INQUIRY AND ASSESSMENT UNIT

ACIDS, BASES, SALTS

All acids are harmful – or are they?

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ACIDS, BASES, SALTS

ALL ACIDS ARE HARMFUL – OR ARE THEY?

Overview

KEY CONTENT/CONCEPTS

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

LEVEL

- Lower second level

INQUIRY SKILLS ASSESSED

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

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

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

ASSESSMENT METHODS

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

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

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

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

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

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

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

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

Activity A: Introduction

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

Rationale

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

Suggested lesson sequence

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

Experimental

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

Rationale

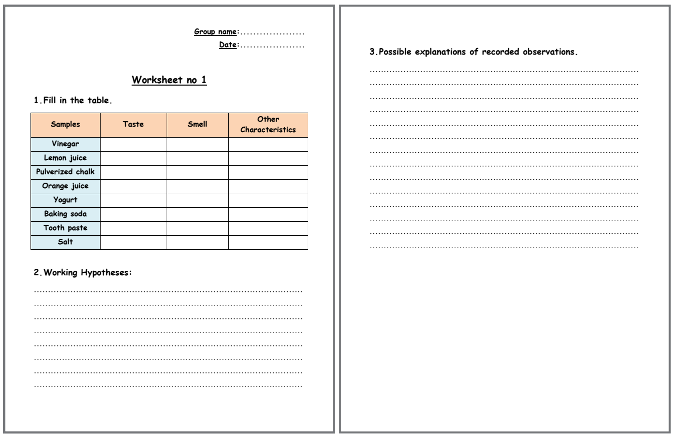
Students carry out scientific experiments in groups to test the hypotheses developed in Activity A: Introduction. They can carry out qualitative evaluation of pH using a red cabbage indicator (Activity B: Qualitative classification of substances using a pH indicator extracted from red cabbage) and quantitative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

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

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

Suggested lesson sequence

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



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

Worksheet no 1

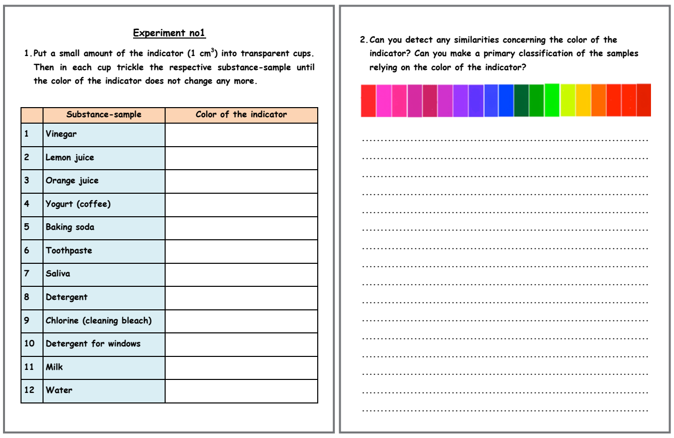
1. Fill in the table.

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

2. Working Hypotheses:

3. Possible explanations of recorded observations.

Figure 1: Worksheet for Activity A: Introduction



Experiment no1

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

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

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

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

Activity C: Measurement of the numerical value of the pH

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

Suggested lesson sequence

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

Experiment no 2

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

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

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

....

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

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

Assessment of the pH scale

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

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

Comments:..

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

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

Comments:..

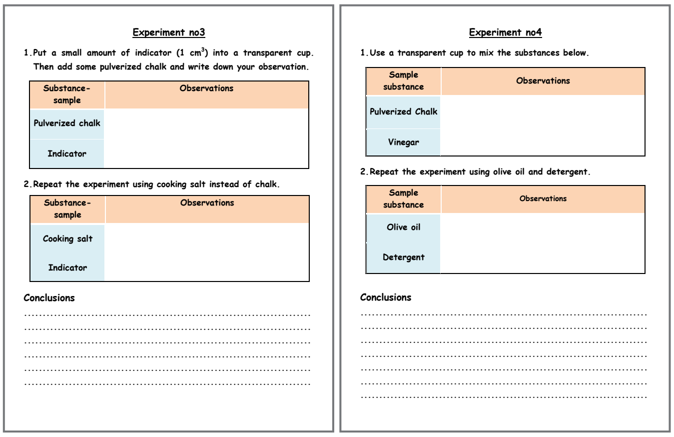
Figure 4: Rubrics for peer-assessment of pH scale constructed in Activity C

Activity D: Identifying salts

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

Suggested lesson sequence

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



Experiment no3

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

Substance-sample	Observations
Pulverized chalk	
Indicator	

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

Substance-sample	Observations
Cooking salt	
Indicator	

Conclusions

....

Experiment no4

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

Sample substance	Observations
Pulverized Chalk	
Vinegar	

2. Repeat the experiment using olive oil and detergent.

Sample substance	Observations
Olive oil	
Detergent	

Conclusions

....

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

Activity E: Acids dissolve salts, bases dissolve fats

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

Suggested lesson sequence

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

Activity F: Conclusions

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

Rationale

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

Suggested lesson sequence

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

Group name:………………
Date:………………

Summarize -Final Conclusions

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

……………………………………………………………………

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

……………………………………………………………………

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

……………………………………………………………………

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

……………………………………………………………………

5)Which substances dissolve fats and which dissolve salts?

……………………………………………………………………

Hypothesis testing

The mistake was:

……………………………………………………………………

The final conclusion is:

……………………………………………………………………

Verified ☐ Modified ☐ Rejected ☐

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

Activity G: Everyday application

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

Rationale

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

Suggested lesson sequence

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

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

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

Assessment of the answers given by the peer group

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

Question no.: ....

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

Comments:..
....
....

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

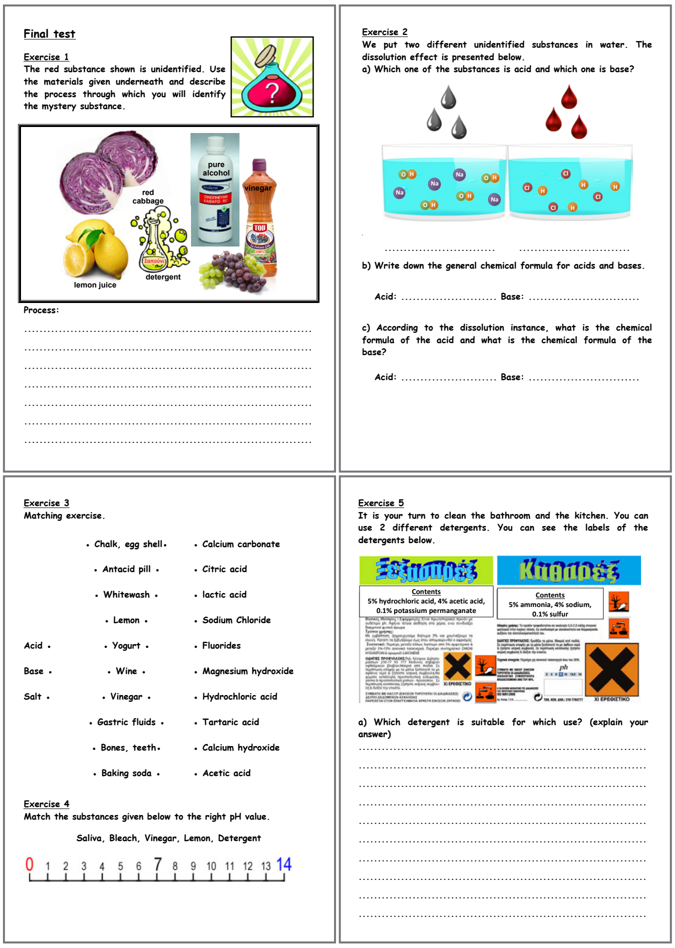


Figure 8: Final test from Activity G: Everyday application

2.2 Assessment of activities for inquiry teaching & learning

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

Developing hypotheses

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

Table 1: Teacher rubric for the assessment of developing hypotheses

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

Assessment of the constructed pH scale

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

Hypothesis testing

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

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

Verified ☐ **Modified** ☐ **Rejected** ☐

Figure 9: Self-assessment of developing hypotheses

Table 2: Rubric used to evaluate constructed pH scale

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

Forming coherent arguments

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

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

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

Scientific literacy

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

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

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

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

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

Scientific reasoning

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

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

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

Working collaboratively (group work and working independently)

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

Table 7: Assessment table for working collaboratively (teamwork)

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

Table 8: Assessment table for working independently

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

3. SYNTHESIS OF CASE STUDIES

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

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

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

3.1 Teaching approach

Inquiry approach used

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

Implementation

The students in all the case studies worked in groups throughout the lessons but there was variation in both how the groups were chosen and the group size, as detailed in Table 9.

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

Inquiry skills addressed

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

Table 9: Summary of case studies

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

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

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

Adaptations of the unit

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3.2 Assessment strategies

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

Developing hypotheses

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

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

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

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

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

Working collaboratively

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

Forming coherent arguments

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

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

Carrying out an investigation (pH scale construction)

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

Content knowledge, scientific reasoning and scientific literacy

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

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

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

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

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

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

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

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

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

Understanding based on metacognition

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

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

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

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

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