed ability and gender

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

CS1 Turkey	• Planning investigations (including implementation) • Working collaboratively • Scientific reasoning (identifying variables; collecting and interpreting data)
CS2 Ireland	• Planning investigations (including implementation) • Working collaboratively • Developing hypotheses (generating questions) • Scientific reasoning (identifying variables)
CS3 Portugal	• Planning investigations (including implementation) • Scientific reasoning (identification of variables)
CS4 Germany	• Planning investigations (including implementation) • Scientific reasoning (identification of variables)

3.2 Assessment strategies

Within the four case studies, the inquiry skill of *planning investigations* was the primary skill assessed. Each case study considered both planning and implementation as part of this skill. In addition, *forming coherent arguments, developing hypotheses* and *working collaboratively* were assessed in different ways, with some teachers using the proposed rubrics. Additionally the content knowledge and evidence of *scientific reasoning* and *scientific literacy* were assessed through the student worksheets and verbal responses.

In **CS1 Turkey** the teacher used a 4-level rubric for the assessment of *planning investigations, scientific reasoning* (identifying variables; collecting and interpreting data) and *working collaboratively* (teamwork). The teacher gave feedback according to the levels specified in the rubric (Table 4). For the assessment, the teacher used teacher observation in class, including providing prompt questions and feedback. The teacher found that it was easier to assess groups, rather than individual students, and suggests that two rubrics may be prepared – one for the assessment of groups and another for individual assessment.

Table 4: Teacher rubric for the assessment of inquiry skills in CS1 Turkey

Inquiry skill	Emerging	Developing	Consolidating	Extending
Planning investigations	Research plan to be feasible. *(Are their plans investigable?)*	Choose materials according to plan. *(Students group choose accurate materials to conduct their plan)*	Relationship between plan and variables. *(Plans whether have some variables or not)*	Alternative plan for possible problem when it may arise research process. *(We can change other variables if our plan doesn't work)*
Identifying variables	Variables mentioned.	Relevant variables mentioned (speed, time, distance etc.).	Relationship between variables and measurements.	Relates to control of variables. *(They should consider some variables that are controls)*
Collecting and interpreting data	Collect some findings at the end of the implementation process (they don't collect data). *(e.g., "We find something about our research")*	Collect data. *(Data must relate to research question or variables)*	Relationship between data and research question. *(Students should explain that relation between data and research question)*	Use data and interpret to answer research question. *(Their interpretations must base on evidence/ data)*
Working collaboratively (teamwork)	Work individually in groups.	Work together in planning an investigation.	Work together in both planning and conducting an investigation.	Work together in planning, conducting, and evaluating an investigation.

In **CS2 Ireland**, the teacher observed student discussions throughout the class period and assessed three aspects of skill development: (1) engagement with task, (2) experimental plan and design and (3) level of relevant questioning and identification of variables. Afterwards, the teacher assessed and graded written plans for the experiment with a view to establishing a baseline for future inquiry activities. The teacher wished to give the students some summative assessment as well as formative assessment (feedback in class and on student worksheets). A five point scale was used for evaluation of each of the three criteria, represented as 5 = excellent, 4 = very good, 3 = good, 2 = fair, 1 = struggling, the criteria for which are summarised in Table 5. In addition, the teacher asked students how they felt about the experience and whether they felt it would help them planning future experiments, which allowed her to gauge the level of engagement with the tasks.

Table 5: Assessment criteria used in CS2 Ireland

Marks	Criteria
13-15 Excellent	Student has demonstrated excellent knowledge of experimental design, planning and sequencing; has shown the ability to pre-empt and solve potential problems in experimental planning; shows exceptional logic and problem solving skills
10-12 Very good	Student has demonstrated a very good knowledge of experimental design, planning and sequencing; has shown the ability to question decisions made in experimental design however could improve by exploring sequencing more carefully; shows very good problem solving skills.
8-9 Good	Student has demonstrated a good knowledge of experimental design and planning, however student must think more carefully about the sequence of steps to be taken in experimental planning. Student also needs to think more about problems that could occur in the experiment they designed and how they would solve these problems.
6-7 Fair	Student while designing and planning experiment gave a list of apparatus and suggested some steps for an experiment. Student needs to think more carefully about how the experiment is planned by asking questions and answering these same questions.
< 6 Struggling	Student showed little to no engagement with task.

In **CS3 Portugal**, the teacher prepared a rubric for the assessment of the skill of *planning investigations*, that aimed to collect evidence concerning identifying the problem, identifying variables, developing a procedure, carrying out investigations and analysing data (Table 6). Thus, this rubric assessed both *planning investigations* and *scientific reasoning*. Evidence of how the teacher used the rubric to assess the students' written artefacts is also detailed in this case study.

In **CS4 Germany**, *planning investigations* and *scientific reasoning* were assessed through teacher observation and questioning during the lesson. The teacher then collected student records for further evaluation after class. In this case study, the teacher placed emphasis on how students documented their investigations using a prescribed protocol, and they were given feedback on the quality of their investigations and their documentation. The teacher did not use rubrics for the assessment, although she expressed interest in using them for future implementations.

Table 6: Rubric for the assessment of planning investigations in CS3 Portugal

Objective	3	2	1
Identify the problem	Identifies the proposed problem with precision	Partially/hardly identifies the problem	Does not identify the proposed problem
Set objectives	Defines coherent objectives according to the identified problem	Defines just some objectives which are coherent with the identified problem	Does not define coherent objectives according to the identified problem
Define operational variables	Operationally defines the variables under study	Defines with difficulty the variables under study	Does not operationally define the variables under study
Devise procedure	Properly prepares a procedure/ strategy that allows for manipulation and control of the variables under study	Prepares a procedure/ strategy that hardly allows for manipulation and control of the variables under study	Prepares a procedure/strategy that does not allow for manipulation and control of the variables under study
Control variables	Outlines a procedure managing a correct control of the variables under study	Outlines a procedure that hinders the correct control of the variables under study	The outlined procedure does not allow the correct control of the variables
Measure data	Correctly registers all data and measurements made	Inconsistently registers all data and measurements made	Inaccurately registers data and measurements
Select appropriate resource	Selects appropriate resources for the problem under study	Selects just a few appropriate resources for the study of the problem	Cannot make an appropriate selection of resources

INQUIRY AND ASSESSMENT UNIT

UP THERE... HOW IS IT?

How to live on the International Space Station?

Vanessa de Andrade, Mónica Baptista, Cláudia Faria, Cláudia Gonçalves, Cecília Galvão

UP THERE... HOW IS IT?

HOW TO LIVE ON THE INTERNATIONAL SPACE STATION?

Overview

KEY CONTENT/CONCEPTS

- Gravity
- The study of gravity in the International Space Station
- Effect of microgravity on everyday activities
- Impact of scientific and technological development in society

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 (choosing appropriate experiment for evaluation; argumentation)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Worksheets
- Student devised materials (investigation report)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – UP THERE... HOW IS IT?

The **Up There... how is it?** SAILS inquiry and assessment unit aids students to learn about the concept of gravity and offers an opportunity to learn about the International Space Station (ISS); understanding its impact on the scientific, technological development and society. In this unit, students are encouraged to develop interest and curiosity about space exploration. While recommended for upper level physics students, the activities could be explored with different disciplinary areas, namely chemistry, biology and geology, or adapted for implementation at lower second level.

The four activities serve to consolidate prior knowledge, before introducing the concept of microgravity and how it might impact on everyday activities. Students plan an experiment that can be conducted in a microgravity environment and end the lesson with a reflection on what has been learned and achieved. These activities can be carried out in a sequence of lessons, which would require about three lesson periods (ideally one 45 min and one 90 min lesson). Through this activity series, students are provided the opportunity to develop inquiry skills such as *planning Investigations, developing hypotheses* and *working collaboratively*, as well as progressing their *scientific literacy* and *scientific reasoning* capabilities. Possible assessment opportunities include student observation, group discussion or presentation and evaluation of student artefacts.

This unit was trialled by teachers in Portugal, Slovakia and Sweden, with students aged 13-16 years (8 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* (Portugal), *scientific reasoning* (observation skills, Slovakia) and *forming coherent arguments* (Sweden).

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The unit **Up there... how is it?** was set up under the 1st SAILS Portuguese workshop for teachers: "Why is there so much talk about INQUIRY across Europe? A proposal to work with the science curriculum in the classroom" (May 2013). It was proposed by Vanessa de Andrade and adapted to the SAILS inquiry and assessment unit structure. The unit develops in four parts (activities A-D); Activity A is a preliminary activity to aid the students' learning about the concept of gravity, while Activity B introduces the activities of the ISS. Activity C allows the students to understand the impact of the ISS in scientific, technological and societal development, and apply their prior learning in a new situation. In the final activity, each student reflects on what he has learned in carrying out the activities, seeking to develop interest and curiosity about space exploration.

Activity A: Up there... how is it?

Concept focus	Gravity
Inquiry skill focus	Working collaboratively
Scientific reasoning and literacy	Scientific literacy (understand how microgravity impacts everyday activities)
Assessment methods	Classroom dialogue Worksheets

Rationale

In this activity, students are invited to read about the International Space Station (ISS). After this, they are urged to imagine what it would be like to carry out some of their routine activities in a microgravity environment and to discuss their individual ideas with the class. This activity is intended to assess students' prior knowledge on the concept of gravity.

Suggested lesson sequence

1. Students are invited to read about the ISS (student document, Figure 1).
2. The teacher poses questions to encourage the students to consider how microgravity conditions would affect their daily routine.
3. Students first discuss their ideas in small groups, then participate in a class discussion of their ideas. They are assigned the following tasks:
   a. Pick one of your daily routines and imagine accomplishing it on board of the ISS. Discuss in groups the following thoughts: What would be different? Why? How could you perform this routine?
   b. Share and debate your thoughts with the rest of the class.

Currently, astronauts from around the world are sent into space. Some astronauts remain in space for months on special spaceships called space stations. There have been some other stations, but currently the International Space Station, ISS, is in service. It circles our orbit about 16 times per day at an altitude of 400 km.

The ISS is an international collaboration involving the joint effort of 16 countries. This structure is the largest and most complex space vehicle ever built and due to its conditions of microgravity, it is a special environment to investigate the effects of a prolonged stay in space. The possibility of controlling the variable gravity creates unimaginable opportunities for research, making the ISS a vital framework for developing and testing new technologies, and for making decisions about long-range space exploration.

There are astronauts' teams – including many scientists – who alternately in periods of about five months, live, work, eat and sleep on the ISS. Their tasks are, for example, doing the maintenance of the station and conducting investigations. Given the environment of microgravity, astronauts incorporating ISS expeditions have to readjust all their daily routines such as eating, sleeping or going to the bathroom, to a new reality; this certainly poses many challenges.

Figure 1: Student document. Adapted from: http://www.nasa.gov/ retrieved on 20th July 2013

Activity B: Lets explore...

Concept focus	Gravity Everyday life on the ISS
Inquiry skill focus	Working collaboratively
Scientific reasoning and literacy	Scientific literacy (understand how microgravity impacts everyday activities)
Assessment methods	Classroom dialogue Worksheets

Rationale

In this activity, students watch a video about everyday life on the ISS. This seeks to aid the students to articulate prior knowledge with new information. Finally, the teacher presents a summary of new concepts and ideas, to ensure that new knowledge is not misinterpreted.

Suggested Lesson Sequence

Let's explore... the ISS along with the commander of Expedition 33, Suni Williams.

1. The students watch a video about everyday life on the ISS. http://www.nasa.gov/mission_pages/station/main/suni_iss_tour.html [accessed October 2015]
2. The teacher offers prompt questions, asking the students to consider how their previous ideas (activity A) match with observations in the video
   a. What have you observed in the ISS that matches with your initial idea? Explain.
   b. What surprised you most during the visit to the ISS?
3. Students share and debate their thoughts with the rest of the class
4. The teacher summarises the key concepts and ideas at the end of the discussion
5. Students are asked to write a question they would like to ask Commander Suni Williams about his experience on board of the ISS.

Activity C: Going further...

Concept focus	Gravity Working in a microgravity environment
Inquiry skill focus	Developing hypotheses Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific literacy (understand how microgravity impacts everyday activities)
Assessment methods	Classroom dialogue Worksheets Student devised materials

Rationale

In this activity students apply the learned concepts to a new situation. They are asked to formulate a question they would like to investigate in a microgravity environment. They must raise a hypothesis and plan an investigation in order to answer their research question. The main goal is not to actually develop the activities on the research plan built by the students (since that would not be possible) but to raise a rich discussion on the conclusions one might reach.

Suggested Lesson Sequence

Going further... conducting an experiment in microgravity.

1. The teacher reminds the students that, as read in the text, one of the tasks of the astronauts on board the ISS is conducting investigations in microgravity.
2. Students are asked to "formulate a question you would like to investigate in a microgravity environment," in which they should:
   a. Clearly formulate hypotheses related to your question.
   b. Present arguments that support your hypothesis, based on correct and relevant scientific knowledge.
   c. Plan an investigation that allows you to analyse your hypotheses.
   d. Describe in detail all the steps, including the variables you want to study, variables you have to control and all the equipment and materials necessary to its realisation.
3. Discuss with your teacher your investigation plan and if necessary reformulate it.
4. Present your planning to the class.
5. With the help of your English teacher translate your investigation plan so it may be submitted to the ISS/NASA.

Activity D: Did you know...

Concept focus	Gravity Working in a microgravity environment
Inquiry skill focus	Developing hypotheses Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific literacy (understand how microgravity impacts everyday activities)
Assessment methods	Classroom dialogue Worksheets

Rationale

In the final activity, students reflect on what they have learned through carrying out the activity.

Suggested Lesson Sequence

Did you know...that during his stay on board the ISS, Commander Chris Hadfield made the first music recording in space? Let's hear it... http://www.youtube.com/watch?v=KaOC9danxNo [accessed October 2015]

1. The teacher asks the students some questions, to help them to reflect on what they have learned
   a. What have you learned while developing this activity?
   b. What would you change if you could perform this activity again?
   c. Difficulties you experienced.
   d. What you found to be the most interesting.
2. Students are asked to reflect on their *working collaboratively* skills through a series of questions
   a. Did you listen to each other's ideas?
   b. Were all group members involved in performing the task?
   c. What worked? And what did not work?
   d. What do you have to change?

2.2 Assessment of activities for inquiry teaching & learning

Within the suggested learning and assessment sequence specific inquiry skills are emphasised for development and assessment. Note, however, that throughout the activities students will have opportunities to practice a range of inquiry skills not identified in the description. It is the teachers' choice to select what inquiry skills they want to address depending on the level of their students. Similarly the teachers can choose whether or not to complete all of the activities described or to select a specific one based on the context of their students and time demands of their curriculum.

This unit provides an excellent opportunity for formative assessment that can be focused on the group written work, the research plan, the communication to the class, collaborative attitudes and students' individual reflections. Table 1 provides an assessment instrument, which details some assessment criteria for several inquiry skills. A teacher guide was devised in cooperation with Portuguese teachers to enable them to follow the same structure for the assessment, where two inquiry skills were selected for assessment (*planning investigations* and *working collaboratively*).

Table 1: Assessment of reasoning skills. Adapted from: Galvão, C., Reis, P., Freire, A. M., & Oliveira, T. (2006). Avaliação de competências em ciências. Porto: Edições ASA.

Criteria/Performance levels	Rating
Formulate questions	
Formulates clear and creative questions, related to the topic under study	4
Formulates uncreative questions, but clear and related to the topic under study	3
Formulates questions, but with little purpose or relevance to the topic under study	2
Doesn't formulate questions	1
Formulate hypotheses	
Formulates relevant hypotheses, well-grounded in scientific knowledge	4
Formulates relevant hypotheses, but with some flaws in scientific knowledge	3
Formulates weak hypotheses, with little grounding in scientific knowledge	2
Doesn't formulate hypotheses	1
Planning an Investigation	
Research plan designed is clear, concise and complete	4
Effective research plan but lacks description of some materials or procedures	3
Effective research plan but needs reformulation. It doesn't consider variables or important limitations	2
Ineffective research plan. Needs major help or it doesn't present any research plan	1
Present and explain ideas	
Presents and explains ideas with scientific accuracy and carries out a well-grounded debate	4
Participates in the presentation, explains and discusses ideas, but with some scientific in accuracies	3
Participates in the presentation, but with great difficulty on explaining ideas and with little discussion. Discourse presents scientific inaccuracies	2
Doesn't participate in oral presentation	1
Overcoming difficulties	
Shows capacity to overcome difficulties individually	4
Shows capacity to overcome difficulties but sometimes needs help	3
Seeking to overcome difficulties individually, but needs help	2
Does not try or does not show capacity to overcome difficulties. In great need of help	1

Teacher guide for the construction and application of an instrument for formative assessment

1. Before class
    a. Build an assessment instrument considering that the main focus will be on *planning investigations* and *working collaboratively* (communication skills);
    b. Adapt the task to students and to the context.

2. In class
    a. At the beginning of the process clarify the assessment criteria (in particular those relating to *planning investigations* and *working collaboratively*).
    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 student artefacts, having regard to the developed instrument and produce written feedback;
    b. Reflect on the assessment process.

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

2.3 Further developments/extensions

During Activity C, students will apply the learned concepts into a new situation. They will be asked to think about and therefore formulate a question they would like to investigate in a microgravity environment. They must raise a hypothesis, and plan an investigation in order to answer their research question. The main goal isn't to actually develop the activities on the research plan built by the students (since that would not be possible) but to raise a rich discussion on the conclusions one might reach. The best research plans can be submitted to NASA (this institution receives and selects activities submitted by schools, performing the best ones on board of the ISS).

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in three countries, producing three case studies of its implementation – **CS1 Portugal**, **CS2 Slovakia** and **CS3 Sweden**. In all three case studies, the teachers and students had previous experience with inquiry but not all of them have prior knowledge about microgravity (**CS3 Sweden**).

The ages of the students involved in the case studies were 15-16 years old in **CS1 Portugal** and **CS2 Slovakia**, and 13/15 years old in **CS3 Sweden**. The students in each class were mixed ability and mixed gender. In **CS1 Portugal**, the unit was implemented in two 11th grade classes (32 students in total), where each class worked in groups of 3-4 members, over two 45-minute classes plus a double lesson period of 90 minutes. **CS2 Slovakia** was implemented with upper second level students (1st class of Gymnasium), consisting of 30 students working in six groups, over three 45-minute lesson periods. **CS3 Sweden** comprises five classes: four grade 7 classes and one grade 8 class. The schools were primary preschool to grade 9 schools and one grade 6-9 school. The students worked in groups of 3-4 students.

In the case studies, the teachers identified different skills for assessment. The teacher in **CS1 Portugal** focused on *planning investigations* and in **CS3 Sweden** on *forming coherent arguments*, which were assessed through evaluation of students' written reports. In **CS2 Slovakia**, the teacher assessed several inquiry skills – *planning investigations*, *developing hypotheses* and *scientific reasoning* capabilities – using formative assessment and a three-level rubric. In addition, students' skill in *working collaboratively* was assessed through teacher observation.

3.1 Teaching approach

Inquiry approach used

In all cases unit was implemented as an *open/guided inquiry*, as anticipated in the unit description. 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.

Implementation

This unit has four activities, each of which addresses the concept of gravity and life on the ISS to form the basis of the inquiry. The activities focus on ensuring students understand the concept of gravity (activities A & B), allowing them to devise an experiment to be carried out on the ISS (in a microgravity environment, Activity C) and reflecting on new knowledge and skills (Activity D). The three case studies utilised text (Activity A) and video (Activity B) to focus the students on the topic of gravity and space. The students in all the case studies worked in groups throughout the lessons (see Table 2).

CS1 Portugal and **CS2 Slovakia** implemented the unit in full, as detailed in the suggested lesson sequence for activities A-D. In Slovakia, a physics teacher adopted the worksheet for the classroom activities with an introductory part related to: How does microgravity work? What is the origin of microgravity? In **CS3 Sweden** activity C was not implemented and the students did not plan experiments. Instead their investigations focused on carrying out daily routines in a microgravity environment. In all case studies, students worked collaboratively and discussed their ideas in groups and with the class.

3.2 Assessment strategies

While the case studies highlighted the development of several inquiry skills, the assessment was only described for a few of these skills (Table 3). 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 3: Inquiry skills identified by teachers in the case studies

CS1 Portugal	• Planning investigations
CS2 Slovakia	• Developing hypotheses • Planning investigations • Working collaboratively (peer discussion) • Scientific reasoning (choosing appropriate experiment)
CS3 Sweden	• Forming coherent arguments • Scientific reasoning (argumentation)

Table 2: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Portugal	Activities A-D	Three lessons (2x45 min & 1x90 min)	• Two classes; groups of 3-4 students
CS2 Slovakia	Activities B-D	Three lessons (45 min each)	• 6 groups of 5 students (30 students)
CS3 Sweden	Activities A-B Activity D	One lesson (60-80 min)	• Five classes; groups of 3-4 students

The element of inquiry that was assessed in **CS1 Portugal** was *planning investigations*. In order to assess this skill, the teacher designed an assessment tool formed by three levels of performance (Table 4). Students' written evidence was examined and assigned a mark of 1, 2 or 3 using the rubric as a guide. The assessment instrument was built before the task implementation in the classroom. After the task completion, students' work was collected and assessed according to the instrument. This instrument allowed the teacher to assess the students' performance regarding in *planning investigations*, particularly in defining a research problem and its objectives; identification of variables to measure and control; construction of a proper procedure with the data to be collected, clear and reproducible and predicting possible limitations to the proposed procedure. The use of this instrument, organised by criteria and performance levels, allowed decreasing the subjectivity of qualitative assessment, such as to assess skills and to enable the teacher to collect information from students' work and facilitating the oral feedback that was carried out after the completion of the task.

Table 4: Rubric for the assessment of the inquiry skill planning investigations in CS1 Portugal

Assessment criteria	Performance level		
	1	2	3
Do students define the goals of the experience clearly and in accordance with their initial research question?	Goals of the experience are not clear or aligned with the initial research question.	Goals of the experience are aligned with the initial research question, but are not clear enough.	Goals of the experience are clear and aligned with the initial research question.
Do students identify variables that should be measured and controlled?	Independent or dependent variables are not identified at all, when applicable.	One or more of the independent or dependent variables are not identified or are irrelevant for the research.	Identifies control, independent, and dependent variables that are relevant for the research, when applicable.
Is the proposed process adequate for collecting relevant data, written in a clear language and easy to reproduce?	Proposed process is not adequate; students do not know which data to collect or they do not know how to proceed in order to collect data. They develop a process for collecting irrelevant data.	Proposed process is adequate, but it still requires reformulation, as students know which data to collect but they do not know how to proceed in order to collect the data.	Proposed process is adequate; students know which data to collect and they know how to proceed in order to collect the data.
	It is difficult to understand the experimental plan. It will be difficult to reproduce it.	The experimental plan is clearly written. Nevertheless, it lacks some detail and so it will be difficult to reproduce it.	The experimental plan is clearly written and it presents enough details for being reproduced later on.
Do students foresee possible limitations of their experimental plan?	Students only consider some possible limitations of their plan or students point out incorrect limitations	Students consider possible limitations of their experimental plan.	Students consider possible limitations of their experimental plan and they reveal understanding of those limitations.

In **CS2 Slovakia**, *scientific reasoning, developing hypotheses* and *planning investigations* were assessed. Students discussed everyday routines, from a physical phenomenon perspective, describing the influence of gravity on these activities. During the inquiry activity the teacher observed group work and provided some support to the students (asking additional questions, outlining short explanations of physics background). The teacher developed a 3-level rubric (Table 5, 1: very low, 2: acceptable, 3: excellent), which was used for evaluation of the student artefacts. The teacher tried to use formative assessment as much as possible, especially during peer discussion, whole class discussion and creating of conclusions.

Table 5: Rubric for the assessment of inquiry skills in CS2 Slovakia

Assessment criteria	Performance level		
	1	2	3
Routines are described in detail, with influence of gravitational force	Routines without gravitational influence, or incorrect routines.	Only title with very short description.	Well described with ideas about microgravity influence.
Originality of routines with comparison to others	Frequently appeared (more than 5 times within classroom)	Only 2-3 times within classroom	Original
Developing hypotheses	Nothing mentioned as hypothesis or completely wrong statement	Sentence is not formulated as statement	Well formulated statement
Planning investigations	No planning	Steps are not in order, or something important is missing	Planning is mostly correct or correct

In **CS3 Sweden**, the unit was implemented in order to assess students' skills in *forming coherent arguments* and *scientific reasoning* (argumentation). To assess students' skills, the teachers listened to the group discussions and collected students' written ideas. The teachers made attempts to assess how students argued for changing their initial ideas, after watching the video. The main success criterion was whether the students could form coherent arguments. Students were given group feedback during the activity. The unit was implemented as a stand-alone activity, and as a result the teachers did not provide summative assessment or use the data for their own planning or evaluations.

INQUIRY AND ASSESSMENT UNIT

WOODLICE

What are the living preferences of woodlice (or other commonplace small creatures)?

Mats Lundström

WOODLICE

WHAT ARE THE LIVING PREFERENCES OF WOODLICE (OR OTHER COMMONPLACE SMALL CREATURES)?

Overview

KEY CONTENT/CONCEPTS

- Introduction to working with living animals
- Living conditions
- Animal behaviour

LEVEL

- Lower second level

INQUIRY SKILLS ASSESSED

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

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

- Scientific reasoning (recording data and observations; drawing conclusions)
- Scientific literacy (data analysis and presentation of results; critiquing experimental design)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Self-assessment
- Worksheets
- Student devised materials (investigation report)
- Presentations
- Other assessment items (post-activity test)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – WOODLICE

The **Woodlice** SAILS inquiry and assessment unit outlines an activity that is intended to aid students in learning about the environment, ecology, and animal behaviour. Students investigate the living conditions of woodlice, which are common in large parts of Europe and are easy to handle. Other small animals with similar habitats may also be used. The expected learning outcomes are: (1) learn to plan, perform and evaluate an experimental study, and (2) identify and explain ecological relationships using scientific concepts, models, and theories. These learning outcomes are part of the science curriculum at lower second level across Europe.

Skills emphasised for development and assessment include *developing hypotheses* and *planning investigations* (designing and conducting an experiment). Throughout the activities students will have opportunities to practice a range of other inquiry skills, such as collecting and interpreting data (*planning investigations*), drawing appropriate conclusions (*forming coherent arguments*), and reporting and discussing results (*scientific reasoning*). Suggested assessment tools are provided in the unit, but it is the teachers' choice to select what inquiry skills to develop and assess. This unit can be implemented over two lessons (45 minutes each).

The unit was trialled by teachers in Sweden, Poland, Ireland, Slovakia and Portugal, with students aged 12-16 years (8 classes in total, mixed ability and gender). Teaching approaches varied, for example in Ireland the teacher formed a *guided inquiry*, while in Poland the students engaged in *open inquiry*. In all case studies *developing hypotheses* was assessed, while the assessment of other skills varied between case studies.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The **Woodlice** SAILS inquiry and assessment unit was developed by the team at Malmö University as a part of the SAILS project. This is proposed as an *open inquiry* activity, in which students are asked to investigate the living conditions of woodlice, which are common across Europe and easy to handle. This activity aids students in learning about the environment, ecology, and animal behaviour. The biology content in this unit is connected to carrying out investigations using living animals. Both ethical and practical issues can be considered. The expected learning outcomes are: (1) learn to plan, perform and evaluate an experimental study, and (2) identify and explain ecological relationships using scientific concepts, models, and theories.

Concept focus	Investigating the living conditions of woodlice
Inquiry skill focus	Developing hypotheses Planning investigations Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (recording data and observations; drawing conclusions) Scientific literacy (data analysis and presentation of results; critiquing experimental design)
Assessment methods	Classroom dialogue Teacher observation Worksheets Student devised materials Presentations

Rationale

Students are asked to obtain woodlice, or other creatures with similar habitats, and to investigate their preferred living conditions. The investigation can be entirely open, allowing the students an opportunity to develop hypotheses, plan investigations to test them, implement their investigations and analyse and interpret their results. Teachers can choose the skills to assess, and alter the implementation to suit their classrooms.

Suggested learning sequence

1. The teacher asks the students to "Investigate the living conditions of woodlice."
2. Some guidance may be provided, such as suggesting variables like intensity of light, amount of moisture in the environment and food preferences.
3. Students then have freedom to form hypotheses, plan investigations to these their predictions and implement the experiments to generate results.

As this is a very open research question, opportunities have been identified for development of many inquiry skills and key competencies. Through this investigation, students can

- Formulate hypotheses about the preferred living conditions,
- Plan an investigation (or a series of investigations) in order to test the predictions,
- Design and conduct the investigation(s),
- Collect, document, and analyse data,
- Draw conclusions supported by the evidence,
- Explain any unexpected results,
- Report, compare, and discuss own results with the results from other students, and
- Suggest how to improve own (or other's) investigation.

2.2 Assessment of activities for inquiry teaching & learning

This unit is particularly suitable for assessing *developing hypotheses*, *planning investigations* (planning and designing scientific experiments), drawing conclusions, explaining unexpected results, reporting, comparing and discussing results, and providing suggestions about how to improve investigations. Use of a 3-level rubric is proposed for assessing investigative skills.

Developing hypotheses – formulate hypotheses about preferred living conditions

There are two aspects for assessment as part of this activity, asking inquiry questions and *developing hypotheses*.

The skill of asking inquiry questions addresses the students' ability to ask questions that can be investigated systematically (Table 1). Questions to guide the students in this skill include:

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

Table 1: Asking inquiry questions

Level 1	Level 2	Level 3
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 develop a hypothesis, students need to collect information and ideas about a question, so that a hypothesis can be formulated (Table 2). Some teacher questions can guide the students:

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

Table 2: Formulating hypotheses

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

Planning investigations

The skill of *planning investigations* can build on the hypothesis developed, as students should plan how to test their hypothesis (Table 3). Planning involves both identifying appropriate equipment and suggesting a functional design. The teacher can pose the following questions to guide the students:

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

Table 3: Planning investigations

Level 1	Level 2	Level 3
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… …identification of variables to change and to be held constant …the order to perform different parts of the investigation … equipment to be used.

Carrying out an investigation, including documentation of data

When carrying out an investigation, students should plan how they will collect data. In this aspect, the appropriate use of equipment is also included (Table 4). Questions to guide the students:

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

Table 4: Carrying out an investigation

Level 1	Level 2	Level 3
The student carries out an investigation from beginning to end, but needs constant support by the teacher/ peers or detailed instructions. The student uses equipment, but handles it 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 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 lacking in accuracy.	The student carries out an investigation from 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.

Forming coherent arguments – interpreting results and drawing conclusions

This aspect is about identifying patterns, making interpretations, and drawing conclusions from the results (Table 5). Students should be able to interpret their results appropriately, form conclusions based on scientific evidence and compare their results to their initial hypothesis. They should develop their *scientific reasoning* capabilities and use reasoning to form coherent arguments. Suggested questions to guide the students in their inquiry include:

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

Table 5: Interpreting results and drawing conclusions

Level 1	Level 2	Level 3
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.

Forming coherent arguments and scientific literacy – evaluating an investigation

This unit can be used for the assessment of *forming coherent arguments*, and developing students' *scientific literacy*. Students should be able to identify possible sources of error in their investigations and decide if the results and the conclusions are reasonable (Table 6). There are three aspects to consider when evaluating an investigation:

- Explain unexpected results,
- Make comparisons with others' results, and
- Suggest how to improve own (or others') investigations

The teacher can pose questions to guide the students during the evaluation process, for example:

- Do your results agree with the results of others?
- How could your investigation be made more accurate?
- Is this reasonable?
- What sources of error are there in your investigation?
- Are these conclusions reasonable?

Table 6: Evaluating an investigation

Level 1	Level 2	Level 3
The student compares their own results with the results and conclusions of others. The student reasons about how reasonable the results are. The student suggests how to improve the investigation.	The student compares their own results with the results and conclusions of others. The student identifies possible sources of error and reasons about how reasonable the results are. The student suggests how to improve the investigation. The student revises the investigations based on suggestions (their own or from others).	The student compares their own results with the results and conclusions of others. The student identifies and evaluates possible sources of error and reasons about how reasonable the results are in relation to the sources of error identified. The student suggests how to improve the investigation based on a comparison of the planning and actual execution. The student revises the investigations based on suggestions (their own or from others). The student reasons about how reasonable the conclusions are.

The task may also be used to assess students' skills in collecting, documenting, and analysing data, but since this part of the investigation is quite simple, it may be difficult to identify weaknesses in student performance. When documenting the investigation in text and with pictures, students should also use graphs, tables and symbols in their documentation. They should decide how the documentation is used in discussions about results and conclusions (Table 7). Questions to guide the students:

- How can you save your results, so that you may show them to others?
- How can you present your investigation and your results, so that someone else would understand how you have done (or be able to carry out a similar investigation)?

Table 7: Documenting and discussing

Level 1	Level 2	Level 3
The student documents the investigation with everyday language and contextual pictures, drawings, etc. The student uses the documentation in discussions around how the investigation was carried out. The student discusses the investigation in an everyday language.	The student documents the investigation with text and pictures, but also supports the documentation with graphs and tables. The student uses the documentation in discussions around how the investigation was carried out and the results obtained. The student discusses the investigation and results obtained, but combines scientific concepts with everyday language.	The student documents the investigation with text and pictures, but also supports the documentation with graphs, tables, and appropriate scientific symbols and representations. The student uses the documentation in discussions around all parts of the investigation, including the conclusions drawn and how the investigation might be improved. The student discusses the investigation and results obtained with the use of scientific terminology.

Teachers implementing the **Woodlice** SAILS inquiry and assessment unit may also assess students' observation skills. Through the use of observations, students can identify properties, find similarities and differences, and describe objects in words and drawings (Table 8). Questions to guide the students:

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

Table 8: Observations

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

This activity may also be used to assess students' understanding of basic ecological concepts, such as species, habitat, physical and biotic environment (Table 9). In particular, student understanding of these concepts may be assessed when *developing hypotheses* (if the hypotheses are grounded in scientific knowledge) and when explaining and discussing the results. To guide the students, the teacher can ask, "How would you classify these into different categories?"

Table 9: Classifications

Level 1	Level 2	Level 3
The student classifies organisms, objects, and substances according to easily observable properties (such as the number of legs, colour, or physical state).	The student classifies organisms, objects, and substances according to their properties, including properties not directly observable (such as weight and conductivity).	The student classifies organisms, objects, and substances according to scientific principles (such as biological taxonomies).

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in five countries, producing five case studies of its implementation – **CS1 Sweden**, **CS2 Poland**, **CS3 Ireland**, **CS4 Slovakia** and **CS5 Portugal** – as summarised in Table 10. The ages of the students involved were 12-16 years. Generally, the case studies describe 2-3 lesson periods of approximately 45 minutes. The most common method of implementation was to work in pairs or small groups, mixed with class discussions. A written report from the students was the most common student artefact to assess, even if performance-based assessment was possible.

3.1 Teaching approach

Inquiry approach used

This unit was developed as an *open inquiry* activity and allowed variation in its implementation depending on the class group. In **CS1 Sweden**, unit was implemented as a *bounded inquiry*. Students discussed in groups, and the teacher collected questions. After discussions there was an evaluation from the teacher. The students decided on questions to investigate and engaged in a follow up discussion at the end. **CS4 Slovakia** also used a *bounded inquiry* approach, in which students started by raising questions, before carrying out their investigation in small groups.

In **CS2 Poland** the unit was implemented as an entirely *open inquiry*. In the first lesson they discussed planning their investigations. Students selected investigation to study. Students planned, carried out and analysed results of the experiments entirely on their own, i.e. which animals, factors to investigate, how to collect evidence. Little direction was given by the teacher.

In both **CS3 Ireland** and **CS5 Portugal**, the teachers chose to use a *guided inquiry* approach. In **CS3 Ireland**, the students first engaged in an open discussion, then the teacher picked three options for students to investigate. In **CS5 Portugal**, a theoretical framework for the inquiry was established using images of ecosystems and an interactive discussion.

Implementation

Working with living animals gave an interesting context for this inquiry, although some students needed to be introduced to particular terminology. For example, the students in **CS4 Slovakia** did not know woodlice prior to this investigation. In some cases, such as **CS2 Poland** and **CS5 Portugal**, other animals were used, e.g. crickets, earworms, beetles, centipedes, meal beetle larvae and earthworms. The starting point of the investigation differed between the case studies.

In **CS1 Sweden**, the activity started with students looking at woodlice with magnifying glasses, to give students a chance to examine how to work with living animals. The teacher started with a general discussion and formulating questions took place in the first lesson. The second lesson was used to carry out investigations, write a report and develop conclusions. In a third lesson, the teacher gave feedback on the reports and students discussed how the investigations could be improved.

A *guided inquiry* approach was implemented in **CS3 Ireland**, where after an initial group discussion to collect students' questions, the teacher evaluated the questions and selected the three particular variables to be investigated (the effect of light, amount of moisture and food preferences on the behaviour of woodlice). Students then developed and noted their hypothesis and used a worksheet to guide students' work/collection of information.

An *open inquiry* was used in **CS2 Poland**, and the teachers did not provide suggestions of which variables could be considered in their investigations. They felt this gave students the possibility to work actively and use their imagination. In **CS2 Poland** and **CS4 Slovakia** the students first looked for a picture of woodlice on the internet, noted the environment in which they live, and then collected some of the creatures. The teacher facilitated rich discussions with the students before they started their investigations. Implementation in **CS4 Slovakia** was also organised over three lessons; the first lesson was used

Table 10: Summary of case studies

Case Study	Duration	Group composition
CS1 Sweden	Three lessons (45 min each)	• Groups of 2 students • Mixed ability and gender
CS2 Poland	Three lessons (45 min each)	• 6 groups of 4-5 students (student selected) • Used with four class groups
CS3 Ireland	Two lessons (1x 40 min, 1 x 80 min)	• 8 groups of 2-3 students • Mixed ability and gender
CS4 Slovakia	Two lessons (45 min each)	• 5 groups of 4 students • Mixed ability and gender
CS5 Portugal	Three lessons (50 min each)	• Small groups (3-4 or 4-5) • Teacher assigned groups alphabetically

for engaging the students, the second lesson for developing and testing a hypothesis and the final lesson for completing worksheets and self-assessment.

The teachers in **CS3 Ireland** and **CS5 Portugal** supported the students by giving them sub-questions, which helped them to formulate a testable hypothesis:

1. Inquiry question to be answered:
2. What do you think will happen?
3. Why do you think this will happen?

Inquiry skills addressed

The teachers trialling this unit mainly focused on the inquiry skills of *developing hypotheses, planning investigations* and carrying out the planned investigations. The inquiry skills identified by the teachers in each case study are detailed in Table 11.

3.2 Assessment strategies

Within the five case studies, the inquiry skills of *planning investigations* and *developing hypotheses* were chosen for assessment in most cases (Table 11). The teachers also assessed students' skills in *forming coherent arguments* and *working collaboratively* and opportunities to develop and evaluate *scientific reasoning* and *scientific literacy* were identified. The assessment methods described in the case studies include teacher observation and classroom dialogue, as well as self-assessment of *working collaboratively* in **CS5 Portugal** and a post-implementation test in **CS2 Poland**. Student artefacts, such as worksheets, presentations or other student devised materials were evaluated in most case studies. The teachers used the rubrics provided in the assessment of activities for teaching and learning section of the unit, with some modifications.

In **CS1 Sweden**, the assessment was based on the knowledge requirement for this year group. The teacher adapted the rubrics to suit the local curriculum for biology. A 3-level rubric was used to assess the students' abilities based on their lab reports, which included both text and drawings (Table 12).

Table 11: Inquiry skills identified by teachers in the case studies

CS1 Sweden	• Developing hypotheses • Planning investigations • Scientific reasoning (recording data and observations) • Scientific literacy (critiquing experimental design)
CS2 Poland	• Planning investigations • Forming coherent arguments • Scientific reasoning (data entry, drawing conclusions) • Scientific literacy (data analysis and presentation of results)
CS3 Ireland	• Developing hypotheses
CS4 Slovakia	• Developing hypotheses • Planning investigations • Working collaboratively
CS5 Portugal	• Developing hypotheses • Working collaboratively

Table 12: Assessment scale used in CS1 Sweden

E	C	A
1. The student contributes to formulating simple questions and planning which can be systematically developed.	The student formulates simple questions and plans which after some reworking can be systematically developed.	The student formulates simple questions and planning which can be systematically developed.
2. 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.
3. 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.
4. The student draws up simple documentation of their studies using texts and pictures.	The student draws up developed documentation of their studies using texts and pictures.	The student draws up well-developed documentation of their studies using text and pictures.

In **CS2 Poland**, the teacher assessed a particular skill per student group: one group were assessed on *planning investigations*, one group on carrying out an investigation and one group on analysing results (*forming coherent arguments*). The teacher used several rubrics from the unit, and adapted to a 6-point scale, which is more commonly used in the Polish school system (Table 13). The assessment was based on teacher observation and evaluation of written reports. The teacher developed a test afterwards for deriving conclusions from the last lesson. The students were disappointed by the grades they received. The teacher commented that group work could be deemed unfair for individuals.

Table 13: Rubric for the assessment of data analysis and presentation of results in CS2 Poland

Assessed skill	2 points level	4 points level	6 points level
Data analysis and presentation of results	The student interprets the data correctly (categorising the measured variables as lesser or greater), but is not able to create a proper graph based on the data	The student presents the data on a graph, but the graph lacks or has poorly developed elements such as axis titles, scale, legend, etc.	The student presents the data on an appropriate graph(s) including all necessary elements such as axis titles, scale, legend, etc. prepared correctly
	The student points out basic/ selected sources of biased/ incorrect results of the experiment	The student enumerates the main sources of biased/ incorrect results of the experiment	The student analyses all main sources of biased/incorrect results of the experiment and indicates the ways to avoid such results in the future
	The student proposes the elements of the method serving to improve the experiment	The student proposes ways to improve the course of the entire experiment step by step	The student compares their results with other groups, discusses data interpretation and proposes methods to improve both their own and the other groups' experiments

In **CS3 Ireland**, the assessment of the skill of *developing hypotheses* was carried out both in-class (as students are discussing the questions or by examining what they have written in-class) or after the lesson (evaluation of student artefacts). The teacher identified several key considerations for the assessment of this skill, and used a 4-level rubric for the assessment of students' worksheets (Table 14):

1. Is the question clear and qualified (e.g. do students mention levels)? Is the question testable and specific enough?
2. Is the prediction linked to the question? Does it suggest an outcome to the investigation?
3. Is the hypothesis justified, for example based on personal experience, students' own observations, or trials?

In **CS4 Slovakia**, the skills of *forming coherent arguments* during peer discussion, *developing hypotheses* and forming conclusions and *planning investigations* were assessed during the discussion, using adapted 4-level rubrics (emerging/developing/consolidating/ extending) to assess the inquiry skills (Table 15).

Table 14: Rubric used to assess developing hypotheses in CS3 Ireland

Assessed skill	Emerging	Developing	Consolidating	Extending
1. Generating questions	A question was formulated e.g. "Do woodlice swim?"	A clear investigable question was formulated, such as distinguishing between moisture, humidity, liquid water	A clear investigable question was formulated mentioning specific levels of food/ light/moisture	A clear investigable question was formulated mentioning specific levels of food/ light/moisture and how it affects the woodlice
2. Making predictions	A prediction is made	A testable prediction is made linked to the question	A testable prediction to the question is made that suggests a clear outcome	A testable prediction to the question is made that suggests a clear outcome based on scientific reasoning
3. Formulating hypotheses	Hypothesis not justified	Hypothesis based on personal experience or inference	Hypothesis based on scientific knowledge or scientific observation	Hypothesis based on scientific knowledge or scientific observation with clear explanation

Table 15: Rubric used for the assessment of inquiry skills in CS4 Slovakia

Assessed skill	Emerging	Developing	Consolidating	Extending
1. Peer discussion and forming coherent arguments	The student describes the course of their own search (information or animals).	The student argues for the search approach and achieves a result (brought woodlice, found out the facts about them).	The student argues logically for the search approach, achieves the result, listens to the experiences of others and responds to them.	The student argues logically for the search approach, achieves the result, responds to the experiences of others, and following discussions, concludes and formulates a hypothesis
2. Formulating hypotheses and conclusions of investigation	A prediction is made.	A testable prediction is made linked to the question.	A testable prediction to the question is made that suggests a clear outcome.	A testable prediction to the question is made that suggests a clear outcome based on scientific reasoning.
3. Planning investigations	The student has a plan to verify the hypothesis.	The student has a plan to verify the hypothesis, consults with others and is willing to compromise.	The student has a plan to verify the hypothesis, consults with the others and is inclined towards a solution that allows them to obtain an accurate result.	The student has a plan to verify the hypothesis, consults with others, and is inclined towards a solution based on scientific thinking.

In **CS5 Portugal**, the teacher decided to evaluate teamwork (*working collaboratively*), paying attention to gender issues and the skill of *developing hypotheses*. Students had to develop a hypothesis, provide a justification for that hypothesis and show the link to the research question. The teacher gave feedback throughout the inquiry process, and assessed the final products. The teacher used a 4-level rubric, adapted from the rubrics provided in the assessment of teaching and learning section of the unit, to assess these skills (Table 16).

Table 16: Assessment criteria from CS5 Portugal

Skill	Emerging	Developing	Consolidating	Extending
1. Working collaboratively (teamwork, interpersonal relationships and group functioning; emotional literacy)	Observes and accepts the colleagues' proposals in the group work, but gives no suggestions; merely accepts what the colleagues are doing (due to difficulties in interpersonal relationships).	Participates in 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 group work and gives positive suggestions contributing to a productive group dynamic.	Participates in 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).
2. Formulating a hypothesis	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.

When assessing teamwork, the teacher focused on selected groups, and completed an observation grid based on the behaviours observed during peer discussions (Table 17). The teacher found that students were able to work within diverse teams. They could produce ideas based on views from team members. They could take into account and deal with disagreements. They managed time and their workload and could agree procedures. Students also self-assessed their performance during group work using a flow chart.

Table 17: Registration grid for the assessment of working collaboratively in CS5 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 quieter colleagues 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			

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