INQUIRY AND ASSESSMENT UNIT

PLANT NUTRITION

Photosynthesis – how do plants grow?

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PLANT NUTRITION

PHOTOSYNTHESIS – HOW DO PLANTS GROW?

Overview

KEY CONTENT/CONCEPTS

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

LEVEL

- Lower second level
- Upper second level

INQUIRY SKILLS ASSESSED

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

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

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

ASSESSMENT METHODS

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

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – PLANT NUTRITION

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

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

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

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

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

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

Rationale

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

Suggested learning sequence

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

2.2 Assessment of activities for inquiry teaching & learning

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

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

Photosynthesis

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

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

Task 1: Making algal balls

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

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

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

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

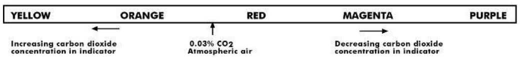

Figure 1: Student worksheet, page 1. Adapted from student sheet 23 *'Photosynthesis… using algae wrapped in jelly balls,'* devised by Science & Plants for Schools (SAPS, www.saps.org.uk).

Task 2: Doing investigations with algal balls

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

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

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

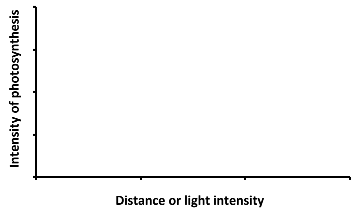

Figure 2: Student worksheet, page 2. Adapted from student sheet 23 *'Photosynthesis… using algae wrapped in jelly balls,'* devised by Science & Plants for Schools (SAPS, www.saps.org.uk).

Planning investigations

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

Table 1: Rubric used to evaluate planning investigations

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

How to divide prepared balls equally

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

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

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

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

Experimental layout

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

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

Recording data and presentation of results and observations

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

Scientific reasoning

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

Table 2: Rubric used to evaluate scientific reasoning

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

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

Table 3: Assessment criteria for sample layout in additive mode

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

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

3. SYNTHESIS OF CASE STUDIES

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

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

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

3.1 Teaching approach

Inquiry approach used

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

Implementation

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

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

Adaptations of the unit

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

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

Table 4: Summary of case studies

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

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

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

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

3.2 Assessment strategies

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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