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.

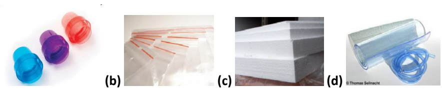
Suggested lesson sequence

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.



(a) (b) (c) (d)

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.

....

....

....

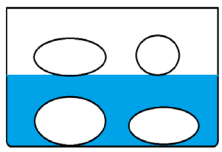
....

....

....

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.

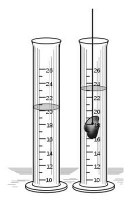


2. Complete the text with the following expressions:

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

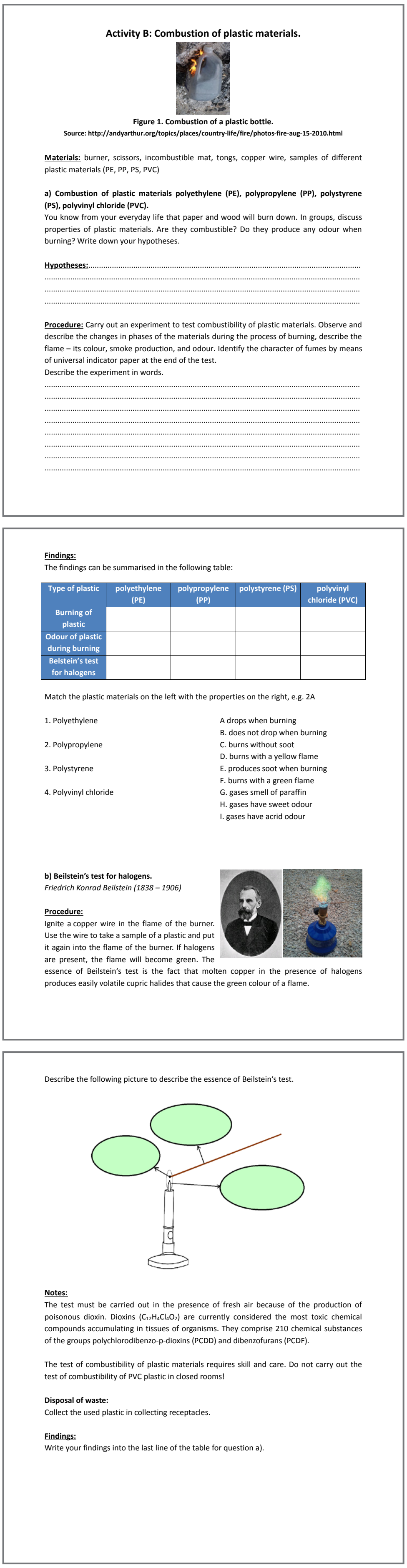
Concept focus	Examine the properties of individual types of plastics during combustion: Prove the presence of chlorine in PVC by the flame test.
Inquiry skill focus	Planning investigations Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (addressing 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.
....
....
....
....
....
....
....
....

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:..

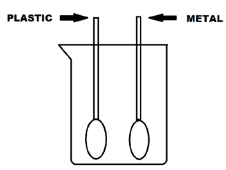
....

....

....

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?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

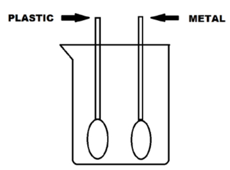
Part 2: Thermal conductivity of plastic materials

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

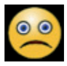
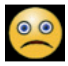
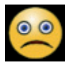
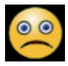
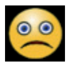
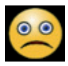
In this section we present some tools for formative assessment, aimed at verifying the development of inquiry skills of *developing hypotheses, planning investigations, forming coherent arguments* and *working collaboratively*. Several assessment opportunities have been identified, and assessment methods 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.