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Strategies for Assessment of Inquiry Learning in Science

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D3.3 Report on finalised evaluation materials for teacher education in IBSE with integrated assessment

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Project name: Strategies for the Assessment of Inquiry Learning in Science (SAILS)
Project number: 289085
Start date: 01/01/2012
Duration: 48 months
Lead partner for this deliverable: King's College London
Project coordinator: Dublin City University
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The research leading to these results has received funding from the European Union's Seventh Framework Programme for research technological development and demonstration under grant agreement no 289085

Contents

1. Introduction

The Strategies for Assessment of Inquiry Learning in Science project (SAILS) aims to support teachers in adopting inquiry based science education (IBSE) approaches at second level across Europe. This will be achieved through the provision of teacher education in IBSE approaches and by developing appropriate strategies and frameworks for the assessment of IBSE skills and competencies. SAILS prepares teachers not only to be able to teach through IBSE, but also to be confident and competent in the assessment of their students' learning in an inquiry classroom.

This document provides an overall report on the evidence-based evaluation of the inquiry activities and the assessment framework, strategies and instruments that have been developed to date through the SAILS project. It provides an overall report on the evaluation materials as exemplified through the case studies of teacher implementation of these materials across the twelve participating countries of the SAILS project. Evaluation materials in the format of draft units (DU) have been developed, comprising of inquiry activities with assessment suggestions, using the assessment frameworks and instruments for IBSE skills (as reported in D3.2 and D2.3). Each partner has collaborated with local teachers to trial these draft units in second level science classrooms and to provide feedback from these experiences through detailed case studies. Analysis of the draft units and case studies provide an insight into how the inquiry activities and their assessments function across a range of different classroom settings. Within this report, cultural perspectives in the evaluation materials and awareness of other equity issues, such as gender, are also evaluated and reported on.

The outputs from this report will inform the development of the final framework/strategy for assessment of inquiry (WP2) and also highlight necessary inputs to the SAILS teacher education programmes (WP4) and the Community of Practice (WP5).

1.1 Background

There is widespread concern about the outcomes of science education in schools (Gilbert, 2006, p.4) with too few young people selecting to study science once it is no longer compulsory in their school system. Research also suggests that the main factor determining attitudes towards school science is the quality of the educational experience provided by the teacher (Osborne et al, 2003) and so clearly, any changes to science learning in the classroom must begin with the teacher.

In 2007, the Rocard report suggested that inquiry based science education (IBSE) may redress some of the problems that were deterring young people from studying science. Inquiry is what learners use to make sense of the world around them and provides both the impetus and experience that helps students acquire problem

solving and lifelong learning skills. The European Union made IBSE an educational priority and funded a number of teacher development projects on IBSE. In addition to this drive to implement IBSE in the classroom, at a more general level there has been a push to develop so-called Key Skills and Competencies or 21st Century Skills within education. These 21st century skills are essentially the characteristics that stakeholders including employers want graduates to have when entering the workforce. The link between inquiry skills and the 21st century skills has been discussed in an earlier SAILS document (D1.1 Report on mapping the development on mapping the development of key skills and competencies onto skills developed in IBSE).

Inquiry based science education is an approach to teaching and learning science that is conducted through the process of inquiry. The term *inquiry* has figured prominently in science education, yet it refers to at least three distinct categories of activities—**what scientists do** (e.g., conducting investigations using scientific methods), **how students learn** (e.g., actively inquiring through thinking and doing into a phenomenon or problem, often mirroring the processes used by scientists), and a **pedagogical approach that teachers employ** (e.g., designing or using curricula that allow for extended investigations). Some of the key characteristics of inquiry learning as described in NRC (2000) and Minner et al (2010) are that:

(1) Learners are engaged by scientifically oriented questions;

(2) Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions;

(3) Learners formulate explanations from evidence to address scientifically oriented questions;

(4) Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding;

(5) Learners communicate and justify their proposed explanations;

(6) Learners design and conduct investigations.

Assessment is a key component of the teaching and learning process; in fact, for many students and teachers, assessment drives classroom activities. Most current assessment methods place a strong emphasis on knowledge recall and do not sufficiently capture the skills and attitudes dimension of key competencies. The result is that many current models of assessment are typically at odds with the high-level skills, knowledge, attitudes and characteristics increasingly necessary in our fast-changing world. Furthermore, if something is assessed, then it is often more highly valued by both teachers and students. New assessment methods are needed that probe students' inquiry skills.

The SAILS consortium made up of 14 partners in 12 countries (Belgium, Denmark, Germany, Greece, Hungary, Ireland, Poland, Portugal, Slovakia, Sweden, Turkey and the United Kingdom) addresses these issues by providing teachers with assessment strategies that will show the effectiveness and efficacy of IBSE to develop desired skills and competencies.

1.2 Developing SAILS units

The approach adopted in the SAILS project is to develop SAILS Inquiry and Assessment Units that can be used by teacher educators with both in-service teachers and pre-service teachers in order to help classroom teachers to broaden their assessment practices. As outlined in D3.2, the strategy of developing a range of SAILS Units which provide examples over a broad range of contexts and classroom cultures as well as a range of teacher experiences was adopted. They should also be suitable for a variety of subjects and educational levels. The SAILS Units show clearly how the assessment practices can link in with the inquiry lesson; they also show teachers the benefits of inquiry in classroom practice and also illustrate the variety of assessment opportunities/processes available to them.

In particular, the SAILS Units have clear examples for teachers of how inquiry skills can be assessed, alongside content knowledge, scientific literacy and scientific reasoning and illustrate the benefits of various types of assessments. More specifically, they will show how evidence of student learning can be collected and evaluated using a variety of methods, e.g. student discussion, written evidence, diagnostic questions etc. These SAILS Units are constructed to be informative to the teachers, relate to classroom practice and include examples of assessment items used with students, assessment criteria and a narrative to explain the assessment criteria. The importance here is to ensure that the assessment items produced illustrate for teachers a variety of examples of assessment practices that they can use within their own context of curriculum implementation.

Initially 34 Draft Units (DU) were prepared comprising of inquiry activities with assessment suggestions, many building on materials that had been developed through other EU projects, such as PRIMAS, ESTABLISH and S-TEAM. Following evaluation (as reported in D3.2), 19 of these were selected (based on a range of inquiry skills, subject areas and assessment methods) for further development and trialling in classrooms. Each of the DUs within the SAILS project has been selected or designed with key inquiry elements in mind so that the student would be at the centre of the inquiry process taking a proactive role. At least one aspect of inquiry skills was identified for assessment within each DU and crafted into an outline of the teaching and learning opportunity (see Section 2).

The 19 selected DUs have been trialled with teachers from across the participating countries in the SAILS project and the feedback from the teachers was collected in the form of Case Study (CS) reports. Through the implementation of the DUs in different educational contexts, we hoped to glean as much information as possible about their prospective use in classrooms across Europe. Case Study reports were collected according to a template provided (see Appendix 1). The CSs provide a narrative of how the teachers approached inquiry within the DU, how feasible the lesson was with the chosen class and the ways they assessed the success of their learners. It also includes any issues relating to cultural perspectives and other equity issues, such as gender.

Each DU was trialled by teachers from approx. 3 countries with selected classes in their schools. The analysis of the case studies was carried out in two stages. Stage 1 involved checking of individual CSs to ensure sufficient detail was given on the implementation and assessment within each study and analysis of the CSs to consider similarities and variation in implementation and assessment approach. In total 81 CSs have been generated to date.

Stage 2 then examined each CS in the context of the DU. In this analysis, specific implementation and assessment issues within a single unit was considered both to validate and add to our findings and to provide the detail and impetus for revising the DU into final SAILS Units. This analysis was carried out by the DU developer in conjunction with the countries that generated the CSs, reflecting on what the case studies informed them about the implementation and assessment of the Unit. In this way, a more detailed analysis was done of each DU by considering the CS from 3-4 countries and this analysis is reported as Syntheses of DUs in Section 4. Both Stage 1 and Stage 2 analyses have informed this report.

Finally, the DU and the synthesis of the CS, along with the detail provided in the CSs will be compiled into 19 SAILS Units (Figure 1.1).

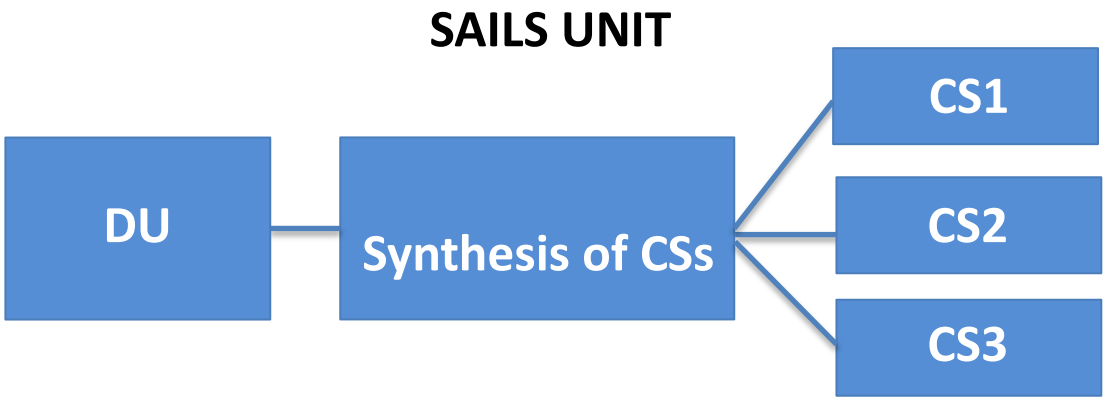


FIGURE 1.1 MODEL OF SAILS UNIT

2. Overview of SAILS Units and Case studies

A final selection of 19 SAILS Units were identified and developed further for extensive trialling across the 12 SAILS participating countries. These 19 Units were chosen as they provide opportunities for the assessment of four key inquiry skills:

1. Planning investigations,
2. Developing hypothesis,
3. Working collaboratively and
4. Forming coherent arguments.

In addition, two broader competencies were identified, as key in the development of 21st Century skills and competencies, and are included across the 19 Units selected.

5. Scientific literacy
6. Scientific reasoning

The final 19 SAILS Units were designed to be suitable for use in developing these six skills and competencies with students from across the lower (11-14 years old) and upper (14-16 years old) secondary school levels. In addition, some of these units were adopted for use with pre-service teachers. The topics of the Units and associated science disciplines and school level are shown in Table 2.1.

School Level	**Discipline**		
	Biology	**Chemistry**	**Physics**
lower	Food labels	Which is the Best Fuel?	Speed
	Wood lice	Acids, bases, salts	Floating orange
		Black tide: Oil in the water	Light
		The probe of the pudding	Collision of an egg
		Reaction rates	Electricity
Upper	Natural selection	Household vs natural environment	Ultraviolet radiation
	Plant nutrition	Polymers- Properties of Plastics	Up there… how is it?
			Global warming

TABLE 2.1 OVERVIEW OF SAILS UNITS AND ASSOCIATED SCIENCE DISCIPLINE AND SCHOOL LEVEL.

The 19 SAIILS Units were selected to provide teachers with the opportunity to facilitate students to develop key inquiry skills and competencies, as have been identified in the SAILS deliverable report D2.3, Report on the assessment frameworks and instruments – Part B and presented in Table 2.2.

Skills and Competences	Includes skills such as:
Planning investigations	Decide what you want to do to find out the answer to the question, Decide what materials you need, Decide how to record the information, Decide how to analyse the information, Decide how to report the findings
Developing Hypothesis	Defining question to test Formulating hypothesis. Making comparisons. Formulating research questions.
Forming coherent arguments	Analysed, supported evidence, drew conclusions
Working collaboratively	Team work, engaged with peers. Offering ideas. Challenging with respect. Actively listening to others. Turn taking. Communication. Peer assessment
Scientific literacy	Understanding how things relate to real world context. Communicating in creative & clear ways.
Scientific reasoning	Addressing problem through logic and use of evidence. Making conclusion Data entry Observation skills Reasoning

TABLE 2.2 OVERVIEW OF INQUIRY SKILLS AND COMPETENCIES FOCUSSED ON IN SAILS UNITS.

Table 2.3 presents an overview of the inclusion of all of these six key skills and competences across the 19 units. However, unit developers also highlighted other specific skills that could be addressed within each unit as outlined in Table 2.3.

TABLE 2.3 OVERVIEW OF SAILS UNIT TITLE, SUGGESTED AGE RANGE AND SPECIFIC SKILLS SUGGESTED WITHIN EACH UNIT.

Unit title	Age range	Skills suggested within the Unit
Acids, bases, salts.	12-13	Developing hypothesis. Planning investigations. Carrying out investigations. Data analysis. Debating with peers. Teamwork.
Black tide: Oil in the water	11-14	Scientific literacy and scientific reasoning. Planning experiments. Collect and record data. Reasoning. Interpreting data. Making inferences. Communication: Using scientific language. Presenting data through various ways. Presenting and discussing different ideas. Attitudes: Curiosity, perseverance, creativity, observation capability, respect for evidence, scientific rigor.
Collision of an egg	15-16	Recognition of variables. Concept of measurement (experiment, observation, measurement, handling variables). Management of quantities. Classification. Recognition of context. Hypotheses. Systems theory. Communication, working collaboratively.
Electricity	12-15	Planning. Developing hypothesis. Teamwork. Researching for information. Prior knowledge of electricity. Working safely.
Floating orange.	11-14	Raising questions. Observation. Plan an inquiry. Team work. Communicate findings
Food labels	11-14	Working collaboratively. Planning investigation. Developing hypothesis. Forming coherent argument.
Global warming	15-16	Using scientific information. Data analysis. Argumentation. Using scientific knowledge. Working collaboratively.
Household Vs natural environments,	14-18	Planning experiments. Identifying scientific questions. Putting forward hypothesis. Conducting experiments. Drawing conclusions using reasoned arguments and evidence. Presenting data in various forms. Consideration of the influence of various factors. Collaboration with others. Providing constructive support to others.
Light.	11-15	Raising questions. Planning and conducting simple scientific investigations. Drawing conclusions based on empirical evidence Communicating and discussing their observations and explanations. Revising explanations based on further investigations. Discussion with peers.
Natural selection.	14-17	Collect meaningful data. Organize and analyse data accurately and precisely. Apply numerical and statistical

		methods to numerical data to reach and support conclusions. Explain any unexpected results. Reflective thinking.
Plant nutrition	11-14	Critical thinking and problem solving. Planning an inquiry. Identifying the variables.
Polymers-properties of plastics	14-17	Researching skills using the Internet. Identify problems, create mind models. Discuss, communicate with peers. Propose hypotheses. Distinguish alternatives.
Reaction rates	11-13	Planning Investigations. Critiquing Experimental Design. Data Interpretation and Analysis. Graphical Interpretation. Working collaboratively. Causality. Making Arguments. Proportional Reasoning. Presenting Scientific Conclusions.
Speed	13-15	Raising relevant question. Planning Investigation. Diagnosing Problems. Scientific literacy. Scientific reasoning
The Proof of the Pudding.	15-16	Planning investigations. Framing hypothesis. Collaboration with others. Problem solving. Modeling. System thinking. Critical thinking. Debating with peers. Forming coherent arguments (assessing own and others' end products). Reflective thinking. Analytical thinking
Ultraviolet radiation	12-16	Raising questions. Hypothesising. Planning investigation. Collecting & interpreting data. Draw conclusion based on evidence. Communicating results and evaluating
Up there … how is it?	15-16	Formulating questions. Developing hypothesis based on scientific knowledge. Planning investigations. Presenting and explaining ideas. Overcoming difficulties. Collaborating in achieving a common task. Showing curiosity towards the subject studied. Time management. Showing tolerance towards classmates and their opinions. Correct use of scientific language. Using ICT/internet. Discussing and debating with peers.
Which is the best fuel?	12-16	Independent enquirers. Reflective learner. Hypothesis. Identify variables. Design and conduct an experiment. Reflect and refine ideas. Collect, organise and analyse data accurately. Draw conclusions based on evidence. Argumentation. Team work and collaboration. Communication.
Woodlice	11-13	Planning, undertaking, and evaluating an experiment using scientific concepts, models, and theories

These 19 units were trialled by teachers across the participating SAILS countries and distributed so that each unit would be implemented in second level classrooms in at

least three different countries. The Units were designed for specific age ranges although teachers could teach the Unit to any age range. In this way over the 19 Units have been trialled in over 80 classrooms across Europe and the cooperating teacher has written a case study (CS) report to describe how they implemented and assessed inquiry in their practice.

Most of the units (18) were designed to involve practical investigations in the inquiry lesson and in some cases the teacher decided to run an inquiry lesson but not use a practical. An example of this was described in the Greek case study on acids, bases and salts, who did a computer-based inquiry.

Table 2.4 presents an overview of all of the 19 units identifying the suggested skills and competency in each Draft Unit (DU). In addition, this table presents an overview of which countries each unit has been trialled in and which of the skills and competencies the Case Study (CS) reports have been focussed on in the implementation of this unit. In some cases, one a subset of the inquiry skill is focussed on in the classroom, e.g. raising questions as the initial part of planning investigations.

TABLE 2.4 OVERVIEW OF SAILS UNITS IDENTIFYING SKILLS AND COMPETENCIES SUGGESTED WITHIN EACH DRAFT UNITS (DU) AND THOSE REPORTED IN CASE STUDIES (CS). THE SYMBOL ■ REPPRESENTS THIS SKILL IS SUGGESTED IN THE DU AND THE SYMBOL ● REPRESENTS THAT THIS SKILL WAS CONSIDERED BY THE TEACHER IN THE CS.

Unit	DU/ CS	Country	Planning Investigations	Developing hypothesis	Forming coherent arguments	Working Collaboratively	Scientific literacy	Scientific reasoning
Acids, bases, salts	DU	Greece	■				■	
	CS1	Greece	●	●		●		
	CS2	Turkey	●				●	
	CS3	Slovakia	●	●			●	
	CS4	Slovakia	●	●			●	●
	CS5	Slovakia	●	●			●	
	CS6	Slovakia		●			●	●
Black tide: Oil in the water	DU	Portugal	■				■	
	CS1	Portugal	●	●				
	CS2	Hungary	●	●		●		
	CS3	Hungary	●	●		●	●	
	CS4	Germany	●					
Collision of an egg	DU	Hungary	■	■		■		
	CS1	Hungary	●	●		●		
	CS2	Denmark	●	●		●		
	CS3	UK	●	●		●		
	CS4	UK	●	●		●		
Electricity	DU	Poland	■			■	■	■
	CS1	Slovakia	●				●	
	CS2	Ireland	●			●	●	
	CS3	Turkey	●	●	●			
	CS4	Poland	●				●	●
	CS5	Poland	●				●	●
Floating orange	DU	UK	■			■		
	CS1	Germany	●			●		
	CS2	Hungary	●			●		
	CS3	Poland	●		●	●	●	
	CS4	Sweden	●	●		●		
	CS5	UK	●	●		●		
	CS6	UK	●	●		●		
Food and Food Labels	DU	UK					■	■
	CS1	Turkey	●			●	●	●
	CS2	Hungary			●			●
	CS3	Ireland					●	
	CS4	Portugal				●	●	
Global warming	DU	Turkey			■		■	
	CS1	Denmark			●	●		●
	CS2	UK				●	●	
	CS3	UK			●		●	
Household vs natural environment	DU	Poland	■	■		■	■	
	CS1	Ireland	●	●				
	CS2	Greece	●		●			
	CS3	Portugal		●		●		
	CS4	Poland	●	●			●	
	CS5	Poland	●				●	●
	CS6	Poland	●			●	●	●

Light	DU	Ireland	■		■	■	■	
	CS1	Ireland		●	●	●		
	CS2	Ireland			●	●	●	
	CS3	Greece	●		●	●	●	
	CS4	Slovakia			●	●	●	●
Natural selection	DU	Denmark	■		■	■		
	CS1	Poland	●		●	●		
	CS2	Hungary	●		●	●		
	CS3	Denmark			●	●		
Plant nutrition	DU	Slovakia	■					■
	CS1	Slovakia	●			●		●
	CS2	Portugal	?	●		●		●
	CS3	Slovakia	●			●		●
Polymers-Properties of Plastics	DU	Slovakia	■			■		
	CS1	Ireland	●	●	●	●	●	●
	CS2	Poland	●			●		
	CS3	Slovakia				●		
	CS4	Slovakia			●		●	
	CS5	Turkey	●	●		●		
Reaction rates	DU	Ireland	■			■		
	CS1	Hungary	●		●	●		
	CS2	Ireland	●			●		●
	CS3	UK	●			●		●
	CS4	Turkey	●			●		
Speed	DU	UK	■			■		
	CS1	Germany	●					
	CS2	Ireland	●			●		
	CS3	Portugal	●					
	CS4	Turkey	●					
The proof of the pudding	DU	Hungary	■	■	■	■	■	■
	CS1	Greece	●	●	●			
	CS2	Ireland	●		●	●		
	CS3	Slovakia	●		●	●		
Ultraviolet radiation	DU	Sweden	■					
	CS1	Denmark	●	●				
	CS2	UK	●			●		
	CS3	Germany	●	●				
Up there… how is it?	DU	Portugal	■	■		■	■	■
	CS1	Portugal	●					
	CS2	Slovakia	●			●		
	CS3	Sweden			●	●		
Which is the Best Fuel?	DU	Turkey	■			■		
	CS1	Greece	●	●		●		
	CS2	Poland	●	●				
	CS3-4	Turkey		●	●	●		
Wood lice	DU	Sweden	■	■				
	CS1	Ireland	●	●				
	CS2	Poland	●	●		●		
	CS3	Slovakia	●		●			
	CS4	Portugal		●		●		
	CS5	Sweden	●	●				

3. Analysis and Evaluation of the Implementation through the Case Studies

As discussed in Section 1.2, each of the DUs was implemented by teachers in a number of classrooms across Europe and this experience was collected in the form of case studies. Teachers were provided with a template (see Appendix 1) to complete which tried to capture the teaching and assessment that had occurred in the classroom. In some cases, an observer was also present, who also added to the CS report. Teachers were also asked to include evidence of their student's work that had been used in assessment to highlight how they made decisions on the inquiry skills and their assessment.

The main questions asked were as follows:

I. How was the learning sequence adapted?
II. Inquiry Skills: Which skills were to be assessed and how?
III. Criteria for judging assessment data: What were the teachers looking for in terms of satisfactory response to the inquiry?
IV. Evidence Collected: What did teachers notice? What evidence was noted or collected?
V. Use of Assessment Data: What did the teachers do next?
VI. New Teachers: What advice might they give to a new teacher doing this?

The CSs have been analysed and highlights are now presented in this section through five sections, looking at how evidence of assessment was collected (Section 3.1), how judgements were made (Section 3.2), how feedback was provided (Section 3.3), working collaboratively and cultural/gender aspects (Section 3.4) and teacher comments on the implementation (Section 3.5).

3.1 How evidence of assessment was collected:

Evidence of student attainment and achievement was gathered in a number of ways. Some of the evidence was collected during the inquiry, others from written reports, some from presentations following the inquiry and, in some CSs, teachers used a combination of these methods. The most common method was informal observations by the teachers during the sessions coupled with teacher assessment of the student's written outcomes from the inquiry. Scrutiny of the case studies shows that the teacher's use of student's written artefacts was the most popular approach to gathering evidence overall of student attainment across all the units. Some teachers did try alternative ways of capturing the assessment evidence; e.g. one UK teacher allowed students (class of 11-12 year olds) to use their mobile phones to provide evidence of their learning in the Egg Collision unit. These students had to discuss and plan their inquiry as part of a small group. The students then recorded their inquiries on their mobile phones to capture what they did with a running

commentary rather than write everything down; they then used these recordings to create narratives and individual reports of what they did and what they found out.

In this section a number of student artefacts are presented and discussed to highlight the variety of approaches that teachers used to assess student work; particular formats include written work and classroom dialogue.

3.1.1 Written work

In this section a number of student artefacts are presented and discussed to highlight the variety of approaches that teachers used to assess student work.

Figure 3.1 shows an example of a dynamic assessment (UK CS on Collision of an Egg). The left side of the example report represents the groups planning and the right captures their data and their findings.

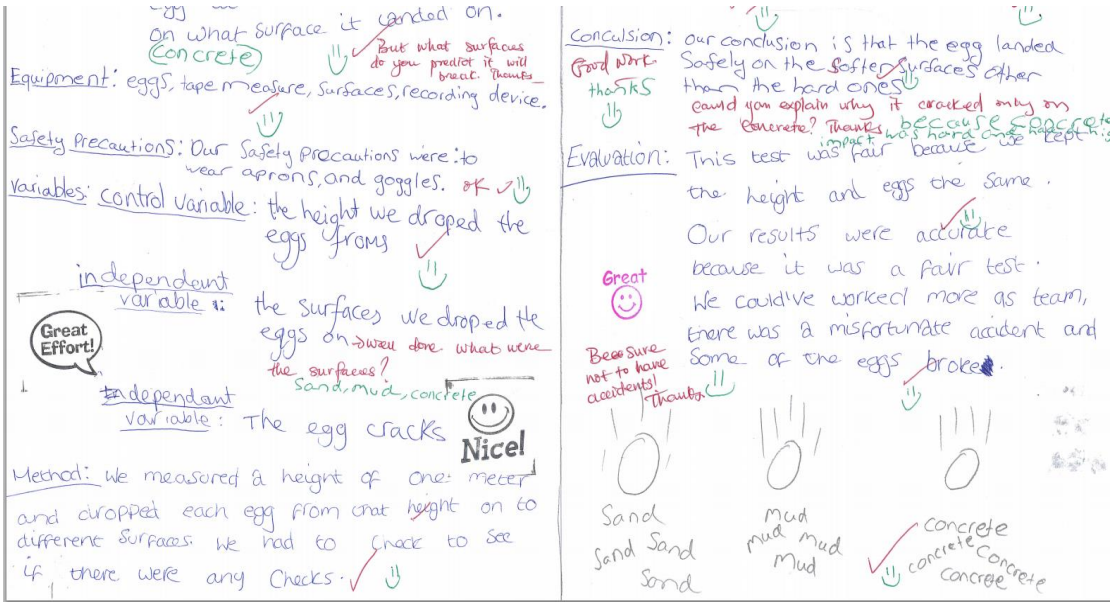
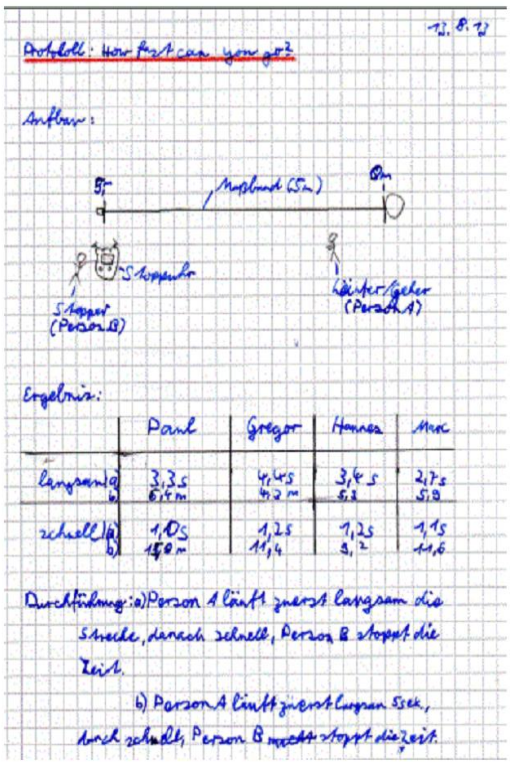


FIGURE 3.1 DYNAMIC ASSESSMENT SHOWING TEACHER INPUT

The assessment process is dynamic as the teacher has provided feedback comments in purple, in the form of questions such as '*But what surface did you predict it will break?*' '*Can you explain why it cracked only on the concrete?*' The student is then given the opportunity to respond as can be seen by green writing and adjustments are made to their written evidence.

Student individual written work can take very different forms. Figure 3.2 shows two examples from the CS Speed. These 12–13 year old students from Germany had worked in small groups of 3-4 students on the first activity in the Speed DU. After their practical inquiry and group discussions, they were then instructed to write individual minutes of their investigation. These were collected by the teacher and

written feedback was given using the rubric from the Unit. These examples show the diversity in the way the students chose to present their inquiry and this personalisation gives the teacher a deeper insight into their understanding compared to a specified writing frame that other teachers used and mentioned in their case studies.



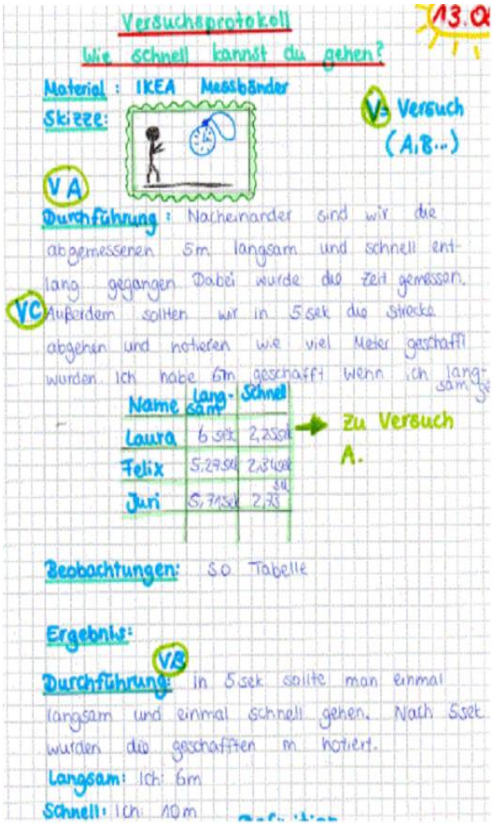


FIGURE 3.2 DIVERSITY OF INDIVIDUAL STUDENT WORK

Other written evidence gathered from students includes the use of 'mind maps' (Electricity Unit, Poland) (Figure 3.3). Using the given rubric, the teacher identified certain key features within the students' mind map that they considered important. This example (Figure 3.3) was considered a good piece of assessment evidence based on the rubric provided (Table 3.1) within the unit on electricity as the students' explanation about electricity, following the investigations, is using more than 10 key words, plus a number of extra core words. Also, this student's mind map used a lot of specific scientific words and also showed some of the relationships between them. In this particular example, the students involved were not experienced in the inquiry approach and neither was the teacher, which made the support given within the unit a learning opportunity for them all. The highly structured rubric and the highly structured approach through the example 'worksheets' were helpful in moving inexperienced teachers' understanding and the students science experiences forward.

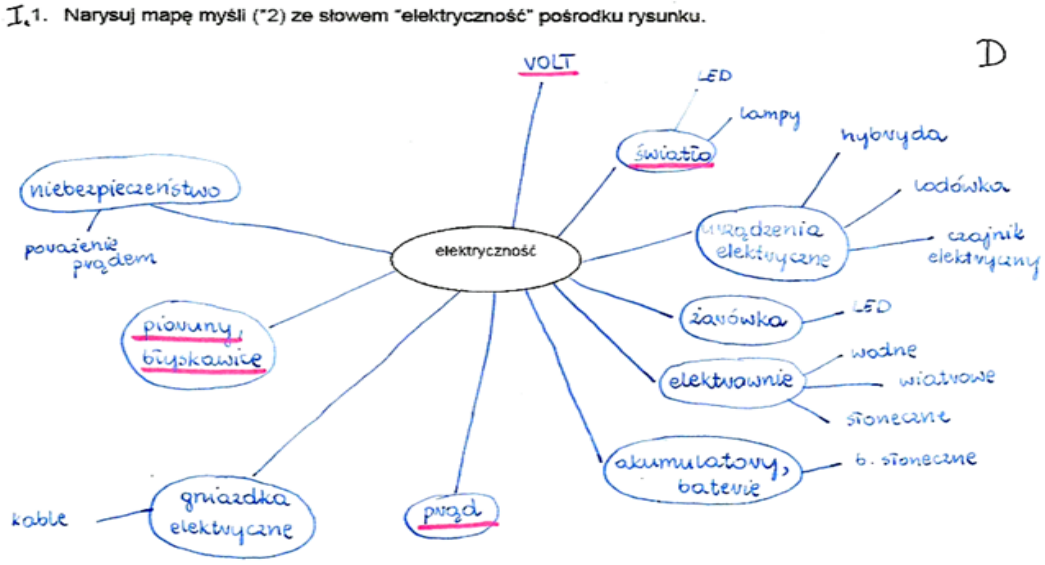


FIGURE 3.3 STUDENT MIND MAP ON ELECTRICITY

TABLE 3.1 LEVEL OF IMPLEMENTATION RUBRIC PROVIDED WITH THE TEACHER GUIDANCE FOR THE UNIT 'ELECTRICITY' FOR THE TASK OF DRAWING A MIND MAP

Performance level	Description
1	Student doesn't draw mind map or draws it putting words not connected to topic (can't explain the connection to the topic).
2	Student can draw a mind map containing 5 words connected to the topic, but there is a lack of connections and relations between them.
3	Student can draw a mind map containing more than 5 words connected to the topic and the majority of the words are from common language. There is a lack of connections and relations between words.
4	Student can draw a mind map with more than 8 words connected to the topic (majority of words are from common language). Student can show the connections between some words.
5	Student can draw a mind map with more than 10 words connected to the topic (most of words are from common language). Student draws connections between words but the structure is not very much expanded.
6	Student can draw a mind map with more than 10 words connected to the topic and most of words are scientific. Student draws proper relations and connections between words.

Photographic evidence formed part of the student work in a number of case studies; e.g. the Unit on Woodlice, the CS from Slovakia of a class of 12 year olds investigating woodlice and raising questions to investigate behaviour in different conditions. The final 'written' evidence involved students presenting their data in the form of models where each woodlouse is represented and stuck onto a circle of paper representing the petri dish (Figure 3.4). The photograph (Figure 3.4) on the left shows the results from four different groups investigating the variables light and dark. The middle photograph (Figure 3.4) shows the actual inquiry in process while Figure 3.4 on the right shows how the groups of four were arranged so that they can see each other as they talk and have easy access to resources. Assessment focussed on the class discussions and is discussed below (Section 3.1.2).

FIGURE 3.4 PHOTOGRAPHIC EVIDENCE; LEFT PICTURE SHOWS THE RESULTS FROM FOUR DIFFERENT GROUPS; MIDDLE PICTURE SHOWS THE ACTUAL INQUIRY IN PROCESS; RIGHT PICTURE SHOWS HOW THE GROUPS OF FOUR WERE ARRANGED.

In a further CS from Sweden on the Woodlice Unit, with a class of older students, aged 14 – 16 years, photographic evidence also was used, but while the students undertook the same inquiry, they approached it differently (Figure 3.5). The inquiry skills selected for assessment included assessing the quality of the hypothesis, and the design of the experiments, recording data, observations, and making improvements on their inquiry. These students worked in pairs. This demonstrates the usefulness of the unit across countries and age ranges as there are opportunities to adapt the approaches to meet the needs of different students, although it does highlight the challenge to define what is expected as an optimal group size.

The teacher used evidence from the whole inquiry process, including the students writing, and their drawings in their lab report to assign a grade, using the rubric below (Table 3.2). As this was done after the class lesson the teacher commented that it was tricky to interpret some of the students' drawings. Instead the teacher or

peers might discuss the students' lab reports with them, as part of the session, and annotate where necessary so this evidence can be more easily understood by others.

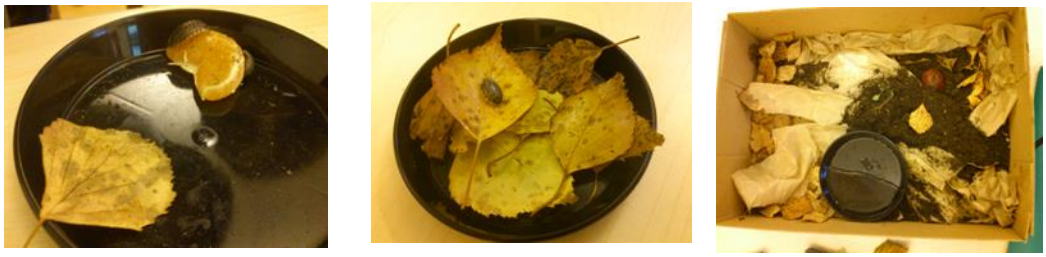


FIGURE 3.5 EXAMPLES OF THE SWEDISH STUDENTS APPROACHES TO THE WOODLICE INQUIRY

The teacher stated that the rubric below (Table 3.2) was relatively easy to use in making summative judgments about the students' attainment, although recognising that not all aspects of the rubric existed within this inquiry. Even so, the teacher was still able to assess aspects of all four foci by drawing on a range of evidence.

TABLE 3.2 RUBRIC FOR ASSESSMENT OF WOODLICE INQUIRY ACTIVITY

E Grade	C Grade	A Grade
The student contributes to formulating simple questions and planning which can be systematically developed.	The student formulates simple questions and plans which after some reworking can be systematically developed.	The student formulates simple questions and planning which can be systematically developed.
The student uses equipment in a safe and basically functional way.	The student uses equipment in a safe and appropriate way.	The student uses equipment in a safe and effective way.
The student contributes to making proposals that can improve the study.	The student makes proposals which after some reworking can improve the study.	The student makes proposals which can improve the study.
The student draws up simple documentation of their studies using texts and pictures.	The student draws up developed documentation of their studies using texts and pictures.	The student draws up well developed documentation of their studies using text and pictures.

3.1.2 Classroom dialogue

A significant number of teachers stated that they provided an opportunity for students to present their group inquiry orally and also provided time for peer discussion within their small groups. On occasion, whole class discussions were organised to share ideas on forming a hypothesis or critiquing different methodology. This approach not only gave the teacher a clear indication of the students' understanding of the inquiry skills, but it also helped the students gain a better insight of the processes of planning and carrying out investigations as a result of sharing ideas and asking questions of each other.

A CS from Slovakia on the Unit on Woodlice, (already discussed in Section 3.1.1 and shown in Figure 3.4) included an example of the dialogue that had taken place. The assessment evidence focused on groups of four students and their discussions. The teacher was able to observe and listen to them as they worked. She made notes of relevant aspects, drawing on the suggestions in the rubrics to recognise progression in their understanding. In this way the teacher was able to capture evidence of hypothesising, as shown in the example. This snapshot of dialogue between a group of students (translated into English) gives an insight into their thinking and reveals a lot about the quality of their reasoning:

> *"I think that some woodlice perished in the box, because I collected them after rain and when I put them into an almost dry box without water they had suddenly died from thirst.*
> *"We pour them some water to the Petri dish, where they will go to drink."*
> *"They are very small, and they could drown, let's instead put a filter paper into a bowl and moisten half. Let's put them on the dry half, whether they will climb over on wet side."*
> *"But what if they will not want to move so much, let's leave them exactly in the middle between the dry and moist paper so that they can choose themselves where they will go."*
> *"Good, is it enough to just put one woodlouse there, what if it isn't thirsty?"*
> *"So let's put 10 woodlice there."*
> *"Why 10? Is six not enough?"*
> *"If they look for moist, all will climb over. But when they are only a few, for example two, it can be a coincidence"*
> *"Yes, let's put more of them into a bowl, than we will count how many climbed and how many remained after 10 minutes. If more than half go into the wet, then we were right."*

The inquiry skills being addressed by this teacher were hypothesising, debating with peers and planning. The teacher noted that the students' responses indicated the quality of their understanding, such as the way they stated their conclusions by drawing on the evidence as demonstrated by these utterances from the students:

"Woodlice like damp places."
"One of the ten of woodlice remained dry, but nine were on the half wet."
"One of woodlice was on the dry side so it was a loser and 9 winners were on the wet half of the paper."

A teacher in Ireland, working with a class of 13 year old students, new to IBSE, reported the unexpected pleasure of her students' achievement as a result of using an inquiry based pedagogy. Initially these students in her class worked as individuals to raise some questions suitable for an inquiry. They then worked in pairs and collectively shaped their joint ideas and undertook their inquiries. Finally, during a series of 5 minute whole class discussions, (using the assessment for learning strategy 'Think-Pair-Share') the teacher was able to gain further evidence of their attainment and achievement because of the dynamic exchanges between the students. Part of this was possible because the inquiry pedagogy gave her the opportunity to observe the students as they did their inquiry as well as from their final written outcomes.

This strategy 'think-pair-share' has been found to be useful in promoting classroom dialogue by providing a supportive environment to share their ideas with a peer. With the confidence they gain from these paired discussions, a whole class sharing of ideas is more likely to be successful as each individual has already been given time to think and rehearse their ideas and then, if necessary, reframe their first thoughts with their partner. Students gain confidence in speaking in class and teachers expect learners to be willing to share ideas and ask questions of each other.

The teacher's role is to mediate the discussions, rather than correct or close down ideas, as this interferes with the dialogic process. In this way students are encouraged to take an active part in their own learning and become more able to articulate their thinking, including revealing any areas of confusion or uncertainty. This requires students to actively listen to their peers and consider the reasoning and logic behind the claims or questions being made. Such dialogue also provides rich evidence for the teacher to make judgements about student understanding and to plan how to guide students towards better understanding.

Throughout the CS reports, it is clear that teachers noted that opportunities for discussion were planned into the inquiry activities; however, they did not generally give details of the questions they used or the evidence that these prompted. However, it was clear from the assessment approaches used that evidence was collected orally in class during the inquiry in many of the classrooms. Being more explicit about how to probe understanding within each of the Units would be a useful addition to the assessment process and of particular value to teachers new to the IBSE approach or whom are teaching outside their subject area.

3.2 How judgments were made

Many of the teachers stated they thought the use of the rubrics would be helpful during the sessions. However a number stated that even though they had a clear intention of doing this they found it difficult to capture sufficient evidence to keep track on all the students. As a result most of these teachers chose to limit their use the rubrics as assessment tools for the student's final written work.

The use of rubrics has already been shown in some of the CS discussed in Section 3.1.1 and shown in Tables 3.1 and 3.2. A case study written after working with Turkish pre-service teachers also reported that they found the rubric below (Table 3.3) more useful after the class session, when they were trying to assess the students' written reports and to write comments on the worksheets. Although the tutor found it a challenge to use the rubrics for assessment of individuals because there was a tension between group and individual assessment, this tutor still reported that they did form a judgment on each student and found that only a few students were in the "Poor" category and required specific intervention to support them.

TABLE 3.3 RUBRIC USED IN PRE-SERVICE TEACHER INQUIRY IN TURKEY

Skill	Poor	Needs improvement	Good
Formulating hypothesis	Hypothesis is not testable or does not include variables	The hypothesis is testable but too general	Hypothesis is testable, not too general or specific, variables are evident
Designing experiments	The suggested procedures are not clear, required materials are not certain	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
Discussing with peers	Not participate in discussions or express opinions or not listen to others' opinions	Express opinions in a timid way, participate in discussions occasionally	Participate in discussions, listen to others, express opinions clearly and respect others

One teacher also stated that observing the students working and interacting with them provided a good insight into their understanding and they were then better able to identify the students who needed a challenge, and others who needed more

personalised attention. She was also able to gain an insight into their attitudes about science and their views of the activities.

An experienced German teacher explained in their case study another approach to allow students to give feedback to the teacher using 'traffic light cups'. The strategy allows students to indicate their need for help during practical work by using different coloured cups (red cup - we need help urgently, yellow cup - we need help but have some time, green cup - no problems). The method facilitates a focused and easy to use feedback system, which can be used to alert the teacher or their peers that they need some additional guidance.

In this CS (UV-radiation Unit in a German school), further feedback from peers and the teacher was facilitated through the use of group poster presentations. Figure 3.6 shows a well-elaborated poster from one student group. The poster shows two very systematically considered approaches and results of the two investigations that the students had undertaken. It shows their notes on their research questions, their hypothesis, how they did their investigations and how they analysed and interpreted their findings.

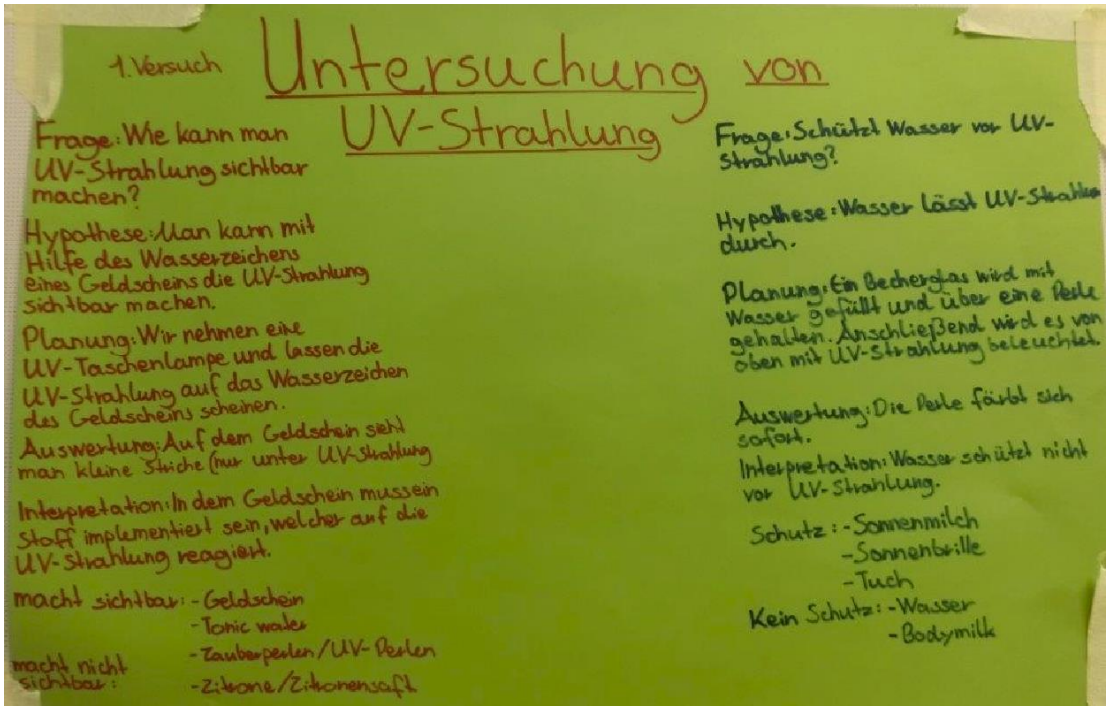


FIGURE 3.6 POSTER PRESENTATIONS FROM UV RADIATION UNIT CS FROM GERMANY

The red colour on the left is the student's first investigation, while the black colour on the right relates to their second investigation. Translation:

- ***Research-question*** *in red = How can UV radiation be revealed?*
  The black = How can you protect yourself against the sun's ultraviolet rays?)
- ***Hypotheses*** *in red = You can reveal UV radiation by particles in a Euro-banknote;*

The black = UV radiation can pass water

- ***Accomplishment of the experiment*** *(short description in both)*
- ***Analyses and interpretations*** *the red = makes UV radiation visible: banknote, tonic water, UV beads;*
  The black – protection against UV Radiation: sun cream, sun classes, cloth; no protection: water, body milk

In this CS, the teacher was able to assess the difference in quality of planning and carrying out investigations by observing the quality of students' approaches and how systematic they were. The teacher described the lesson as being very positive because students were focussed and motivated by their investigations. The teacher's observations, the progress reports during the investigation and the revision of the poster presentation showed a qualitative distinction in the skills of different students within the different groups and this gave valuable feedback to the teacher which could then be used to adjust future lessons.

As evidenced by the CSs, a number of teachers stated that teacher observation and formative feedback was a common aspect of their pedagogy yet few overtly included these within their case studies to form a holistic judgement on student's attainment as part of the teaching and learning process. Within a CS format, it is difficult to capture all of the experiences within the classroom (background of student learning, teacher background, experience in inquiry, assessment practice etc.) and therefore it is difficult to determine the reasons for the lack of its detail in the CSs. It is likely that these teachers may need support, through the teacher education programme, in developing the assessment literacy to be able to describe and explain what they did. While some of the case studies suggested that the teachers had not had much experience of providing formative feedback, a small number of these inexperienced teachers did suggest that for the next inquiry lesson, they would consider sharing the rubric or similar assessment tools with their students as part of the learning sequence and training them to use it as a peer or self-assessment tool.

3.3 How feedback was provided:

Feedback was found to both remediate problems and to share good ideas forward in the inquiry process. While the CSs mainly reported on the feedback that teachers gave to learners at various stages during the inquiry and on their written work, some reported on how feedback provided a useful way of moving ideas forward with the whole class. These opportunities arise through the process of working in small groups as well as when presenting their findings to their peers within whole class discussions.

Many of the teachers stated in the CSs that students received both verbal and written feedback. In the main the teachers from across the partner countries, stated that feedback during the students' work was mainly given through conversations with students. One example of a misconception being identified by the teacher through their observation and listening in on a group was noted in a case study from Turkey, using the unit 'Polymers' with a class of pre-service teachers. It was noticed that some of these students thought that they had to sink an irregular shaped piece of plastic all the way down to bottom of the graduated cylinder to measure the displaced water accurately. The teacher addressed this misconception by giving feedback through a quick demonstration to show that once the material was under the water, the water level did not change as the material was pushed down to the bottom. Initially students predicted that the water level would continue to rise as the material was pushed further down toward the bottom.

As shown in Figure 3.1, some feedback was provided on student work using stickers stating '*great*' or '*nice*' on particular aspects of their work. Here there was a deliberate effort by the teacher to avoid giving a grade or level for the work in order to focus the students on the learning. The students initially found this odd as they were used to summative grades which they could compare with each other. Additionally, the teacher then often included questions either within the text or at the end to help the learners reflect on and improve their work (Table 3.4).

TABLE 3.4 TEACHER FOLLOW-UP QUESTIONS AND FURTHER STUDENT ELABORATION (BASED ON FIGURE 3.1)

Student report	Teacher follow-up question	Student correction
On what surface it landed on	But what surface do you predict it will break?	Concrete
Independent variable: the surfaces we droped (sic) the eggs on	Well done. What were the surfaces?	Sand, mud, concrete
Conclusion: Our conclusion is that the egg landed safely on the softer surfaces other than the hard ones	Could you explain why it cracked on the concrete?	Because concrete was hard and had a high impact.

In a class of Irish 13 year olds, undertaking the unit on Speed, verbal feedback was given to the students in the form of questioning. The teacher asked students to

reflect on what they would do differently the next time. Students therefore reflected on their original thinking and knew that they would have a second chance to practice these skills, which was considered by the teacher to be a motivating factor.

It was clear from the CSs that where a rubric was provided in the unit, the teachers often used these as an inspiration for their feedback on student artefacts. As a result of teacher feedback, teachers reported that most students were then able to adjust their original ideas and actions. Some teachers commented that they found the main difficulty regarding formative feedback during the session using a rubric or other organised tool, was related to the management of a large number of working groups in the class and limited time.

In one class of Portuguese students there were 10 groups of 3 students undertaking the unit Plant Nutrition. These students were not experienced in the inquiry approach but they were generally high attaining students and eager. While the teacher found the use of oral feedback to students and assessing their presentation of their hypothesis using a rubric beneficial, the greatest difficulty was related to the teamwork observation grid because of the high number of dimensions within the rubric and the expectation that the teacher should record the frequencies of each of the observed behaviours. Consequently the teacher decided to focus on just two groups but feared that this meant teacher support to other groups was compromised.

Some teachers tended to use the criteria for success as an integrated part of teaching and learning process rather than just an end of activity task. These teachers often adapted the rubric approach and crafted criteria more appropriate for their class and their own management. These rubrics were often had greater direct involvement from the students in stating the descriptions of quality at different stages of its evolution. By promoting the use of student's self and peer assessment these teachers found they were more able to focus their attention on verifying the students own judgments by focusing on a few students. In this way managing time and a full class became less of an issue as they and their students became more skilled in the process.

The 'arrow' rubric example (Figure 3.7) illustrates an approach one UK teacher used with his experienced students during the Egg Collision inquiry. The teacher, together with the students, discussed what quality performance might look like for a particular inquiry skill. These ideas were then used by the teacher to create the progression in quality within the rubric, as represented by the wording in the 'arrow' diagram below. The students were then able to work together and review their work, and the way they worked, to decide not just where the 'best fit' was for them, but more importantly what aspects of these skills they should focus on and address next. In other words, the students were able to set interim targets and work towards

these, which suggests a more self-regulated approach to learning. Each student had a copy of the 'arrow' and used highlighter pens and other coding systems to monitor their own progress. The teacher would discuss these with groups of students and give additional feedback and guidance as necessary. In this way, the principle of the rubric was more tightly integrated into the teaching and learning process and made more relevant to the needs of the class and the topics under study.

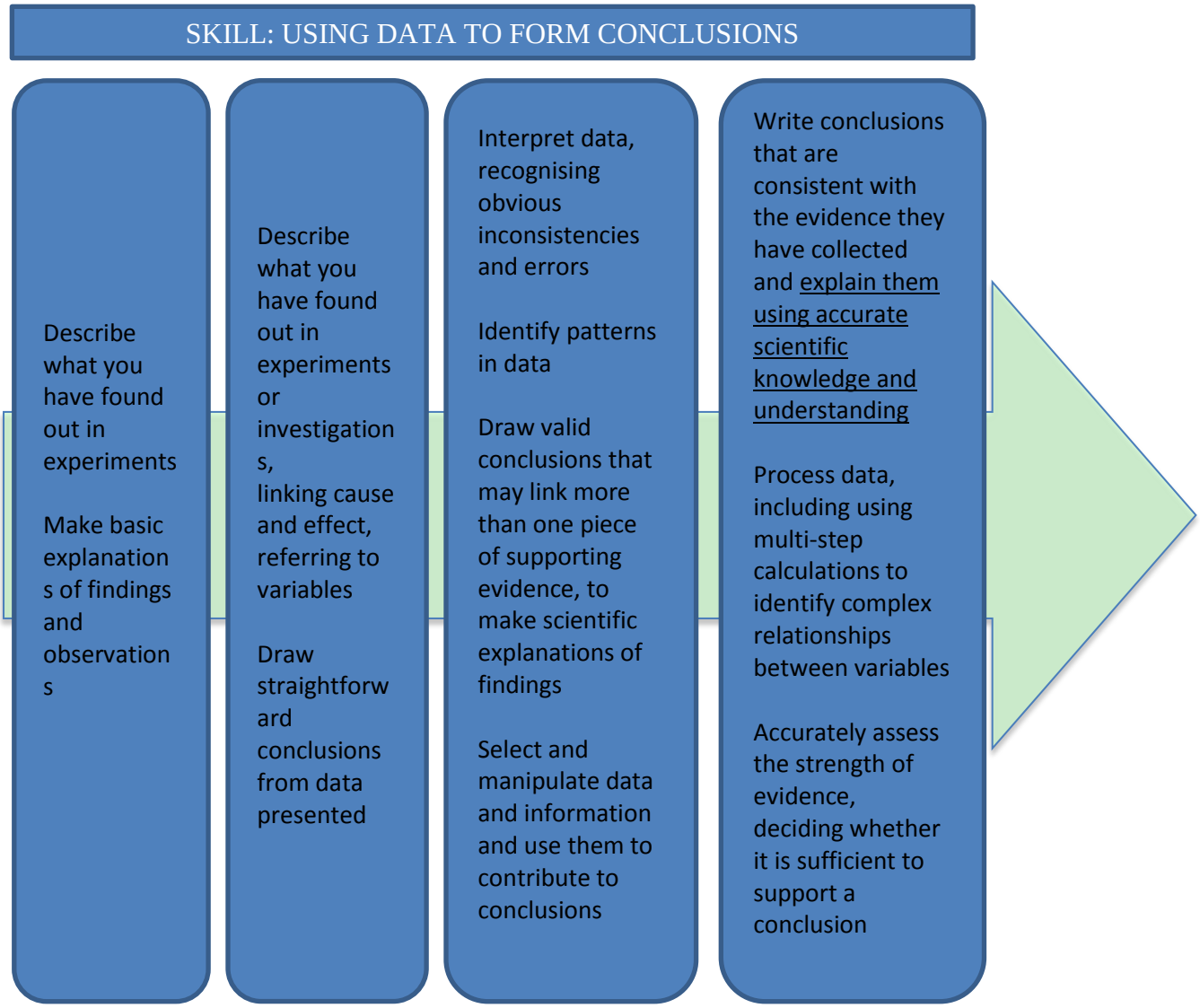


FIGURE 3.7 AN EXAMPLE OF THE 'ARROW' RUBRIC TO GIVE FEEDBACK TO STUDENTS (UK TEACHER)

3.4 Working Collaboratively and cultural/gender aspects

All of the units advocated students working in groups for their inquiry, and nearly half of the teachers who completed case studies, also included aspects of working collaboratively within their inquiry assessment focus. Many of teachers created group sizes of 4-5 students although a few teachers chose to use pairs. Most

teachers appeared to take a pragmatic view to organising the group size based on the amount of resources they had available for use. The majority of teachers did not give any other purpose for assigning students to groups. In mixed gender classes the majority of teachers also chose mixed gender groups, and organised their groups based on students' existing friendships or groupings used in their other science lessons. Very few teachers gave any reason to explain their group selection; however, one teacher proactively created an all-girl, all-Muslim group in a mixed gender class as a mechanism to encourage these girls to actively talk and share ideas. This particular teacher had noticed that in mixed gender groups these students were passive and rarely contributed to group discussions yet when these individuals were together they appeared more relaxed and able to discuss things.

Sometimes, teachers elected to be more flexible in their approach to group work to fit the contexts and approaches of the inquiry activities. For example, in two of the Danish classrooms, who were using the Ultra violet Radiation Unit, the session started off with a large group discussion to have a 'class brainstorm' and ascertain what the students already knew about ultraviolet radiation. The class then worked in smaller groups to undertake their inquiries. The results from their three investigations were then presented by each group and ideas shared with the rest of the class.

Most of the CSs did not explicitly state if gender issued were addressed directly in group work or during the inquiry activity. Issues of equity and unconscious gender bias are now considered within the Teacher Education Programmes (TEP) – through consideration of teacher-student interactions and how they play out in the classroom e.g. if the teacher talks more, or differently to boys or girls. Other methods are discussed in the TEP programmes (D4.4).

In the CSs of two countries, Portugal and the UK, there were 7 detailed accounts of how gender issues were tackled through making visible and open to negotiation the gender dynamics and power relationships of the classroom as part of learning and inquiry (Matthews, 2006). Students used sheets in which they could discuss how well they had worked as a group, and debate how the boys and girls got on together. This method legitimates the students discussing how they got on socially and emotionally in order to improve their understanding of each other and to improve collaborative behaviour (Matthews, 2004). Table 3.5 and Figure 3.8 give an example of the student sheet used in Portugal (translated). This teacher noted in the CS that:

> *Students loved to complete the self-assessment sheet, because they had never done anything like that and were amazed by the kind of questions proposed. A true reflection was required. They said they found it very important*

TABLE 3.5 STUDENT SHEET ON GENDER ISSUES IN GROUPS (CS PORTUGAL)

1. **Were you able to say all that you wanted to say? (For example: always, sometimes, rarely)**

Yes, I was able to say everything I thought almost always, and I was heard.

2. **What kept you from saying what you wanted to say?**

Sometimes the fear of saying something wrong inhibited me, but not after some reflection and confirmation of what I was saying.

3. **Do you think your colleagues understood what you have told them?**

Yes, we articulate well and understood each other.

4. **How do you know your colleagues understood what you said?**

When each one gave his opinion, demonstrated in other words what the other one said, and sometimes we were able to finish the line of thought and answer each other.

5. **After exchanging ideas with your colleagues did you change your point of view?**

Yes, when our ideas complement and make sense, we were able to improve each others answers.

6. **How did you feel towards the colleagues of your group who had a point of view that was different?**

I took it well. First I try to understand and if it was possible and suitable we articulate the answers and if there was an impasse we voted.

7. **Did you defend your ideas?**

Yes, I argue and grounded ideas and my point of view.

8. **How did you defend your ideas? How did you organise your arguments?**

I defended my ideas arguing, based on, the textbook and my personal notes and relating the text with my reasoning.

9. **Who spoke the most?**

No one stood out, both had initiative, willingness to work and expose our ideas.

10. **Who listened to others the most?**

We all respected and heard each other. Overall, we worked well and I have nothing to point out to my colleagues, actually at a certain point I was responsible for the work delay because I missed one meeting on Facebook without notice, and yet they understood. My colleagues were as well very intuitive and we articulate each other easily. Yes I would return to work with this group, but I would also like to change.

One Portuguese teacher developed the schemata (Table 3.6) below to help her make judgements about different students within the group. This process uses a set of descriptors and decisions about the frequency that these occurred that helps the teacher focus in on collaborative group work behaviour.

TABLE 3.6 JUDGEMENTS ON COLLABORATIVE GROUP WORK BEHAVIOUR (PORTUGAL TEACHER)

Teamwork			
Behaviour	Student A	Student B	Student C
Does not interrupt when others speak	3	4	3
Questions the colleague regarding what he is saying	3	2	2
Defends his point of view	3	3	2
Talks with kindness	4	4	4
Challenges a more quiet colleague to speak	3	3	1
Congratulates the colleagues when they present a positive idea	3	3	2
Assumes an active role in order to solve conflicts between colleagues	No conflicts observed	No conflicts observed	No conflicts observed
Defines/clarifies the work's objectives	3	2	2
Defines/distributes/negotiates tasks among colleagues	3	2	1
Draws attention to time	2	2	2
Faced with distractions draws the group's attention to the work	2	1	1
			1-never; 2- sometimes; 3-often; 4-frequently
Student A - Consolidating - Often participates in work group organisation and often contributes with positive suggestions for a productive dynamic in the group.			
Student B - Developing - sometimes participates in work group organisation and contributes very little with positive suggestions for a productive dynamic in the group.			
Student C - Developing - sometimes participates in work group organisation and contributes very little with positive suggestions for a productive dynamic in the group.			

In the UK, in one classroom the students responded well and gave thoughtful answers when completing the Working Collaboratively sheet. In another, in an all-girls' school, the girls were unsettled as they were unsure about making comments on how they all got on. However, they did so constructively. What is clear here is that attention to gender awareness is at an early stage in many of the classrooms, and those teachers that have actively tried to strengthen and support a better awareness have been successful in achieving this within an inquiry approach. It is

important now that more explicit support on gender and cultural awareness is incorporated into the TEP so that these processes become more widespread.

3.5 Teacher comments on classroom implementation

Many of the teachers reported that a distinct difference between their usual science lessons and an inquiry based lesson was the changed role of teacher and student. An example of this is captured by a Portuguese teacher undertaking the unit 'Oil on Water';

> *In a traditional science class, the focus is more on what the teacher says and does. However in an Inquiry class the students have a more active role and the inquiry approach becomes the lesson focus.*

A further difference between the two approaches includes the way the students are organised to work as an active member of a group where everyone has a role to play, rather than working as an individual in the class. The benefits of which are clearly stated by this Portuguese teacher:

> *Students work in groups in order to address the questions and problem. This means that in an inquiry lesson the students are more autonomous and responsible for their learning while the teacher guides and facilitates.*

Many of the teachers reported that an inquiry approach took a longer time than traditional science lessons. A few teachers reported that they found their main difficulties of implementing an inquiry based approach to teaching and assessing were related to managing the in-class assessment process related to the teamwork observation, especially when there was a large number of classroom working groups or a lot of descriptors within an assessment tool. However other teachers reported that they recommend observing just one or two groups in detail within any one session and over time gather evidence of every students understanding and with the use of student self-assessment.

Knowing when to intervene and how long to leave, while students worked out plans for their inquiry, was a new challenge for many of the teachers. Some teachers commented that they noticed their students had not discussed their inquiry plans with them and as a result the students rushed straight from their question to their investigations without reflection on the planning processes. This led to the students making errors. However, nearly all of these teachers also noted that it was through the students presenting their ideas to other groups that the opportunity for discussion between peers occurred. As a result, this peer discussion seemed to guide the students towards a better understanding of how to do their inquiry. This demonstrates the need for teachers to have the courage not to intervene too quickly.

Within the design of each unit there is an assumption that if students work actively while learning science and follow the general processes of scientific discovery, then they will acquire better knowledge and skills. It is also assumed that the inquiry activities have been structured in such a way as to maintain interest and motivation because of the students' take greater responsibility and can follow their own lines of inquiry. This motivation and engagement of students was confirmed by the comments made by the teachers in many of the case studies. Many of the teachers commented on the positive attitudes of the students during these inquiry sessions.

This is illustrated by the feedback below from students and a teacher on using the Woodlice unit in a Polish class. The teacher stated that even though a few students were 'zoophobic' and initially very anxious about dealing with live animals, the students were all fascinated by discovering the world around them using the inquiry approach.

This was confirmed by this collection of student feedback:

> *Interesting experiments. Cool/interesting lesson. Everyone in our group had his/her own view. A novel form of a lesson/education – easier to be learned. You can let your imagination free – invent an experiment. Possibility to learn something on one's own and not basing on dry facts. Work in groups / cool cooperation. I'd like to have more such lessons / I liked it very much.*

A Portuguese teacher working with students aged 12 – 14 years also commented on the positive view from the students as they undertook the inquiry 'Oil on Water' stating;

> *Students enjoy Inquiry classes. It seems that the time runs faster. When the class get to the end, some students are impressed and ask, "already?" Other times, when the class returns to a more traditional format, they ask, "When do we get back to work in groups?"*

A similar reaction happened in one of the Hungarian classrooms:

> *My students enjoyed working on the activity … and were good at working together. The three boys in one of the groups caused the greatest surprise because, while they tend to be quiet and moderately active in regular classes, they were now very lively and motivated and I got to know a different side of them.*

Several teachers reported that they started to view the learning of some of their students differently through engaging in an IBSE approach. The opportunity to learn new things about students understanding is captured here by an Irish teacher undertaking the Speed unit with her class;

> *I was surprised by the volume of questions generated and was equally impressed by the quality and relevance of the questioning and planning.*

Students were noted as being '*excited to impart information'* and '*engaged in open and active discussion*'. The teacher goes on to comment on this engagement and high levels of motivation, '*they actually questioned other students' planning activities with a lot of 'what if…' and 'but if you…' type questions'.* This teacher also discovered, through her observations, that some high achieving students were struggling and this was because they were not used to taking responsibility for their learning. They stated in their own words that they were *'accustomed to being given information and not thinking for themselves!*'

From the CS reports from the teachers, they stated that students generally enjoyed greater autonomy and were highly motivated in the inquiry classroom; they developed their inquiry skills as a result of working with engaging and relevant contexts; they enjoyed working as part of a group because it gave them the chance to 'talk things through'; they enjoyed gaining an insight into their own contribution within 'the team' and they generally found self and peer assessment beneficial to their learning.

4. Synthesis of Case Studies within each Unit

The preparation and presentation of the final SAILS units, has involved the development of initial draft units which have been trialled by at least three teachers across the participating countries. The unit leader has collaborated with relevant SAILS partners to compile a synthesis report of all the CS reports in that unit. This synthesis discusses the DU implementation and how adaptations were made by teachers along with an account of the assessment strategies adopted. By this stage over 80 case study reports had been produced by teachers and 17 syntheses of the CSs have been completed and are presented in the following sections, and outlined in Table 4.1.

TABLE 4.1 LIST OF UNIT SYNTHESIS AND CONTRIBUTING CASE STUDIES.

SECTION	UNIT	CASE STUDIES
4.1	Acids, bases and salts	CS1 Greece, CS2 Turkey, CS3-6 Slovakia
4.2	Black tide: Oil in the water	CS1 Portugal, CS2 Hungary, CS3 Hungary and CS4 Germany
4.3	Collision of an egg	CS1 Hungary, CS2 Denmark, CS3 and CS4 UK
4.4	Electricity	CS1 Slovakia, CS2 Ireland, CS3 Turkey and CS4 and CS5 Poland
4.5	Floating Orange	CS1 Germany, CS2 Hungary, CS3 Poland, CS4 Sweden, CS5 and CS6 England
4.6	Food and food labels	CS1 Turkey, CS2 Hungary, CS3 Ireland, CS4 Portugal
4.7	Household vs. Natural Environment	CS1 Ireland, CS2 Greece, CS3 Portugal and CS4-6 (three teachers) Poland
4.8	Light	CS1 Ireland, CS2 Ireland, CS3 Greece and CS4 Slovakia
4.9	Natural Selection	CS1 Poland, CS2 Hungary, CS3 Denmark
4.10	Plant Nutrition	CS1 Slovakia, CS2 Portugal, CS3 Slovakia
4.11	Polymers – properties of plastics	CS1 Ireland, CS2 Poland, CS3 and CS4 Slovakia (B) and CS5 Turkey
4.12	Reaction Rates	CS1 Hungary, CS2 Ireland, CS3 England, CS4 Turkey
4.13	Speed	CS1 Germany, CS2 Ireland, CS3 Portugal, CS4 Turkey
4.14	The proof of the Pudding	CS1 Greece, CS2 Ireland, CS3 Slovakia
4.15	Ultraviolet Radiation	CS1 Denmark, CS2 UK, CS3 Germany
4.16	Up there, how is it?	CS1 Portugal, CS2 Slovakia, CS3 Sweden
4.17	Woodlice	CS1 Ireland, CS2 Poland, CS3 Slovakia, CS4 Portugal, CS5 Sweden

4.1 Acids, bases and salts

In this unit, students explore acids, bases and salts as substances that are used in everyday life. The unit includes seven learning activities with the intention of increasing students' interest and motivation in the topic and helping them bridge the gap between observed phenomena and scientific theory. The activities refer to elements from everyday life that contain acids and bases in order to motivate students to understand basic chemical properties and how to detect acids and bases through experimentation with the use of an indicator. The students are given the opportunity to develop a number of inquiry skills such as developing hypothesis, carrying out an investigation, forming coherent arguments and working collaboratively. In addition, they have the opportunity to enrich their scientific literacy and reasoning capabilities. Finally, by performing the described activities students will gain experience in working together, making arguments with justification and presenting their evidence to back up their conclusions.

This unit was trialled in three countries producing six Case Studies (CS) of its implementation as follows:

- CS1, Greece
- CS2, Turkey
- CS3, CS4, CS5, CS6, Slovakia

Teachers who had some experience in teaching through inquiry implemented all of the case studies. However, the students involved had not been taught through inquiry before except for the case studies, CS4 (one lesson experience from CS3), and CS6 (one lesson experience from CS5).

The ages of the students involved in the case studies were 12 years old in CS1, 14-15 years old in CS2 and 13-14 in CS3-CS6. The students in each class were of mixed skills level and mixed gender. CS1 case study was implemented in 4.5 hours. CS2, CS3, and CS4 case studies were implemented in 1 hour each. Finally, CS5 along with CS6 were implemented in 5 lessons.

4.1.1 Teaching Approach

Inquiry approach used:

The inquiry approach used in all the case studies was that of guided inquiry (Wenning, 2007). According to Wenning (2007) the guided inquiry process is characterized by a teacher-identified problem and multiple questions that lead the way to proceed in the experimentation in order that the goal of the lab experimentation is achieved. Through this model students are able to exploit pre-existing knowledge in order to formulate initial hypothesis, which will then help them structure their research.

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:

CS1	23 students in groups of 4-5 teacher allocated groups to be mixed skills level, mixed gender
CS2	18 students in groups of 3-4 self-selected, mixed gender
CS3, CS4	18 students in groups of 3-4 teacher allocated groups to be mixed skills level, mixed gender
CS5, CS6	25 students in groups of 3-4 self-selected

The unit has the following main activities:

- A1. *Initial experimental activity for the motivation and active engagement* of the students with the inquiry. Students taste various sample substances of acids and bases from everyday life and "record" the taste feeling, the smell, and other general observations for each one of them.
- A2. *Experimental activity for the detection* of acids and bases using pH indicator extracted from red cabbage.
- A3. *Experimental activity where students make pH measurements* in order to construct their own pH scale.
- A4. *Experimental activity for the introduction of* the existence of salts, their properties and the fact that they have no effect on indicators.
- A5. *Experimental activity where students discover* the property of acids to dissolve salts and the property of bases to dissolve fat.
- A6. *Summarization activity where students through discussion* and their observations and records from the previous activities and worksheets they reach and write their final conclusions.
- A7. *Activity for the connection of students' gained knowledge with everyday life*. Groups are free to rely on their worksheets as well as in books in order to answer open questions. The evaluation of the answers is made by peer group with the use of a holistic rubric, which assesses the accuracy and completeness of students' answers.

The starting point for the case studies CS1, CS2, and CS3 was A1 activity. CS1 was based on all activities A1-A7, while CS2 was based on activities A1-A5. CS3 was based on activities A1-A3. In CS4 the starting activity was A4 because the students had already been exposed to activities A1-A3 in previous lesson through CS3.

Finally, the CS5 and CS6 case studies include activities that the teacher proposed as adaptations of activity A2. 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 pupils of 8th grade at Primary school.

The following inquiry skills were identified by the teachers in each case study:

CS1 Developing hypothesis, planning investigation, carrying out investigations, data analysis, debating with peers, teamwork

CS2 Observation, classification, making comparisons and building relationships with daily life

CS3 Formulation of hypotheses, understanding

CS4 Development of scientific literacy, understanding, reasoning, formulation of conclusions, communication skills

CS5 Suggestion of hypotheses, understanding, science literacy, planning of procedures of exploring

CS6 Suggesting of hypothesis, scientific reasoning, development of scientific literacy – understanding based on metacognition

In CS1 the teacher performed all the suggested activities as described in the corresponding four phases of the unit. The four phases correspond to the guided research teaching model of Schmidkunz & Lindemann (1992). Through this model students are able to exploit pre-existing knowledge in order to formulate initial hypothesis that will then help them schedule their research. Lower secondary school curricula in countries like Greece and Cyprus make use of this model in science courses considered as the optimal choice (Sotiriou et al. 2010). In phase 1 "Bringing up the phenomenon to a problem - Formulating Hypotheses" the teacher presents the concept/problem/theory under research and starts a discussion with students in order to emerge alternative theories. The students then perform hypotheses and predictions that constitute the guidelines for their research. In phase 2, "Experimental approach of the problem" the students set-up the experiment with the support/guidance of the teacher. During experimentation, students make measurements and record their findings. In phase 3, "Conclusions" the students summarize through discussion their observations and records from the previous phase. Based on these observations they reach their final conclusions, which have to be written down separately. They also compare the results that they end up with the

initial hypothesis they had developed in initial phase. In phase 4, (Consolidation - Apply new knowledge in everyday life) the teacher questions and assigns exercises and tasks aimed at consolidating of the acquired knowledge. Through this, students' also learn how to apply the newly acquired knowledge to their own lives.

In CS2 the teacher started the lesson by asking students what they eat at breakfast, lunch and dinner to motivate them. Then teacher asked follow-up questions related to students' answers. For instance, students said "sweet, sour or bitter" teacher responded "why you felt this and what it had for this taste". After the new question some of the students said that these foods consist of different substances. So we can say that every student's answer reshaped teacher's question in this warm-up activity. Then, the teacher followed the suggested learning sequence. The students used self-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 judgement 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. Teacher encouragement and feedback motivated students. For instance, when some groups did not achieve a colour change in the vinegar, the teacher and students talked altogether to discuss why it did not change. After this the teacher encouraged them to do activity again.

In CS3 the teacher gave additional tasks to the students during A1 activity ("Find out on the Internet (in encyclopaedia, in textbook) the meaning of the term INDICATOR" and "Suggest the procedure how to prepare an indicator from cabbage. What tools will you need?" because they did not have experience with inquiry-based activities and they needed to know the meaning of the term indicator. Also, the teacher asked from students to prepare at home the indicator. Also, during the 2nd activity students worked with homemade indicator (cabbage extract) and they searched the pH values of available solutions on the Internet. To motivate and stimulate students the teacher posed the following open questions:

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

In CS4 the teacher followed activity A4 without any modifications. As students were already familiar with the function of indicators from the previous inquiry-based activities, during this activity they observed that the indicator does not change its colour in solutions of powdered chalk and in a solution of kitchen salt. They were supposed to explain this phenomenon. The teacher modified activity A4 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 pupils 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 the inquiry activity was: "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 of the acids they explored and they found out about the practical importance 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 pupils´ worksheet, its realization and recording of the observed changes into a well-arranged table. Organisation of the inquiry was also very important – pupils had to arrange the samples of solutions of acids according to their order in the table (or to mark them with numbers), but they also had to be careful and do not 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 is the first aid procedure after an acid-spill?

In CS6 the inquiry activity was: "How do chemists distinguish acids from bases?" and it was based on the activity A3 of the unit as well as on the previous proposed activity. The underlying 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:

- 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 and realized inquiry-based activities. They determined colour changes of solutions and measured pH of acid and base solutions. They have already had experience with inquiry-based method from the previous lesson, during which they explored acids. In this lesson, bases were added.

4.1.2 Assessment Strategies

Within the six case studies, the inquiry skills of developing hypotheses, forming coherent arguments, carrying out an investigation, and working collaboratively were assessed in different ways. Additionally the content knowledge and evidence of scientific literacy and 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 a Hypothesis

Evidence of the students' skill in developing a hypothesis was captured in all case studies except CS2 and CS4. The students formulated and wrote in a worksheet a hypothesis about what will happen during the realization of an experiment. In most cases the teacher developed his/her own rubric to assess the skill except in CS1 where the teacher firstly asked from groups to self-assess their hypothesis during the conclusion phase and then he checked and corrected their assessments.

Working Collaboratively

In CS1 and CS4, there are examples of working collaboratively being assessed by the teacher as well as being self-assessed by the student. In CS1 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 gained experience of each role. The teacher observed the groups during the activities and characterized their collaboration as satisfactory. In CS4 the communication skills were verified by the students. They used an assessment table, which was filled in after the inquiry-based activities. This was separate from the assessment of group work and the assessment of individual work.

Forming Coherent Arguments

All CSs include activities where students try to formulate coherent arguments. However, this skill was assessed during the conclusions phase at the end of the students' exposure to the underlying inquiry based scenario. There were two different assessment strategies. In CS1 the teacher verified the underlying skill using peer assessment and a rubric that he had already developed and shared with the

students. In CS3 and CS5 the teacher created self-assessment cards for students, which were given to students after the teaching of the topic.

Carrying out an investigation (pH scale construction)

There were several points where the teacher could assess the skill of carrying out an investigation. The unit proposed a specific assessment point. This was when students were measuring pH to construct a pH scale. There were also two different assessment strategies. In CS1 the students constructed the pH scale and the teacher verified the underlying skill using peer assessment and a rubric that the teacher had already developed and shared with the students. In CS2 the teacher observed the construction of the pH scale and assessed it in a formative way. Finally, in CS3 the construction of the pH scale was also assessed in a formative way using the scale (correct-with mistakes-incorrect-disinterest)

Content knowledge and scientific literacy/reasoning

All CSs include activities for assessment of content knowledge and scientific literacy and reasoning. In CS2 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 correctly answered questions asked by the teacher
- Measurements which were correctly obtained from pH scale
- Whether or not the students correctly categorized acids, bases and salts.
- Inferences, these inferences i.e. acids change pH paper to red colour and matter and bases change pH paper to blue colour.
- Whether the student gave some examples which are related to daily life

The criteria were not shared with the students beforehand. The teacher observed the groups to decide whether the groups met the criteria. Additionally, the teacher asked questions to each group. For instance, “what do you think about this matter?” “why do you think like that about this subject?”.

In CS1 each group had to answer some questions about acids and bases in everyday life. These questions also elicit previous knowledge gained by the students in Physics courses. In order to answer, groups were free to rely on their worksheets as well as in books. The evaluation of the answers was made by peer groups with the use of a holistic rubric, which assesses the accuracy and completeness of students’ answers. The rubric provided students with a guide to grade the worksheets based on the weight factor of each criterion which they had been notified about in advance of the activity. The teacher led the discussion in the last part in order to facilitate the final correction of answers. Finally, with the completion of the scenario, every student

completed an individual test. The test contained a range of questions including matching questions, fill in the blank questions and short answer questions in order to assess his/her personal performance.

In CS3 and CS4 the skill understanding was assessed through analysis of the self-assessment cards completed by the students after finishing the inquiry-based activities. In CS4, a scale questionnaire was used to evaluate understanding of the observed phenomena according to the following criteria:

- Explanation of the fact that the indicator did not change its colour in solutions of powdered chalk and kitchen salt
- Explanation of the fact that mixing of an alkaline and acidic solution creates a neutral solution

In CS5 the skill understanding (development of scientific literacy) was assessed by metacognition. After the lesson, students filled in a questionnaire with the following questions:

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

4.2 Black tide: Oil in the water

In this unit, students are introduced to concepts involving sustainability on Earth: ecosystems - disturbances in the balance of ecosystems, sustainable management of resources - natural resources - use and consequences, protection and nature conservation, costs, benefits and risks of scientific and technological innovations, classification of mixtures related to energy. Since the seventies of the twentieth century that oil spills in the ocean are in the news. The Amoco Cadiz accident, which occurred in the French administrative region of Brittany in March 1978, is one of the best known. This disaster spilled 1,635,000 barrels of oil, equivalent to about 220 tons. The Exxon Valdez spill a much smaller amount, 260 thousand barrels, about 35 tons. The consequences for the living species (including human beings) and ecosystems are dramatic. The Exxon Valdez case was adopted for study. This unit aims to explore some of these consequences mobilizing scientific culture and pursuit for students to apply knowledge and science processes.

Synthesis of Case Studies

This unit was trialled in three countries, producing four case studies of its implementation. (CS1 Portugal, CS2 Hungary, CS3 Hungary and CS4 Germany). All the case studies were implemented by teachers who had some experience of teaching through inquiry and the students had already experienced inquiry activities except for CS1 where the students have no experience with inquiry.

The students involved in the case studies were 12-14 years old in CS1, 13-14 years old in CS2, 15-16 years old in CS3 and 12 years old in CS4. Also the students in each class were mixed ability and mixed gender. In CS1 the students group revels a very good performance level in school achievement.

The case studies CS2 and CS4 describe 2 lesson periods of 45 minutes each. CS3 describes 1 lesson period of 45 minutes plus a double lesson period of 45 minutes. CS1 describes 6 double lesson periods of 45 minutes.

4.2.1 Teaching Approach

Inquiry approach used:

The inquiry approach used in all the case studies was that of bounded inquiry, i.e. it was guided in the sense that the teacher posed the initial question but there were open inquiry opportunities in that students had freedom in addressing the question.

Implementation:

The students in all the case studies worked in groups throughout the lessons.

This activity starts from the analysis of an environmental problem and requires from students the planning of an experimental activity. This can be totally open (students propose all planning and implement it) or can be guided (students propose and discuss a planning but follow a given protocol). Basically it develops through

collaborative work and can be used to integrate different curricular subjects (physics, chemistry, biology, geography, mathematics, environmental education).
The improvement of the activity can come from different suggestions resulting from the different case studies, such as:

- Although the original unit is more focused on observation skills it can be improved by collecting data through physical measures (e.g. surface area and volume) (CS2). It can also be improved by creating devices for the oil removal (CS4). One important aspect to discuss with students can be how to find a good cleaning agent to remove oil from the bird feathers, allowing them to survive to this kind of environmental disaster (CS3).

This activity aims to contribute to the understanding of inquiry process, namely experimentation, and to the promotion of thinking skills and attitudes and values enabling students to play an active role in decision-making about socio and environmental concerns.

The teachers in each case study identified the following inquiry skills:

CS1 Planning investigations, formulating hypothesis and implementing an experience

CS2 Formulating hypotheses, research questions, identifying, defining variables and working collaboratively

CS3 Developing hypotheses, planning an investigation, interpersonal skills: cooperation, flexibility, precision and scientific literacy

CS4 Planning an experiment and conducting an experiment

4.2.2 Assessment Strategies

The skills assessed through this unit could be: planning experiments (in particular formulating hypothesis and identifying the different variables involved), presenting coherent arguments and working collaboratively. This assessment could be realized through the analysis of students' artefacts (all case studies), direct observation of students working in groups using rubrics (CS1), and peer assessment, through oral comments on the ideas of other students (CS4). The assessment data could be used to give oral feedback during the activity, namely during collaborative work (all case studies), and written feedback at the end of each task, in order to allow students to reformulate their work (CS1 – written feedback to planning an investigation).
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 and formative assessment guided the student learning during the class.

In CS1, the teacher used an assessment tool that assesses three dimensions: to set objectives; to define strategies and procedures; to identify and select appropriate resources. The instrument contains three performance levels. The students' written work was carried out in class. The teacher's written comments were made after class. In class the teacher handed the students work with written feedback, and they had the opportunity to read the feedback and to ask questions. The teacher was following the work development, questioning students and it was very clear regarding to what was intended, answering all the students' questions.

In CS2, the teacher used the worksheets handed in by the students and the questions asked by the teacher at the end of the second-class period. Assessment was formative and each group was given oral feedback.

In CS3, the teacher guided the students with facilitating questions. The groups were given grades based on the collected worksheets and the photographs they took during the activity. Another source of assessment was the students' work during the completion of the task.

In CS4 - the teacher used mainly two different formative assessment strategies: a) Peer assessment: Students commented the ideas of other students; b) Teacher watched, were listening and gave advice for additional experiments. There was no use of rubrics. Also no criteria have been fixed in a written format before the unit. However, the teacher had a clear idea about the expectations in this unit.

4.3 Collision of an egg

The unit was primarily planned to evoke students' inquiry skills in designing experiments. In its simplest form, two independent variables can be defined in the experiment: the height, from which the egg falls down, and the type or the quality of the ground onto which the egg falls. The dependent variable was of dichotomous nature: whether or not the egg crashes on the ground. Besides designing the experiment, students' capabilities in forming hypothesis can be developed, and – from the affective side of personality – their motivation can be enhanced, since the way they carried out the experiment may result in immersion in doing science. Thirdly, working collaboratively with peers is a must when implementing the research design they have developed. In fact all kinds of inquiry skills can be addressed through this unit. This unit is suitable to address all phases of scientific inquiry.

The ethical issue of experimentation with things that may potentially be food can be at least in part resolved by pointing to the knowledge gains students receive from experimentation: they even learn how to take care of eggs.

Synthesis of Case Studies

Four case studies are involved in the current synthesis: the original Hungarian study, the Danish study, and two case studies from England.

Time required for case studies: 90 minutes in Hungary; 2 hours in Denmark; 4x60 minutes in one of the English case studies, and "5 lessons" (maybe 5x45 minutes) in the other.

Age groups involved: 15-16 years in Hungary; 13 years in Denmark; 12-13 years and even 11-12 years in England;

4.3.1 Teaching Approach

Inquiry approach used:

Unstructured problem in Hungary, with materials and equipment provided; in England the lessons were held in laboratories. In the first English case study "students were encouraged to generate a list of equipment that they needed for their inquiry" while in the second they "were shown buckets of different materials (sand, vermiculite and flour) and eggs (rubber and real) as a prompt for them to plan an open-ended investigation".

Implementation:

Students worked in groups in all case studies (in groups of 4; however, Denmark did not give exact data).

Adaptations of the unit:

The unit allows for various implementation designs with various levels of teacher guidance. For example, the two English case studies differed in the level of teacher guidance (whether or not the students chose and gathered the materials and equipment needed, or received it as a starting package). Lesson design took into

account students' previous experiences about inquiry lessons. The Danish students were novices to inquiry, therefore the teacher tried to follow pre-planned sequential lesson phases. However, students in the first English case study (those who were free to choose materials and equipment) had previous experience with inquiry lessons.

4.3.2 Assessment Strategies

Even though the unit gives the possibility of assessing several inquiry skills, in real classroom situations teachers are advised to focus on at most two (or in exceptional cases three) inquiry skills. In the case of six groups this might mean 6x2 group-level assessment protocols which in practice seems to be quite a challenge to carry out.
The rubrics presented in the unit draft served as the basis of formative assessment even when there were deviations from those. The original rating scale provided examples for differentiating between three different levels. The Danish teacher "tried to use what she remembered from the rubrics intended for assessment", but real-life procedures overwrote her plan, and the rubrics became unusable. The first English case study reports on conscious deviation from the rubrics given in the unit draft, and the teacher assessed students "using their own understanding". The second English case study reports on using rubrics.

Planning an investigation is the focus of the current unit. The original three-level scale used in the Hungarian case study is based on the assumption that students will make some suggestions on how the experiment should be carried out. The students' suggestions may be of different standards, from just raising quick ideas to elaborating whole plans. The two consecutive levels in the rubrics are: understanding the process, and proceeding with the planning of the experiment. According to the four case studies, students' previous involvement in classroom inquiry will give the basis for any rubrics or other ordinal scale assessment. Those who have already had some knowledge about dependent and independent variables may receive feedback based on the quality and feasibility of their chosen variables. Those who are completely new to classroom inquiry may be assessed according to their intuitive understanding of keeping constant one variable while manipulating the other. In the second English case study, students' self-assessment was supported.

Making hypothesis is a skill that was also measured on a three-point ordinal scale in the original unit draft. Even at the lowest performance level students are expected to form a hypothesis, and on higher levels they can justify and explain it. In the first English case study, the assessment of this skill was based on "how students identified what variable to measure". In the second English case study, peer-assessment was carried out on the basis of "is this hypothesis a testable statement".

Debating with peers –this inquiry skill was also addressed in the case studies albeit not explicitly. In the second English case study, the teacher's statement (students worked in a "meaningfully collaborative way") describes the working climate and the possibility of making this whole-class judgment possibly more explicit in the classroom. The first English case study reports on students' smooth group work (e.g., "analysed their results together"), however, the fact that some students left work too early points to the possibility of a refined ordinal scale in measuring the quality of debating with peers.

4.4 Electricity

4.4.1 Teaching Approach

Participants

The Draft Unit *Electricity* was implemented in four countries: Slovakia, Ireland, Turkey and Poland (unit developer location) by 14 teachers in altogether 17 classes of lower or upper secondary schools, comprising 333 students. Lower secondary learners have been chosen from mixed classes in Turkey (1 class), Poland (1 class) and Slovakia (11 classes). In Ireland the unit was implemented in two all-girl lower secondary classes, while a mixed class at upper secondary level was selected in Poland and Slovakia.

Organization of the lesson

Implementation of the unit took 45-90 minutes, depending on the country. That means only one lesson in some classes in Slovakia and two lessons in all other countries. Learners worked in groups of 2-3 pupils having mixed abilities (Ireland), of 3-5 pupils (in Poland), of 4 persons in each class in Slovakia and as a whole class comprising of 16 students in Turkey. Each learner was given one worksheet and completed it individually, except for one class in Poland where the learners took individual notes.

Content

In all 17 cases the Draft Unit *Electricity* was implemented as a guided inquiry activity, as anticipated in the DU description. In three classes (Poland, Turkey and Ireland) learners did not have lessons on electricity prior the implementation, while in all other classes the lessons were provided as revision. If electricity had not been covered before the implementation of the DU, the mind map was used to set the everyday context. If electricity had been introduced beforehand, the mind map was utilized as a revision exercise. In one class the mind map was used for comparison at the beginning and at the end of intervention.

The unit was usually followed as provided, however in some cases (Ireland and Poland) sec. IV was partially or entirely skipped during the lesson.

Feasibility

Teachers implementing the *Electricity* unit shared opinion that it was doable in two lessons. Slight modifications were proposed by some of the teachers, namely introduction of generation of research questions (Turkey), use of a mind map both at the beginning and at the end of a unit (Ireland, two classes), construction of a model of an electric circuit (Ireland, two classes) and omission or shortcuts in sec. IV (Poland and Ireland).

4.4.2 Assessment Strategies

In the presentation of the unit there was clear indication of assessment opportunities provided. No teacher implementing the unit has used all of these.

Inquiry Skills and scientific literacy/reasoning

In original scenario of the unit three skills have been chosen to be assessed during implementation in the classroom. *Scientific literacy and reasoning* about electricity could be evaluated four times - in two brainstorms, by design of a mind map and with use of graphical and schematic representations of working electric circuits. *Planning an investigation* was anticipated at one moment of the lesson and could be a part of a group work assessment. *Searching for information* was given at the end of the unit and could be used as a homework exercise.

In addition to these, three other assessment opportunities were realized by teachers implementing the *Electricity* DU in their classrooms and proposed together with new assessment tools. *Constructing a model of an electric circuit* was added by an Irish teacher. *Engagement in* a *group work* was proposed by one of Polish teachers. G*enerating a research question* was added by a teacher from Turkey.

Assessment tools

At different moments of the lesson the unit offers several assessment tools, based on three components, namely rubrics, brainstorming chart and a tool for self- and peer assessment of engagement in a team work.

In the original unit the rubrics are proposed for assessment of four activities – twice for assessment of *scientific literacy and reasoning* (a mind map and use of graphical and schematic representations of working electric circuit), once for assessment of *planning an investigation* and once for *searching for information*. All, rubrics are based on four levels of learner development. Rubrics were implemented without changes except for one case in Poland where a teacher decided to extend rubrics

from four to six levels, in analogy to the idea of six-level scale of traditional grades that she was used to in her teaching practice. Additionally original rubrics for *constructing a model of an electric circuit* were included by an Irish teacher.
Brainstorming chart is introduced in the *Electricity* unit twice as the assessment tool for evaluation of *scientific reasoning and literacy,* at the moments when an entire class takes part in a vivid discussion.
Self- and peer assessment tools are not included in the original scenario, but were added by one of Polish teachers for evaluation of *engagement in a group work*.

Implementation and evidence
Learners working with *Electricity* DU were assessed both as they worked during the lessons and afterwards, on the basis of tasks completed in worksheets. Solely in Slovakia all teachers used only the latter strategy of assessment. In addition to that in many cases teachers posed questions and gave feedback orally (Turkey, Ireland, Poland), but it was undocumented. Different teachers had preference of different assessment tools.
Mind map activity with rubrics was used only in Poland and Ireland, and in the latter it was utilized twice, at the beginning and at the end of unit implementation, thus in Irish classes rubrics for assessment of a mind map were changed accordingly. Evaluation of planning an investigation with use of rubrics was introduced in Poland and Slovakia. Activity of searching for information was given as a homework exercise only in Slovakia and as such it was assessed with rubrics. Group work engagement was evaluated by self- and peer- assessment tool only by one teacher in Poland, who added this tool to the original scenario of the unit. Constructing a model of an electric circuit was assessed only in Ireland, since rubrics for this activity was an original contribution of an Irish teacher to the unit. Evaluation of generating a research question was implemented only by a teacher in Turkey who did not propose any specific assessment tool for this activity and based her judgement on her own opinion.
Problems encountered.
Teachers in Slovakia considered the assessment based on observing students during their brainstorming activity (assessing pre-knowledge, activity and creativity) and drawing a concept map rather problematic. Thus they utilized only the rubrics. At the same time a teacher in Turkey liked to implement brainstorming chart, but reported substantial problems with implementation of rubrics during the lesson and would rather prefer to utilize this tool for evaluation of student worksheets. Teachers in Ireland and Poland did not mention any problems in implementation of the assessment strategy originally proposed for this DU.

4.5 Floating Orange

This unit was designed initially for teachers in England because they were keen to move away from assessing inquiry skills through laboratory reports and wanted to start assessing during the process of the inquiry. One of the skills they were keen to encourage in their learners was students raising their own questions and then devising appropriate methods to test their ideas. A further area that they were keen to begin encouraging and assessing was teamwork and collaboration, which the teachers felt were important life skills that an inquiry approach can engender.

Clearly, in different country contexts, the teachers had other pedagogic aims and so adapted the unit to suit their classrooms. However, in each of the implementations there was a strong practical component relating physics with students' daily lives. The unit then led from planning to executing experiments. In doing so, they addressed the skill of planning investigations, gained experience in working together, developed their reasoning capabilities, and learnt about density and upthrust.

Almost all students were able to carry out the experiment albeit with different degrees of guidance. Most students were reported to be motivated and enthusiastic.

This unit was trialled in five countries, producing six case studies of its implementation (CS1 Germany, CS2 Hungary, CS3 Poland, CS4 Sweden, CS5 and CS6 England). The CSs were carried out by school students with the exception of CS4 Sweden, where the activity was done with teachers. In the schools, the case studies were implemented by teachers who had some experience of teaching through inquiry but the students involved had generally not been taught through inquiry.

All CSs concern a single class period of around an hour, with the exception of CS2 Hungary, who did the inquiry over two 45 minute periods.

4.5.1 Teaching Approach

Inquiry approach used:

The inquiry approach used across the case studies ranged from open to guided inquiry. In CS4, CS5 and CS6, a more open approach was taken where the participants were provided with apparatus to explore ideas and generate a question, which they then investigated. In CS2 and CS3, the teacher set the inquiry question through an introduction and worksheet instructions that guided the students towards generating a question and working out how to tests this. In CS1 Germany, an intermediate approach was taken as the teacher provided a broad inquiry question – Do different citrus fruits have the same floating characteristics? The German students then had to plan an inquiry to answer this question.

In each of the case studies, the students explicitly or implicitly dealt with density. This led them to take measurements of the way the oranges and other fruits floated

in water. Some students adapted apparatus by drawing scales on the sides of beakers or on the fruit itself to try and get a more accurate measure of how the floating behaviour changed as they changed parameters, such as depth of water, temperature of water, salinity of water or as they changed the fruit by either removing the skin, breaking it into smaller pieces or making holes in the fruit. In all cases they used observational and measurement skills and from these data made inferences that led them to investigate further and find an answer to the question they raised.

In all cases the skill of planning investigations was addressed and the students showed that they could recognise variables and, in some cases control and manipulate variables. Even when the teacher posed the questions to be investigated, students raised subquestions which often served for them to identify variables. The majority of the students were able to decide how they would take measurements of the variables they had identified, with the exception of CS2, where the students had some difficulty deciding how they would do this and had to be prompted by their teacher. This was a surprise to the Hungarian teacher who felt that the novelty of inquiry perhaps intimidated his students.

All partners focused on the planning aspect of inquiry with CS4 looking to assess all aspects of an investigation, although this was possibly because CS4 worked with teachers rather than school students and so could take a broader look at assessment. CS3 also decided to assess whether students could form coherent arguments in their answers. The following inquiry skills were identified by the teachers in each case study:

CS1	• Planning an investigation • Debating with peers
CS2	• Planning an investigation Debating with peers
CS3	• Raising scientific questions • Planning an investigation • Conducting an experiment • Working collaboratively • Forming coherent arguments
CS4	• Formulating hypothesis and research questions • Designing experiments • Recording data and observations • Improving an experiment
CS5 & CS6	• Raising an inquiry question and developing Hypothesis • Working collaboratively • Designing an experiment (Working beyond original question)

All partners worked in groups during the inquiry although CS1, CS2 and CS3 required the students to produce individual written artefacts as well for assessment purposes.

4.5.2 Assessment Strategies

All teachers used a criterion-referenced approach to assessment and mainly used rubrics, although CS3 Poland simply stated what they considered a suitable performance for each skill and presumed that anything above or below this would be commented on. CS1, CS4, CS5 and CS6 engaged in on-the-fly assessment during the process of the inquiry, while CS2 and CS3 assessed using the worksheet and students' reports on the inquiry. However, in all the case studies, the way the students worked collaboratively was assessed from direct observation during the inquiry. Within the case studies, the inquiry skills of raising a question, formulating an hypothesis, planning an investigation, forming coherent arguments and working collaboratively were assessed in different ways.

For some skills, the assessment was carried out after class and was based on a written artefact produced in class. Others involved the formative assessment that guided the student learning during the class. For example, CS1 used Fist to Five, i.e. to give feedback the students used their fingers as a scale (fist: I did not understand – five fingers: Everything is totally clear) and "green, red and orange cups" during the inquiry for students to signal to the teacher how confident or not they felt with that aspect of the inquiry. In the English classrooms, the teachers used a range of questions designed to probe understanding during the inquiry process, while, at the same time trying not to lead the students towards a specific route within the inquiry. For example, they would ask "what was your reason behind that choice?" or "why did you choose that specific method? Were there others you considered?" CS2 gave feedback at the end of the first lesson, based on observations of the class activities, and at the beginning of the second lesson, based on the written plan of the inquiry they had produced.

In CS3 and CS1, the teacher reported that the students enjoyed the inquiry activity. In CS1 and CS5 and CS6, the students used peer and self-assessment to both report back on how they had responded to the inquiry but also to set themselves targets for future inquiry activities. CS4 also used peer assessment with its teacher group. CS3 used a written feedback sheet from the teacher after the inquiry had been assessed.

CS1 noted that some groups required different time slots during the planning phase as some groups raised a question and decided to work with that while other groups were more willing to generate a range of questions and then decide which would be best to pursue.

Summary

While some changes were made to the original inquiry to fit the context of the specific classroom or adapt to particular learning needs of students, the main ideas of raising testable questions and planning an inquiry were done in all CSs. While, for several of the partners, an inquiry learning approach was relatively novel, it was clear that teachers had begun to look at formative routes for assessment, such that guidance and advice could be given to students as well as strengthening feedback to teachers through specific assessment for learning strategies in CS1. It is interesting how all the teachers seemed able to assess working collaboratively during the process of the inquiry. Perhaps one of the most relevant findings was that students enjoyed and were motivated by the inquiry activity and the teachers seemed relatively confident in both facilitating the inquiry and assessing it.

4.6 Food and food labels

This Unit was designed to include inquiry through scientific reasoning and discussion. The topic, food and food labels, is one that students encounter many times throughout their time in school. The main reason for including it in the curriculum is to help students understand what makes a healthy balanced diet. From this stance they can then look at their own diet and that of others and make recommendations about how to improve their diet.

However, it is often the case that the ideas behind obtaining a balanced diet are not considered in sufficient detail. Students tend to encounter simple categorisations of food such as healthy or unhealthy or as fats or proteins. In these situations the true composition of foods and the amounts needed to keep someone healthy are not looked at. Hence, students do not have sufficient knowledge and skills to make the choices that they need to when it comes to their own diet.
The original unit looked at two different types of skills. Proportional reasoning is the first skill. It is included because students need to be able to compare different amounts and types of food in their diet. The second is a raft of skills that fall under the umbrella of **investigative/process skills.** Furthermore 'discussion' and 'collaborative work' are key features of this unit and they were assessed in several of the case studies.

Clearly, in different country contexts, the teachers had other pedagogic aims and so adapted the unit to suit their classrooms. However, in each of the implementations there was a strong practical component and the unit was related to students' daily lives. The unit then led on from analysing food labels and composition of meals and daily menus to an inquiry that investigated the amount of vitamin C in a range of foods and drinks. In this inquiry activity the skills of Planning Investigations, working together and reasoning were experienced and developed through practical work. Most students were reported to be motivated and enthusiastic.

Synthesis of Case Studies

This unit was trialled in four countries, producing four case studies of its implementation - CS1 Turkey, CS2 Hungary, CS3 Ireland and CS4 Portugal. The case studies were carried out by school students; CS2 and CS3 carried out the inquiry with lower High school students while CS1 and CS3 worked with upper High school students. Teachers who had some experience of teaching through inquiry implemented the case studies however, the students involved had generally not been taught through inquiry previously.

CS3 and CS4 completed the inquiry activity in one period of approximately one hour, while CS1 and CS2 completed the inquiry activity over two 45-minute periods. CS1 and CS4 looked at all areas of the unit, while CS3 adapted the activity and asked students to discuss what they felt junk food was and consequently only assessed argumentation. CS4 decided to use the ideas in the activities to adapt the Packed Lunch activity and asked students to design a snack, and so apply the knowledge they had gained through the inquiry. CS4 decided to assess teamwork and debating with peers.

4.6.1 Teaching Approach

Inquiry approach used:

The inquiry approach used across the case studies was guided inquiry as the teachers felt that they needed to introduce some ideas about nutrition and diet before the students commenced the activities. The teachers then set the inquiry question and the students worked collaboratively on the various activities. In all partner countries, the students worked in groups. All of the schools were mixed gender with the exception of the Irish school (CS3), which was all female. The teacher made no specific choices regarding how to form the groups for the activities beyond whom the teacher felt would work well together.

Implementation and Adaptation of the Unit:

In each of the case studies, the students explicitly or implicitly dealt with the concept of healthy diets and food choice. CS1 and CS2 carried out most of the activities in the unit, with CS1 dividing some of the activities to be done by younger groups (Food Labels) and others for older groups (Packed Lunch Activity). The Turkish group were quite resourceful, getting children to produce their own food labels by looking up food composition, when no food labels were available for the activity. Additionally the Turkish group could not find a supply of chemicals for the Vitamin C analysis and therefore decided to test foods for fat content instead.

4.6.2 Assessment Strategies

A range of different approaches to assessment were adopted in the different case studies. In CS1 Turkey used a criterion-referenced approach and devised rubrics. The skill Critical thinking was assessed in the Food Label activity. This skill is an important component of the 21st Century Skills set and a pertinent part of scientific literacy. For the most part, students were assessed as groups but the teacher did also managed to assess a few individuals too.

Assessed skills	Students' achievement			
	Emerging	Developing	Consolidating	Extending
Critical thinking	Mostly correctly orders a sufficient number of food cards for each nutrient with no interpretation.	Correctly orders a sufficient number of food cards for each nutrient, draws appropriate conclusions about individual groups of nutrients and occasionally about combinations of 2 nutrients.	Mostly correctly orders all available food cards and draws appropriate conclusions for a combination of 2 or 3 groups of nutrients. Brings up considerations of quantity in discussion.	Mostly correctly orders all available food cards and draws appropriate conclusions about all groups of nutrients in combination. Makes a valid point about quantity in discussion.

Making reasoned decisions was the second skill assessed. This skill builds upon critical thinking and was used to assess the choices made for their lunchbox. Decision making incorporates both teamwork and discussion when carried out through a collaborative learning approach. The teacher was able to assess individual performance within the group situation.

Assessed skills	Students' achievement			
	Emerging	Developing	Consolidating	Extending
Making reasoned decisions	Mentions ideas but does not write them down. Does not respond to the arguments of others.	Mentions ideas and occasionally writes them down. Occasionally responds to the arguments of others.	Speaks and writes ideas in the form of decisions and occasionally supports these ideas with arguments. Represents a critical stance in discussion.	Speaks and writes ideas in the form of decisions and invariably supports them with appropriate arguments. Adopts or refutes others' arguments as appropriate.

The Turkish students were also assessed for their capabilities at planning an investigation using the following rubric:

Assessed skills	Students' achievement			
	Emerging	Developing	Consolidating	Extending
Planning an investiga-tion	Does not have any ideas about how to plan the investigation or actively participate in the teamwork. Follows the calculation of the answers passively.	Has some ideas about how to plan the investigation and what method to use but has no confidence in implementation. Needs help to calculate the answers.	Chooses an appropriate method of investigation and can support the choice with arguments. Can plan the details of the investigation. Can calculate the answers correctly.	Chooses an appropriate method of investigation and can support the choice with arguments. Can plan the details of the investigation taking possible sources of error into consideration. Calculates the answers correctly and efficiently.

The following rubric was used to measure collaboration:

Assessed skills	Students' achievement			
	Emerging	Developing	Consolidating	Extending
Communica tion and collabora-tion	Written communication lacks confidence, information or is entirely absent. Communicates more fluently in speech but lacks purpose.	Communicates fluently in writing but some information is missing. Attempts to express independent opinion but lacks confidence. Oral communication is more fluent and usually has purpose.	Communicates fluently in writing and expresses independent opinion with confidence. Communicates fluently and with purpose in speech but the arguments are not always apt. Listens to others and occasionally reflects on their opinions.	Communicates fluently in writing and expresses independent opinion with confidence. Communicates fluently and with purpose in speech and presents apt arguments. Listens to others, reflects on their opinions, shows flexibility and gives in to arguments if appropriate.

CS2 Hungary took a different approach to assessment. The teacher collected individual student work and marked it for the proportional reasoning activity and for the Food Labels activity.

In the Vitamin C investigation, different groups required different amounts of input from the teacher. This is reflected in the assessment rubric that the teacher developed. For example, he recorded that Groups 1 and 5 “quickly understood the task”, while Group 2 “did not understand the relationship between the amount of vitamin C and the number of drops of reagent.” While groups 3 and 4 “worked out a plan with the educators help”, Group 6 “understood the task”. The Hungarian teacher similarly recorded notes on the implementation relating to data collection and using evidence-based arguments to form conclusions. These notes formed a comparison between the groups and enabled the teacher to act formatively in response to the assessment evidence.

CS3 Ireland listened to group discussions during the ‘Junk Food” discussion and used their professional judgement to decide how successful individuals were in grasping this concept.

In CS4 Portugal, the teacher expected the students to be able to develop a proposal of a well-adjusted snack that suited the energy needs of teenagers and considered the taught content. She also expected the students to be able to demonstrate a capacity to analyse and interpret data contained in the food composition table, and to be able to support their snack proposal in class. By listening to the group discussions, she was able to judge whether they achieved this or not. Afterwards, each group presented their own proposal to the class, which became another opportunity for assessment.

Summary

While there were some changes made to the original inquiry to fit the context of the specific classrooms (availability of resources / adaption for particular learning needs of students) the main ideas of reasoning through discussion were completed in all of the CSs. Two of the countries also went on to do an investigation looking for first-hand evidence of the comparisons of food groups within foods. While, for several of the partners, an inquiry learning approach was a relatively new approach, it was clear that teachers had begun to look at formative opportunities for assessment as well as documenting summative achievements. Perhaps one of the most relevant findings was that students enjoyed and were motivated by the inquiry activities and that the teachers seemed relatively confident in both facilitating the inquiry and assessing it.

4.7 Household vs. Natural Environment

In this unit the environmental implications of using various cleaning and washing agents at home are explored. In the socio-scientific example provided, a simple experiment looking at of the growth of cress in various conditions is used to investigate the impact of different commercially available chemicals on the environment.

Participation in this unit enables students to scientifically assess the consequences of daily decisions taken in their homes, and thus develop a sense of responsibility for the actions they take. In a familiar context, students also have an opportunity to develop a range of inquiry skills, including the planning of an experiment, asking questions and making hypotheses, as well as drawing conclusions. Determining a method to recording their observations between the school meetings is of particular importance.

When working in groups, students can learn how to form arguments, cooperate, and present their ideas and their results obtained using various formats such as tables, diagrams and photographs. Furthermore, they also learn how to critically evaluate their results.

Well-conducted classes help to challenge student misconceptions (alternative conceptions), such as: all chemicals are toxic; the toxicity does not depend on the concentration, or there is a linear relationship between the toxicity of a substance and its concentration (in all cases, the greater the amount of a substance, the more powerful it is). By using the metaplan technique, students are also intended to discuss the topic and develop tips on using cleaning agents and detergents in households, as well as finding information about other professional eco-tests.

This unit can be organized either as a more open inquiry (various cleaning agents, various species – aquatic, terrestrial plants) or a more guided discovery (e.g. the influence of the laundry detergent on the growth of garden cress), depending on the students' IBSE experience.

A tool was proposed to assess the following competencies: **students' prior knowledge from everyday life and previous educational levels, involvement in the discussion, inquiry plans, data presentation, searching-for-information skills, and group work (self-assessment).** The tools proposed in the unit are provided for formative assessment. They include: observation sheets, rubrics and self-assessment.

Synthesis of Case Studies

The unit was tested in four countries: Ireland (CS1), Greece (CS2), Portugal (CS3) and Poland (CS4-6, three teachers). Most of the teachers had not used IBSE approaches

previously (CS4-6) and for the most part, the students had no prior experience of IBSE (CS1-6) with the exception of some students from CS1 having a little experience of IBSE.

The classes were implemented with different groups of students' aged:

- 13-14 years old (21 students in Greece CS2, one group of students from Ireland CS1 and some students from Portugal CS3),
- 15-16 years old (one group of students from Ireland CS1 and some students from Portugal CS3),
- 16 -17 years old (38 students in Poland CS4-6).

The students worked in groups usually of 3-5 persons (CS2, 3, 4-6). The groups were formed independently by the students (CS3), or the students were assigned to a particular group by the teacher (CS4). Most of the groups were co-educational, but there were also some groups composed of students of the same sex (apart from CS1, also 1 group in CS3).

4.7.1 Teaching Approach

Inquiry approach used:

Since most students had not conducted studies using the IBSE strategy previously, the teachers chose to use a more guided than open inquiry approach. They developed and provided worksheets to students that guided their work (CS1, 2 and 4); they also asked guiding questions and decided on the final version of the experiment plan (CS2).

Implementation:

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

Adaptations of the unit:

Half of the groups began their work with a discussion on cleaning agents used in households and their potential impact on the environment (CS 1, 4 and 6). In CS2, the teacher presented two short videos (one video was concerned with how cleaning agents are made, while the other presented an advertisement of an environment-friendly detergent). In CS3, the students were invited to answer the question "How

can we contribute to sensitizing the educational community to the issue of the environmental impact of human activity?" While, in CS5, as students had discussed the issue earlier in their lesson and had also attended hands-on laboratory classes during which they synthesized detergent and soap, the teacher decided to start the unit with planning an experiment

Most groups carried out a study on the impact of cleaning agents on the growth of cress. In other cases: the younger students from CS2 finished their work doing the theoretical part only, but the teacher noted that "it was a topic that you could leave and return to and yet manage to pick it up again quite readily, which made it easy to carry out as additional work"; in CS6, it was suggested to expand the research to include the impact of other chemicals, namely NaCl (used in winter to remove snow from roads) and acetic acid (simulating acid rain). While in Portugal the students carried out the synthesis of detergents and investigated their biodegradability.

4.7.2 Assessment Strategies

Inquiry Skills and scientific literacy/reasoning:

The teachers decided to evaluate planning (CS2, 4 and 5) conducting and documentation of observations and measurements (CS4), data presentation (CS4, 5 and 6), drawing conclusions and forming arguments (CS 2, 4 and 5), cooperation in the group (CS3 and 6) and searching for information (CS5 and 6). In two cases studies the skill of making hypotheses was distinguished and evaluated separately (CS3 and 6), as well as the skill of drawing conclusions (CS4).

Assessment tools:

The following competences were evaluated: students' prior knowledge from everyday life and previous educational levels, students' involvement in the discussion, their inquiry plans, data presentation, searching-for-information skills, and group work (self-assessment). Some project partners group and/or teachers developed their own assessment tools, e.g. worksheets (CS3), a true/false test (CS4), their own rubrics – usually more detailed (e.g. CS4) or more holistic (CS6). In the latter case, to assess the skill of data presentation, the following criteria were also introduced: clarity, use of all possibilities of the software ingenuity, originality, diligence; arousing listeners' interest, comprehensiveness, language correctness and drawing of conclusions supported by literature. In some cases students were involved in preparation of a worksheet (CS4). In one case an evaluation tool developed by someone else was added (CS3). This opinion questionnaire (Brian Mathews, 2006, p. 104) was completed individually at the end of the activity.

Implementation and evidence

The teachers selected some of the proposed competences to evaluate. In CS3, developing a hypothesis and teamwork were selected. In CS2, planning investigations and forming coherent arguments were evaluated. In CS1 identifying variables and developing a hypothesis were selected and in CS4-6, one teacher (1) chose formulating a hypothesis, data presentation, searching for information and group work, another teacher (2) focused on planning, presentation of results, searching for information and drawing conclusions and finally the third teacher (3) evaluated planning, carrying observations, data presentation and drawing conclusions.

In some cases, the teachers indicated that they had presented the evaluation criteria to the students (e.g. CS2), and in other cases they either did not or did not report that they did.

In the first case, it was found that students had difficulties using the rubric during the peer assessment. The teacher believed the rubric wasn't the problem but rather a problem of the maturity of the students in such a kind of assessment. Generally, the "rubrics" were positively assessed by the teachers (Greece, Poland).

Inquiry plans/ Identifying variables/ Researching conjecture/developing a hypothesis

The competencies assessed in CS3 included, among other things, knowledge in a given subject, scientific language, the ability to analyse information and use it. In CS2 and CS1, the 3 level rubrics proposed in unit, were applied. In CS4-6, one teacher used the 0-1 system of a good/bad hypothesis (CS4), while the other teachers (CS5-6) applied observations and rubrics of 3-4 levels.

Data presentation (forming coherent arguments)

In Greece (CS2) and Poland (CS5- 6), the 3 level rubrics proposed in the unit, were applied. One of the teachers (CS4) evaluated not only oral presentation supported by a visual one, but also made use of worksheets developed by the group.

Searching for information

In the case of a teacher from Poland (CS5), both the skills of drawing conclusions and searching for information were evaluated on the basis of PowerPoint presentations prepared by the students.

Teamwork

Only two teachers evaluated cooperating in groups, one from Poland and one from Portugal. The group self-assessment tool proposed in the unit proved useful for the Polish teacher in one case only "Owing to that questionnaire it is easy to deduce which person is a leader" (CS6), when the students conducted an experiment themselves at home. The teacher from Portugal (CS3) implemented his own

teamwork observation sheet for the group that he had contact with in the laboratory (registration grid – "Number of times that certain behaviour is observed"); he was taking notes and he also applied his own teamwork self-assessment card including the evaluation of empathic listening, assertiveness (Exhibits and keeps his point of view), interpersonal support, and conflicts management. In the case of the Polish teacher (CS6), three skills: data presentation, searching for information and teamwork were evaluated based on a PowerPoint presentation shown by the students. The teacher from Ireland (CS1) negatively evaluated the self-assessment proposal, claiming, "*The **rubrics** given were helpful in guiding assessment except the self-assessment one, which did not provide any real useful feedback*."

The plans of the experiment and hypotheses were presented in writing, which facilitated the assessment (CS3). The students did not commit themselves into reading the texts and writing the answers; they have read and wrote as little as possible.

Problems encountered.

One of the teachers was worried that "The students didn't have any previous experience in inquiry lessons and their answers were a bit unformed. All the groups managed to propose a cleaning agent, a plant and a basic set of inquiry steps. The teacher reported that no-one reached the excellent scale." (CS2). The lack of the best marks should not be surprising. At least some assessment tools in the unit were intended for those who already know the basics of scientific research methodology, e.g. they know what is required from a well-formed hypothesis, or what dependent and controlled variables are. Other elements, such as group work self-assessment, do not require training in the area of IBSE, but the principles of proper self-assessment should be discussed with the students. In this case, the problem was also to separate the group and individual evaluation, for example "I have evaluated the work of whole groups, because the students shared their work equally". Another issue was to hand over the evaluation function, typical for the teacher's role, to the students – "I decided to evaluate each skill with the same table designed by myself. That is because the students carried out the experiment at home, so it was difficult for me to carry out a student's self-assessment, to evaluate the group and cooperation in it." (CS4) and "The students should be heard regarding self-assessment, and difficulties should be identified." (CS3). The teachers pointed out to the fact that the proposed evaluation methods were laborious, especially the evaluation of students' homework: "I didn't expect the homework assessment to have been so time-consuming." (CS4).

4.8 Light

In this unit, students examine the basic physical properties of light and its interaction with materials in a predominately qualitative fashion. In this unit it is assumed that students have no prior formal knowledge of the subject beyond their existing own conceptions and a series of eight activities are presented to develop students understanding of the concept of light and its characteristics. Students are facilitated to identify that sources of light have specific physical characteristics and these can determine properties of light, such as its colour and intensity. They investigate the interaction of light with matter and explore phenomena such as reflection and refraction. The unit activities are presented as a guided inquiry-based approach and an individual student worksheet is provided for each activity.

This unit was trialled in three countries, producing four case studies of its implementation (CS1 Ireland, CS2 Ireland, CS3 Greece and CS4 Slovakia). All the case studies were implemented by teachers who had some experience of teaching through inquiry but the students involved had generally not been taught through inquiry.

CS1-3 involved lower secondary students: CS1 was a class of 22 girls working in groups of three, CS2 was a class of 22 boys aged working in pairs and CS3 involved a mixed gender class of 24 students working in groups of three or four. The students in CS4 were a class of 28 mixed ability and mixed gender upper secondary level students aged 17-18 years old working in groups of two or three.

The case studies (CS1-3) involving lower secondary students describe double lesson periods, approximately 80 minutes each, and the case study for upper secondary (CS4) describes a single 45 minute lesson.

4.8.1 Teaching Approach

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

A total of 8 activities were proposed in the Unit and each teacher selected 2-3 activities to complete with their students, based on the school curricula and timing available. All teachers used the materials with the students working in small groups to complete the activities and to facilitate peer discussion. Each student individually completed the associated worksheet in CS1, 3 and 4 and completed the worksheet in

pairs in CS2. Groups were set by the teacher for carrying out these activities and in the case of CS4 these groups were formed for a school term.

CS1 All girls (13-14 years), groups of 2-3 Activities: 1 and 2

CS2 All boys (13-14 years), groups of 2 Activities: 1, 2 and 3

CS3 Mixed gender (12-13 years), groups of 3-4 Activities: 4 and 5

CS4 Mixed gender (17-18 years), groups of 2-3 Activities: 2, 3 and 7

The teacher in CS3 started with Activity 4 and at the end of this activity asked students to plan an investigation to *determine the correct explanation of the phenomena of the dispersion of white light*. The teacher posed probing questions to the students as they were recording their plans. Before carrying out Activity 5, the teacher showed a couple of online applets to the students that allowed them to investigate the effect of different coloured filters. Again at the start of Activity 5, the teacher asked students to plan an investigation to *create white light without using the seven colours of the rainbow*. The teacher finished this activity by introducing the students to a game that explored the difference between mixing colours of light and mixing colours of paint. Finally, the teacher asked from students to examine the pixels of their mobile phone screen using a magnifying glass in order to verify the usage of red, green and blue light mixing and students were really impressed at what they observed.

The teacher in CS3 used the three level assessment criteria described in the unit for "Interpreting results and drawing conclusions" to make judgements on the student's abilities of forming coherent arguments. However, the teacher in CS1 described and used a different 3 level criteria for making judgements on the skill of forming coherent arguments and did this both for written responses on worksheet as well as making judgements on verbal responses.

In CS4 the students at upper secondary level were required to submit their lab worksheets and these were then evaluated by the teacher. In the next lesson the teacher discussed the activities with the students and gave feedback given to each individual student, especially about the possible improvements. Students are then required to improve worksheets based on the teacher recommendations. The final version of the worksheet is collected and included in the student's personal portfolio as part of their school leaving exams (matura).

The following inquiry skills were identified by the teachers in each case study:

CS1 Forming coherent arguments, formulating hypothesis

CS2 Generating questions, developing scientific concepts, identifying misconceptions and redirecting to correct concepts, critiquing

experimental design, experimental problem solving

CS3 Planning investigations, forming coherent arguments

CS4 Working collaboratively, forming coherent arguments, scientific reasoning, scientific literacy

4.8.2 Assessment Strategies

Within the four case studies, the inquiry skills of planning an investigation, forming coherent arguments, developing hypothesis and working collaboratively were assessed in different ways, with some teachers using proposed rubrics. Additionally the content knowledge and evidence of scientific reasoning/literacy was assessed through the student worksheets and verbal responses.

Forming coherent arguments

CS1 presented 3-level criteria for making judgements of the skill of forming coherent arguments and applied these criteria to both student verbal and written responses to questions posed in Activity 1 - Sources of Light, questions 5-7. The teacher noted classroom dialogue between the teacher and 11 out of 22 students, arising from specific questions posed by the teacher during class time. The teacher critiqued all 22 students written responses to worksheet questions to make judgement on this skill after the class.

CS4 highlights opportunities for assessing this skill in 3 of the other proposed 2 - How does light travel?, 3 - Understanding Shadows and 7 - Exploring refraction. Throughout these activities the students are introduced to the skill of forming arguments and in other activities are required to discuss the relevance of their arguments (In case where they are not sure, they ask the teacher for help). At the end of each activity each group is required to present their own solution with argumentation. CS4 highlights that argumentation is implicitly included- at the beginning students only say what they think about the problem, but not why. During IBSE activities they are encouraged to use arguments for each of decisions and not just for the final statement. The teacher can review students' answers in the worksheets and write down comments for improvement of argumentation skills. However, the teacher did not provide any criteria or collect any evidence of students developing this skill.

The teacher in CS3 used the three level assessment criteria described in the unit for "Interpreting results and drawing conclusions" to make judgements on the student's abilities of forming coherent arguments. CS3 presents students artefacts and gives an account of the judgement made by the teacher on student responses in Activity 4 – Exploring White Light and filters, questions 2-5.

Working collaboratively:

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

Developing hypothesis:

CS1 used the 3 level criteria proposed for making judgements on the skill of formulating hypothesis based on written responses to Activity 3 Understanding Shadows, question 7-8.

Planning Investigations:

CS3 used the 3 level criteria proposed for making judgements on the skill of planning investigations based on students recorded plans for an investigation (1) to *determine the correct explanation of the phenomena of the dispersion of white light* and (2) to *create white light without using the seven colours of the rainbow*, as required at the start of activity 4 and activity 5, respectively.

Scientific reasoning:

The teacher in CS3 observed how well students could explain in their own words the concepts of the topic.

CS4 observes that step by step reasoning of scientific background is created and students are focused on conceptual understanding of the problems not only on memorizing of knowledge…this approach supports the development of scientific reasoning a lot. The teacher identifies reasoning to be related to conceptual understanding of the problems and it could be "measured" by concept test questions.

Scientific literacy

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

4.9 Natural Selection

In this unit students are introduced to the connection between the biological concepts of natural selection, genetic drift and fitness in small populations. The inquiry skills that are addressed in this exercise are (1) carrying out an investigation (within the skill: Planning investigations), (2) working collaboratively, and (3) forming coherent arguments. Students work from a fixed procedure on modelling organisms with multiple genes using Lego bricks in different colours to represent the different types of genetic dispositions. The large amount of data produced in the exercise calls for good organizational skills and a common understanding of the task within the group doing the investigation.

Synthesis of Case Studies

This unit was carried out and case studies were written in two different countries (Poland (CS1) & Hungary (CS2)) as well in the developing country (Denmark (CS3)). The teachers using the unit were familiar to or experienced in doing inquiry teaching.

Some students who carried out the task were not familiar with inquiry learning whilst others were very experienced.

The age group of the students was in all cases was 15 – 18 years. In all cases, the students were of mixed ability. This was especially pronounced in CS2 where the student group included some with special educational needs, emotional and behavioural disorders as well as students ranging from dyscalculia to attending advanced math programs. This was the situation as the case study was implemented in an alternative secondary school.

In CS1 and CS3, the groups used consisted of 4-5 students of mixed gender and mixed abilities. In CS2 the group size is not included in the case report but the class consisted of 5 groups of mixed gender. Students with dyscalculia were placed in a special group.

In CS1 and CS2 the task was carried out over a period of 4 – 5 lessons (45 minutes each) while in CS3 the task was carried out either in 2 lessons of 90 minutes or within one block of 180 minutes.

4.9.1 Teaching Approach

Inquiry approach used:

In all cases the inquiry approach used was structured inquiry. All groups worked with the same question and the same method but due to the in-build randomness of the task the students got different results from the investigation.

Implementation:

In all CSs students had previously received lessons on the biological concepts of natural selection, genetic drift and fitness. In order to start the exercise the students in CS1 started out by translating the materials from English to Polish while using the instructional videos as support for this translation. In all CSs the groups were randomly organized (except for the dyscalculia group in CS2) and were mixed gender.

Adaptations of the unit:

In CS1 and CS2 there was a lack of both time and Lego Bricks to carry out the full exercise. In both cases, this resulted in the students investigating less than the 5 generations mentioned in the instructions. In CS1 there was an adaption of the exercise in that the students worked with cohorts of 5 "legorgs" instead of 10-20 individuals' generation as the instructions said. In CS2 coloured cardboard pieces were used instead of the lacking bricks, when drawing the gene pools for generation 2 and 3. In CS1 and CS3 students completed a conceptual pre and post-test on the biological concepts of natural selection, genetic drift and fitness. In CS1 the teacher used these test in the overall assessment of the students. In CS3 the tests were analysed through a Darwinian landscape model and students who showed positive changes in their Darwinian understanding of either one of the concepts were invited to a follow-up interview.

4.9.2 Assessment Strategies

All three cases studies focused on working collaboratively and forming coherent arguments. Additionally, CS1 and CS2 also focused on carrying out the investigation (under the skill of planning investigations). In CS1 and CS2 the teachers made their own rubrics for assessing the students' skills.

In CS1 the rubrics were as follows:

SKILL a) – PLANNING.

I. Adapting the method of the natural selection modelling with the use of legorgs.

Tool: Three-level rubric

2 points level	4 points level	6 points level
Student can present the consecutive steps of the natural selection simulation, but without details	Student can create an action plan of the natural selection simulation with legorgs, with few teacher's advice	Student can him/herself elaborate an instruction for the experiment based on the English language instruction films, with proper detailed description of the consecutive phases

SKILL B) – CARRYING OUT THE EXPERIMENT

I. Adequate data collection, precise setting them together and analysis.
II. Use of numerical and statistical methods to obtain well-documented results.

Tool: Students' skills assessment form

Level	Skills
1 (2 pts.)	Group performs measurements, but not always consistently
2 (4 pts.)	Group performs measurements using the same methods sensibly and consistently throughout the experiment.
3 (6 pts.)	Group performs measurements consistently throughout the experiment and can discuss the degree of their reliability and precision.

Skill c) – analysis of data and presentation of results

Tool: Observation sheet

Students' actions	**yes**	**no**	**points**
1. Students discuss the experimental layout and data collection method.	X		1
2. The leader forces his/her solutions upon other group members.		X	1
3. Students collect data systematically.	X		1
4. The 1st generation table (illustrating legorgs gene configuration and their fitness) is laid out properly.	X		1
5. Students fill in adequately the data into the 1st generation table.	X		2
6. The 1st generation 1^{st} gene pool table is laid out properly.	X		1
7. Students fill in adequately the data into the 1st generation 1^{st} gene pool table.	X		2
8. The 1st generation 2^{nd} to 5^{th} gene pool tables are laid out properly.	X		2
9. Students fill in adequately the data into the 1st generation 2^{nd} to 5^{th} gene pool tables.	X		2
10. *Students collect and analyse data for following generations analogically to the 1st one.	X		*
11. A graphical representation of results is created.	X		2

Total: 15 pts

* Up to 5 bonus points to be earned for active students for this task.

SKILL D) – DERIVING CONCLUSIONS

Based on the experiment carried out, the students should conclude, that directional (various types of selection) and random (as genetic drift) processes acting on casual phenotypic variability (conditioned by the genetic one) result in changes in allele frequency in populations, and thus in micro evolutional changes.

For the correctly formulated conclusion, considering dependence between natural selection and genetic drift in the course of the evolution: 3 points.

Or

For the conclusion either considering (i) only the random processes (genetic drift) or (ii) only the natural selection or (iii) identifying the results obtained with real evolutionary processes – 1 point per feature.

Maximal no. of points to be earned in total: 30

Mark levels: 0-8 (unsatisfactory/bad), 9-14 (mediocre), 15-22 (satisfactory), 23-26 (good), 27-30 (very good)[2]

In these rubrics there is a primary focus on planning investigations and a minor focus on working collaboratively and forming coherent arguments. It is not clear if these skills were assessed otherwise.

In CS2 the rubric produced addressed mostly data organization and hypothetical thinking:

Assessed skill	Student performance		
	Emerging	Developing	Consolidating
Performance	Cannot interpret the tasks without help but manages to do the measurement with some help although not always accurately.	Can interpret the tasks without help, carries out the measurements making sure that they measure in exactly the same way every time.	Quickly understands the tasks, is consistent with measurements and discusses the validity and problems of measurements.

[2] Polish 6- mark system was adapted (in descending order): 6 (“celujący” = excellent, not used in this case), 5 (“bardzo dobry” =very good), 4 (“dobry” = good), 3 (“dostateczny” = satisfactory), 2 (“dopuszczający” = mediocre), 1 (“niedostateczny” = unsatisfactory/bad) [translator’s remark].

Analysis and interpretation	Identifies sources of error in analysis. Cannot draw conclusions without help.	Identifies sources of error in analysis. Can draw conclusions.	Identifies sources of error in analysis, discusses their effects on results. Formulates conclusions with accuracy and in great detail.
Communication	Spots unexpected events but cannot account for them.	Spots unexpected events and tries to find an explanation.	Spots unexpected events and can offer an explanation.

Other skills were assessed using oral feedback. However, this feedback is not further described in CS2.

In CS3 the students handed in a written report based on the original follow-up questions from the instructions. During the exercise the teacher gave oral feedback mainly through posing questions back to the students instead of giving them the answers.

In CS1, the evidence collected relates to students performance according to the rubrics and includes their answers to the conceptual pre- and post-test. In CS2 the collected evidence includes the schematic data collection and the final figure on interpreting these data. In CS3, written reports, interviews with students and video analysis of these students' behaviour during the exercise and interview with the teacher are used as sources of evidence.

There seem to be a common understanding across all three case studies that the exercise is good for training students to working collaboratively and forming coherent arguments. Although, this is only possible there is enough time for the students to work through the exercise. In both CS1 and CS2 this seemed to be a problem.

4.10 Plant Nutrition

In this unit, students collect evidence that light is necessary for photosynthesis to occur. They also realize that if photosynthesis occurs, the level of carbon dioxide in the environment decreases whereas in the dark, the opposite occurs as the production of carbon dioxide increases (due to respiration). A sensitive carbon dioxide indicator is used (hydrogen carbonate indicator) to help students measure whether carbon dioxide is increasing or decreasing in the environment around the plant material. This causes the pH of the solution to change as shown by the change in colour of the indicator. These observations help students to build a bridge between observed phenomena and scientific theory. Opportunities to develop a number of inquiry skills such as formulating hypotheses, making decisions during the planning of the experiment and rationale, data recording (graphical interpretation of data), reasoning and argumentation are promoted in this unit. Students gain new experiences of working together, and discuss their decisions and conclusions.

This unit was trialled in two countries, producing three case studies of its implementation (CS1 Slovakia, CS2 Portugal and CS3 Slovakia). Teachers who had some experience of inquiry implemented the case studies. However for the most part, the students had not been previously taught through inquiry.

In CS1 the students were aged between 11 and 12 years old and in CS2-3 they were between 15 and 16 years old. In all case studies, the classes were mixed gender and mixed ability. In CS1 and CS3 the unit was taught in a 180 minute block while in CS2 was taught in two parts: a 150 minute lesson followed by a 100 minute lesson.

4.10.1 Teaching Approach

The optimal total number of students for this unit is 15-18. It is also possible to work with classes of about 30 students, but the assessment is more difficult for the teacher. When being taught with large numbers it's recommended to use interactive demonstrations and discussion sequences. The unit focuses on student proposals relating to the preparation and arrangement of samples, formulation of assumptions and hypotheses.

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 to formulate predictions.

Implementation:

All teachers randomly organized working groups with 3 or 4 members. Single-sex and mixed-sex groupings experiences are reported on in the case studies.

In all of the case studies, students' worked in groups throughout the lessons, however there was variation in both how the groups were chosen and the group size:

CS1-5 groups of 3-4 students. Self-selected.

CS2-10 groups of 3 students. Except 2 groups that were only girls, the rest were mixed-sex groups.

CS3-6 groups of 3 students. Teacher allocated groups to be mixed ability and mixed gender.

In Portugal, teachers (CS 2) tried to verify if the predominance of one gender could affect the dynamics in class, but due to the small number of groups (in which was possible to watch the gender effect) it is not possible to formulate a clear conclusion.

Students must already know the principle of photosynthesis in advance of completing the unit. In the case studies, this was ensured through a teacher-moderated discussion. Pupils formed groupings themselves in CS1 while in CS2 the teacher randomly organized students. Groups can choose a form for documentation and final presentation of their work and the result of experiment (powerpoint presentation, poster, video documentation). In Portugal (CS2), students were told they would have to produce a written document using a Word processor, where they would write the group's answers to the activity questions. In class at the 1st stage each student in each group was provided an introductory work document, with the objectives and the theoretical framework (CS2). The students had computers with Internet access (one per group), so that they could search about terms/concepts and new information either on algae or the selected reagents.

Each group attempted to define the problem and the objectives of experiment, discuss and design their own procedural steps, identify which variables are involved, and make predictions about the expected results.

The experiment was followed by analysis and interpretation of results, and group discussion to answer to the given questions (CS1 helpful), or at the end, the students individually completed a questionnaire on how went the work in their groups (CS2). The self-assessment template (Additional supporting material) focused on what students thought about and if they were understood by peers during the discussions.

4.10.2 Assessment Strategies

- Providing of feedback through discussion with peers
- Individual assessment of pupils on the basis of documentation of the experiment
- Clarifying doubts and questioning
- Students self-assessment

The criteria for assessment were prepared in tabular form (CS1, 2 and 3). The table below represents a synthesis of these criteria in rubrics.

Each student is able to achieve a basic level of skills (emerging), which then develops. Consolidating skills arises from repeated practice. The most skilled pupils are able to extend this skill alone.

When students work in groups, it is easier to formatively assess the work of the group as a whole. The teacher can readily include the result of a group in the columns of table, rather than the reasoning of 3 or 4 individual pupils. The teacher sees the discussions and outcomes at a group level. Only later will the teacher be able to continuously observe the work of individual students during activities. A teacher can make a good picture about the reasoning of individual students, when group work is followed by a phase in which every student writes their own conclusions or answers to the teacher's questions. It is not possible to observe and assess all skills at the same time. Simply, the teacher must focus on one skill at a time.

The criteria table provided is only a recommendation. The teacher may adapt criteria to the needs in their own classroom or develop their own criteria. The table can also be used for pupil self-assessment. This allows the student starting as a beginner to see the next steps and how to get the next level. The criteria in the table can be adapted to the age profile of the students. Conclusions formulated by pupils revealed that younger pupils (12 –13 years) tended to focus their attention on the process-site. They didn't perceive the experiment as being a helpful proof of photosynthesis. In their conclusions they reported that the indicator changes colour as a variable dependent on the distance of the sample from the light source, but they didn't relate a colour change to the change in CO_2 concentration (CS3). They also don't have enough experience to design their own table (CS1).

Inquiry skills and processes		**Emerging**	**Developing**	**Consolidating**	**Extending**
Planning an investigation	Distribution of material	Indicates chosen method	Indicates chosen method and argues its speed	Indicates chosen method and argues its accuracy	Compares speed and accuracy (effectiveness) of different methods
	Layout of samples	Procedure precise, but small distances between samples (for example 10 cm)	The layout is less accurate.	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. One sample is placed in total darkness.
	Data entry	Data entered into a continuous text of process	Time is marked, records distances in a table	Shall produce a graph	Recognizes the inverse correlation of light intensity and the carbon dioxide content represented by the colour of the indicator
Reasoning	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 easy than find 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 compare methods (Example: It is the best way to achieve different rate of carbon dioxide concentration that indicates changing rate of photosynthesis)

	Thinking about photosynthesis is 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 points to the 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)

Summative evaluation of written work and the presentation of hypothesis went very well according to the scale used. The greatest difficulty seems to be related to teamwork observation grid (CS2). The table containing rubrics was useful for assessing teamwork. Watching and noting the activity in a grid was difficult for teacher. They were not able to watch all groups simultaneously. It is very helpful to assess teamwork, for example assessment according to the criteria in the table below (CS2).

Skills	Emerging	Developing	Consolidating	Extending
Teamwork Interpersonal relationships and group functioning (emotional literacy)	Observes and accepts the colleagues' proposals in the structure of the group work, but gives no suggestions; merely accepts what the colleagues are doing (due to difficulties in interpersonal relationships).	Participates in the structure 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 structure of the group work and gives positive suggestions contributing to a productive group dynamic.	Participates in the structure 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).

Formulation of 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 planed experiment and are based on the research questions.	Formulates hypotheses that are consistent with the planed experiment. Those hypotheses are based on the research questions and identified variables.

In addition to the criteria presented in the tables, other tools listed in the "ADDITIONAL SUPPORTING MATERIAL" were used in CS1-3.

Further criteria may be simplified so that they can also be used for self-assessment. It is beneficial for pupils when the criteria are formulated in an additive mode. That is, identifying what needs to be added to the basic skills in order to develop to the next stage i.e. from emerging to developing to consolidation to extending as in the example below:

Example:

Skill	Emerging	Developing	Consolidating	Extending
Layout of samples	Procedure precise	+ the layout is less accurate (different light intensity), time is marked	+ able to explain the procedure in practical terms	+ able to reason the procedure, builds on the fundamental of photosynthesis

4.11 Polymers – properties of plastics

In the Properties of plastics unit, students learn about the combustibility of plastic materials, their thermal and electric conductivity and their density. The initial problem is provided by the teacher, following which, the teachers or students can define the experiment.

The activities are designed so that students work in groups, where they discuss together, argue, and suggest solutions for the suggested problem. In these activities, both structured and guided inquiry can be used. Students tabulate their results and through this develop skills necessary for research including: data collection and recording, data processing, carrying out experiments and developing hypotheses. In groups, students also discuss conditions required for the conductivity of plastic and they compare these conditions with the conductivity of other substances.

The unit allows for teachers to use various formative assessment tools (teacher, peer and self-assessment tools) to assess the development of scientific literacy and reasoning and inquiry skill, which can be found in the case studies discussed next.

This unit was trialled in four countries producing five case studies (CS1 Ireland, CS2 Poland, CS3 Slovakia (A), CS4 Slovakia (B) and CS5 Turkey). In four of the five cases, the unit was trialled with students at lower secondary school level. In CS5, the unit was trialled with elementary pre-service teachers who had limited prior knowledge of science. These students were 20 years old, whilst in CS1, CS3 and CS4 the students were mostly 14 years old and in CS2 they were 16 years old. In all case studies the students were of mixed gender. With the exception of CS1 and CS5 the students' had little to no experience of learning through inquiry.

4.11.1 Teaching Approach

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. In all cases studies examples of students being led by multiple teacher questions and completion of worksheets were documented and in others examples of student being given an opening question to investigate on their own for a period of time were also noted.

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 using groups. There were some differences in recorded in terms of group size and how they were organised. The group sizes ranged from pairs to groups of six. In CS1, CS2, CS4 and CS5 the students themselves arranged the groups. In CS3 the teacher selected the groups. This arrangement was based on

students' previous results and organised so that students with similar results were not in the same group. It was indicated that in CS4 the group leader was picked on the basis of previous good results, organisation skills and trust of peers. In CS4 the students chose to further divide themselves based on gender where in the case study 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.

Case study	Group Size	Group Arranged by	Gender
CS1	Pairs, threes, and fours	Student preference	Mixed
CS2	Pairs and threes	Student preference	Mixed and single sex
CS3	Fives and sixes	Teacher arranged	Mixed
CS4	Fours	Student preference	Single sex
CS5	Fours	Student preference	Mixed and single sex

In all case studies, the class activity started with a teacher introduction that then moved onto discussing plastics and their everyday use. This was mostly followed by student discussion and then moved onto 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 where worksheet 1 was slightly modified as noted in the case study. The teachers implemented the unit over different time periods. In CS4 and CS5, one lesson was spent on the inquiry activity. In CS2 and CS3, two lessons were used and in CS1, four lessons were allocated to the unit delivery.

The unit is divided into four key activities:

1.1. Determining density of plastic materials by comparing with water density
1.2. Combustion of plastic materials
1.3. Thermal stability and thermal conductivity of plastic materials
1.4. Electrical conductivity of plastic materials

The teachers had the option to choose a part of or the entire unit. In CS2 and CS5 the teachers attempted to implement all four activities. In CS5, the teacher chose to change the order of the activities where Activity 1.2 was completed last so the student 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, the teacher chose not to conduct the Beilstein test due to concerns of the emissions and due to time pressures did not get to complete Activity 1.4 as intended. Similarly, in CS1 Activity 1.4 was not completed.

This teacher also chose to alter the sequence where Activity 1.2 was completed last. In CS3, the teacher decided to focus solely on Activity 1.3 and in CS4, the teacher concentrated their implementation on Activities 1.1 and 1.2.

4.11.2 Assessment Strategies

The teachers used a variety of formative and summative assessment strategies, these included teacher observation, teacher questioning, student self-assessments 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 the teacher solely assessed 'working collaboratively' and in CS2 the teacher focused on assessing 'working collaboratively' and 'planning investigations (including data collection)'. In the table below the inquiry skills and features that were assessed are summarised.

Case study	Inquiry skill and feature assessed
CS1	Planning investigations (data collection), developing hypothesis, forming coherent arguments, working collaboratively, scientific reasoning, scientific literacy
CS2	Planning investigations (including data collection), working collaboratively
CS3	Working collaboratively
CS4	Forming coherent arguments, scientific literacy
CS5	Planning investigations (including data collection), developing hypothesis, 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 and in others the assessment level related to the skill being assessed e.g. in CS1, the teacher assessed 'working collaboratively' at the group level and 'scientific literacy' at an individual level. The assessment strategy used to assess each of the inquiry skills and features are now discussed.

Planning Investigations

This skill was assessed in CS1, CS2 and CS5. In CS1, the teacher used questioning and observation strategies to formatively assess this skill. He used the planning rubric from the unit to help formulate these questions and make judgements. 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, the planning investigation including data collection was assessed through analysis of student worksheets and student-completed self-assessments. The teacher adapted the rubric in the unit to develop a fourth level for assessing planning investigations and developed a further four-level rubric for assessing data collection. In CS5, the teacher used observations and completed worksheets to assess the students. He also developed his own three-level rubric, which was used to assess all the skills he focused on.

Developing Hypothesis

This skill was assessed in CS1 and CS5. In both of these case studies the teacher based their assessment on observation of discussion and questioning. In CS1 the teacher solely focused on formative assessment whereas in CS5 the teacher also used the worksheets to assess the students. Both teachers used rubrics to inform their judgements. In CS1 the teacher used the unit rubric whereas in CS5 the teacher used an adapted rubric.

Forming Coherent Arguments

This skill was assessed in CS1 and CS4. In CS1 the teacher used observation and questioning to assess the students 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 (Activity 1.2 and 1.3). In CS4, 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 students understanding.

Working Collaboratively

This skill was assessed in CS1, CS2, CS3 and CS5. In CS1 the teacher assessed this skill through observation and through analysis of students' completion of the self-assessment tool provided within the unit. He noted that students added further statements to the self-assessment tool that gave even more information on their skill development. In CS2, the teacher also used observations and analysis of student self-assessments as methods for collecting data. An observation card was developed to aid with recording engagement and scientific accuracy during discussions. Additionally, the teacher evaluated students' ideas that were noted during discussions. The teacher developed a new four-level rubric to assess this skill. In CS3 the assessment was focused on student self-assessment and used the questionnaire provided in the unit as the criteria for judgements. Finally in CS5, teacher observation was the strategy employed. This teacher also developed a rubric to judge student skill level.

Scientific Reasoning

This skill was formatively assessed in CS1 where the teacher used questioning and observations to evaluate the students. The teacher indicated the assessment was targeted at the individual and the group. The teacher provided the students' task orientated feedback and used challenging questions to steer and develop students' reasoning.

Scientific Literacy

This skill was assessed in both CS1 and CS4. In CS1 the teacher assessed the skill in a summative manner and used students' final reports as the assessment data. In CS4 the students completed the metacognition questionnaire from the unit. 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.

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 notes that they found it difficult to listen to student discussions while simultaneously trying to record observations on students 'working collaboratively'. Similarly in CS1, the teacher wasn't able to observe as much as intended, as he was restricted to helping the students at the fume hood. Interesting, the teacher in CS5 chose not to complete 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 teachers used worksheets as assessment data. Interestingly in CS2 the teacher noted that the tables 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 reported using student self-assessment tools as assessment data. The teachers appeared to find these beneficial for example in CS3 the teacher noted they would use the strategy again and found it useful for discussing how to improve the quality of group work.

In summary, this unit has been trialled and implemented in four countries. The case studies identify the versatility of the unit in that it allowed 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.

4.12 Reaction Rates

This unit was trialled in four countries, producing four Case Studies of its implementation (**CS1** Hungary, **CS2** Ireland, **CS3** UK, **CS4** Turkey). All the case studies were implemented by teachers who had some experience of teaching through inquiry but the students involved had generally not been taught through inquiry (except for **CS3**).

The ages of the students involved in the case studies were 11-14 year old in **CS2**, **CS3** and **CS4** and 15-16 year old in **CS1**. The students in each class were mixed ability, and mixed gender in **CS1**, **CS3** and **CS4**, but all boys in **CS2**.

Generally the Case Studies describe two lesson periods of approximately 40 minutes each; **CS4** describes a single 40 minute lesson.

4.12.1 Teaching Approach

Inquiry approach used

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

Implementation

The students in all the Case Studies worked in groups at various stages throughout the lessons, but there was variation in both how the groups were chosen and the group size, as shown in Table 1.

TABLE 1: SUMMARY OF CASE STUDIES

Case Study	Activities implemented	Duration	Group size and selection method
CS1	Activity 2 Activity 3	One lesson (90 min)	• 5 groups of 4 students • Self-selected
CS2	Activity 1	Two lessons (40 min each)	• 6 groups of 3-4 students • Self-selected
CS3	Activity 1 Activity 3	Two lessons (40 min each)	• 6 groups of 3-4 students • Teacher allocated groups to be mixed ability and mixed gender
CS4	Activity 1	One lesson (45 min)	• 5 groups of 5 students • Teacher allocated groups

As detailed in section 1, above, this Unit has three Activities, each of which uses an everyday context of an effervescent vitamin C tablet dropped in water to form the

basis of the inquiry. The Activities focus on the methods to trap the gas and determination of the gas evolved (Activity 1), methods to measure how fast the reaction occurs (Activity 2) and investigation of effects of variables on reaction rate (Activity 3). All of the Case Studies revolved around the practical activity. The three Case Studies at lower second level (**CS2**, **CS3** and **CS4**) focussed on the inquiry skills of Critiquing Experimental Design, Working Collaboratively and Planning an Investigation. **CS2**, **CS3** and **CS4** started with Activity 1, as it was an introductory inquiry, appropriate for lower second level students. **CS3** implemented a modified version of Activity 3, looking at the variables affecting rate of reaction, without using quantitative data. **CS1** however, with a student group from upper second level, started with Activity 2, leading on to Activity 3.

The starting point for **CS2**, **CS3** and **CS4** was students observing a demonstration by the teacher of the vitamin C tablet dropped in water. Then the students engaged in discussions prompted by the demonstration, as detailed in Table 2.

TABLE 2: STUDENT ACTIVITIES FOLLOWING TEACHER DEMONSTRATION (ACTIVITY ONE)

CS2	• Students wrote their observations • Discussed difference between fizzing and dissolving
CS3	• Students planned how to collect the gas • Students planned how to identify the gas
CS4	• Students planned how to collect the gas

These starting points all focussed the students on active engagement with the task.

Adaptations of the unit

Following the initial demonstration and student planning of the investigation, in **CS3** the learning sequence is described where the teacher allowed the students to first plan the investigation, and then present their plans to another group who critiqued their plan. The students did not get a chance to implement their method – however the teacher noted that doing so would be beneficial. In **CS2**, following an extensive brainstorm and discussion on properties of different gases, the students were shown three different experimental methods to collect the gas and they critiqued the methods. Following this, the students had to devise a suitable effective way to collect a sample of the gas. In **CS4**, the students implemented their plans.

In **CS2**, students used a 'brainstorm word wall' and a 'place-mat worksheet' to note their ideas after observing the initial demonstration (see Case Study 2).

In **CS1** and the second lesson of **CS3**, the students set out to determining the rate of the reaction and variables that affect the rate (using Activity 3). In **CS1**, the teacher prepared a worksheet for the students (see Case Study 1), with questions relating to the planning of the investigation and setting agreed criteria to compare results. In both **CS1** and **CS3**, groups had to discuss their ideas for speeding up the rate of the reaction with other groups before they generated the plan and carried out their investigation.

The inquiry skills identified by the teachers in each case study are detailed in Table 3

TABLE 3: INQUIRY SKILLS IDENTIFIED BY TEACHERS IN THE CASE STUDIES

CS1	• Planning (and implementing) investigations • Graphical Interpretation • Causality (Identifying cause and effect relationships) • Making Coherent Arguments
CS2	• Critiquing Experimental Design • Working Collaboratively • Experimental problem-solving
CS3	• Planning investigations • Critiquing Experimental Design
CS4	• Planning investigations • Working collaboratively • Data Interpretation and Analysis

4.12.2 Assessment Strategies

Within the four case studies, the inquiry skills of Planning Investigations, Making Coherent Arguments and Working Collaboratively were assessed in different ways. Additionally the content knowledge and evidence of 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.

Planning Investigations

Evidence of the students' planning an investigation was captured in the written plan generated by the students in **CS1** and **CS3**. In **CS4**, the plan was presented as a drawing with explanations and assessment judgement was made, after the activity, based on the level of detail presented.

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

CS3 shows an example of peer assessment. After generating their own plans in groups the students critiqued those from another group, and were asked to suggest possible improvements stating why.

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

Working Collaboratively

The CSs show examples of working collaboratively being assessed by the teacher as well as being self-assessed. In **CS1**, the teacher observed students working well together and noted that one group of students, who were normally quiet in class, were very lively and motivated while working on this activity. In **CS4**, the teacher observed the groups working and noted how one member of one group acted as the group's teacher and how different personalities influenced the group working together.

In **CS2**, the group-work place-mat was used to determine each individual input to the group and provided evidence of the student work. This teacher shared the 'criteria for success' for the lessons with the students. In **CS3**, the teacher used self-assessment to determine the quality of the group work using a questionnaire to the students on how they worked within their groups and how they treated the other gender.

Dialogue

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

4.13 Speed

In each of the implementations, there was a strong practical component relating physics with students' daily lives. The teacher posed students questions they answered by planning and executing experiments. In doing so, they addressed the skill of Planning Investigations, gained experience in working together, developed their reasoning capabilities, and learnt about speed, distance and time. Almost all students were able to carry out the experiment albeit with different degrees of guidance. Most students were reported to be motivated and enthusiastic.

This unit was trialled in four countries, producing four case studies of its implementation. (CS1 Germany, CS2 Ireland, CS3 Portugal, CS4 Turkey). All the case studies were implemented by teachers who had some experience of teaching through inquiry but the students involved had generally not been taught through inquiry (except for CS3).

All case studies concern a single class period. CS1, CS2, and CS4 describe experiences with activities A(i) How long does it take you to walk 5 metres, walking slowly, then walking quickly? and A(ii) How far you can walk in 5 seconds, walking slowly, then walking quickly?, while CS3 describes activity B: Getting to School .

4.13.1 Teaching Approach

Inquiry approach used:

The inquiry approach used in all the case studies was that of bounded inquiry, i.e. it was guided in the sense that the teacher posed the initial question but there were open inquiry opportunities in that students had freedom in addressing the question.

Implementation:

In each of the case studies, distance and time served as an introduction to the concept of speed; students were not given prior formal teaching on these topics. With the exception of CS3, the students worked in groups throughout the lessons but there was variation in both how the groups were chosen and the group size:

CS1	In groups of 3 students
CS2	In groups of 2 students
CS3	In groups of 4 students
CS4	In groups of 4 students

In all cases the skill of Planning Investigations was addressed. Even though the teacher posed the questions to be investigated, students raised subquestions which often served for them to identify variables. In each case the students conducted their own investigations based on their plans. All teachers engaged in on-the-fly assessment and gave both oral and written feedback. Three of the teachers used rubrics to help them assess. On-the-fly assessment was used mostly for formative group assessment. The teachers in Ireland (CS2) and Portugal (CS3) used individual summative assessment for formative purposes.

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

The following inquiry skills were identified by the teachers in each case study:

CS1, CS2, CS3, CS4	Planning and implementing an investigation
CS2	Working collaboratively

4.13.2 Assessment Strategies

Within the case studies, the inquiry skills planning an investigation, forming coherent arguments and working collaboratively were assessed in different ways. For some skills, the assessment was carried out after class and was based on a written artefact produced in class. Others involved the formative assessment that guided the student learning during the class.

Planning an Investigation

CS1 emphasised how students documented their investigations using a prescribed protocol, and they were given feedback on the quality of their investigations and their documentation.

In CS2, the teacher observed student discussions throughout the class period. Afterwards, the teacher assessed and graded written plans for the experiment with a view to establishing a baseline for future inquiry activities. The teacher asked students how they felt about the experience and whether they felt it would help them to plan future experiments.

CS3 contains a rubric that helps teachers assess the skill of planning investigation and how the teacher used the rubric to assess the students' written evidence.

4.14 The proof of the Pudding

This unit was trialled in four countries, producing case studies of its implementation. (CS1, CS2, CS3, CS4). All the case studies were implemented by teachers who had some experience of teaching through inquiry but the students involved had generally not been taught through inquiry (except for CS3).

Student groups:

CS1-Ireland: 24 students, 15-16-year-old, mixed-ability, all-female,

CS2-Slovakia: one class, 15-16-year-old, co-ed but single-sex groups (2 or 3 members/team)

CS3-Greece: 19 students, 15-16-year-old, self-selected groups, 3-4 members, mixed ability, mixed gender

CS4-Hungary: group-A: science class, 24 students, 14-15-year-old, mixed-ability, mixed gender. group-B: 10 students, biology class, 17-18-year-old

4.14.1 Teaching Approach

Implementation

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

CS1:

The content that was addressed in the case study was states of matter, gelatine structure and nature of science.

The teacher introduced the inquiry task anchoring question. In the *planning phase* of the investigation the students were guided by worksheet 1 through the following

tasks: class and group discussion, ranking and choosing variables, making predictions, listing required materials and tools. The teacher assigned homework to investigate gelatine and complete an individual plan for the following investigations.

In the phase of *carrying out inquiry* the students discussed their homework and they were given a more detailed recipe and noted what variable they were evaluating. They then revised their plan, implemented it and recorded notes during the experiment on Worksheet 2. The investigated variables were: gelatine type and concentration, liquid type (milk, soya milk, water, and various fruit juices), temperature of liquid.

During the *evaluation and feedback* students completed presentations and answered teacher questions on their work, listened and took notes and judgements on other groups presentations.

CS2:

To prepare students for research the teacher carried out an approx. 15-minute motivational interview with the students on the previous lesson of biology. Students answered the questions and after a discussion they formed pairs and groups of three members. With the teacher, they agreed on two tasks: (1) to plan and carry out an experiment to test the ratio of liquid and thickeners, and (2) to propose a homemade recipe for 500 g of the pudding.

CS3:

The unit as implemented by the teacher is related more to biology and the topics of nutrients and healthy diet.

The students started to discuss the Inquiry question posed: *"How can we make a really good cheesecake?"*, and further research questions that arose. The teacher observed them while at the same time he set more questions to guide them. The students described several viewpoints of the meaning of "good", most of them relating to a healthy diet. The students described the main quality criteria of the industrial cheesecake as: cost, ease of manufacture, good taste, and appearance.

The *worksheet 1* encouraged students to analyse the product from different perspectives and examine their prior knowledge. It includes a cheesecake recipe that students are asked to analyse from different perspectives. The students presented their answers to the worksheet questions in class, where there was discussion and feedback. The teacher also gave the students two internet links in order to help students with their calculations and he also explained to students how to use these tools.

The *worksheet 2* helped the students to formulate hypothesis on how they could rewrite the initial recipe in order to increase nutritional value and decrease the energy content of the end product.

Using *worksheet 3* the groups had to draw two bar graphs for the total content of nutrients for a 100 g cheesecake, one for the initial recipe and one for their suggested recipe.

Worksheet 4 could be used as a guide to implementing the suggested recipe at home. The teacher explained to students the steps of the worksheet and gave them feedback to their questions. At the final lesson, the teacher asked students to present and discuss their experience along with their findings to class.

CS4:

The content of this CS focusses on groups of nutrients, colloidal systems, and healthy nutrition. In terms of IBSE skills, this CS focusses on planning experiment (within it constructing the model system), stating hypothesis, searching for information, and several types of debating and thinking skills (comparing, classification, connecting, and analogical thinking).

During the *preparatory phase* the students' prior knowledge is determined and any deficiencies addressed. In this phase, teacher presentation dominated; the students answered the teacher's questions and tuned in to the task, their interest increased and their conceptual knowledge was stimulated. In the *second phase* the students had to construct a model system to plan the jelly state of the pudding. They had to understand that before doing the real processes on a large scale it is practical to try out in a model system what works and how. In the *third phase* the groups presented their prior ideas and compared them with the features of the end product. Through evaluating each other's work they gave critical comments.

Adaptations

The unit description is more of a framework than a set script. By interpreting the problem under inquiry and the learning goals correctly, there are many ways and possibilities to adapt it to the local requirements. The case studies describe the reasons for the adaptations, which would be typically connected to the time required for the inquiry (CS2), the way it could be fit into the curriculum (CS2,3) and the lack of students' research experience (CS1). During adaptation, teachers assembled different supporting materials e.g. student handouts (CS3), and introductory supporting materials (CS4). The teacher selected the skills to be assessed based on the specific group's needs and developmental goals. They assigned aspects, determined skill levels, which were correlated with the student activity observed along the specific tasks. Specific adaptations were:

CS1: The adaptations were decided upon based on the short time available and students' limited previous experience of inquiry and science. The teacher followed the general sequence outlined in the SAILS unit.

CS2: Adaptation of the unit was necessary for two consecutive hours (biology and chemistry). It took place in a divided class (16 students) during two lessons (90 minutes). It was also necessary to mention the topic to fit into the thematic units that are currently taught.

CS3: The teacher made adaptations to the suggested activities in order to fit with the State Curriculum and the background of the students at this level.

The teacher assembled and provided 3 worksheets which gave the students sufficient support to start working individually. The teacher could assess the achievements and the skill level based on the answers to the questions on the worksheets.
In this trial, emphasis was put on the second part of the unit's task so the students dealt more with biology rather than chemistry topics.

CS4: We compiled the plan of the unit on the basis of non-structured or half-structured problems. We had to find a topic interesting for students and encourage them to have individual research.

4.14.2 Assessment Strategies

CS1:

The assessed skills were planning investigations, developing hypothesis, working collaboratively, critiquing of experimental design and forming coherent arguments. The skills were assessed using teacher observation, questioning and review of documentation measured against pre-developed criteria (rubrics). Formative assessment was used during the classroom activities (observation, questioning) and summative assessments were used when the teacher reviewed student worksheets and reports.

CS2:

The assessed skills were planning investigations, working collaboratively and forming coherent arguments. The teacher assessed them directly in dialogue with students, on the basis of the students' references how they planned the test and also on recorded testing. Furthermore they assessed students' argumentation during preparation of the recipe for homemade pudding. Teachers watched how the members of groups collaborated as well. During the activity oral formative feedback was provided by the teacher. During the peer assessment, students listened to their classmates' arguments. Evaluation rubrics were not used, but teachers monitored the way of students referred to their plan and watched correctness of the arguments.

CS3:

The students answered all the worksheet questions. The teacher asked students to present their answers in class in order to discuss these issues between them and take feedback. Between the activities of the worksheet there was one where students had to fill in the cells of a table that contained the nutritional value of the recipe ingredients as well as their energy value.

The teacher used the students' artifacts in *worksheet 2* and the related rubric in order to assess the skill "formulate a hypothesis".

The students made a *peer assessment* on the conclusion section of the *worksheet 3* using the rubric "*Forming Coherent Arguments*". The teacher discussed the criteria of the rubric with students and after that he asked them to perform the assessment.

The students' *observations* and their final conclusions written in *worksheet 4* were assessed by the teacher as well.

The teacher used the underlying question as an artifact on how the groups managed to *test their hypotheses*.

The following skills were assessed in this case study: Formulating a Hypothesis, Testing a Hypothesis, Forming Coherent Arguments, Working Collaboratively, Observing, Making Comparisons, and Understanding. In order to assess the previous skills the teacher used rubrics (see in the case study)

CS4:

The main tool of formative assessment was the teacher's oral feedback which was linked to student's activities. We used different assessment tools with the different student groups. In science class we used a rubric method presenting student's achievement in two inquiry skills: planning investigation and scientific reasoning. The assessment rubric linked directly to the lesson and could be used to help the students' further development from the existing skill level. The assessment could be evidence-based on the basis of students answers collected with the questionnaire.

During the *preparatory phase* the students' prior knowledge could be assessed. In the *second phase,* the group work was assessed by the teacher's observation and oral feedback. During the planning of the models each group was visited by the teacher. In the third phase of the task the groups evaluated each other's work, and they expressed critical comments. Both self- and group assessment took place in this phase. In the *final phase* of the task the reflective thinking had to be evaluated: how much the students are able to recall their own thinking.

4.15 Ultraviolet Radiation

4.15.1 Teaching Approach

Types of investigation

This unit could be implemented using various inquiry approaches. For example, an open inquiry approach was used by a teacher in Denmark while bounded inquiry/teacher-initiated approaches were used in Germany and the UK.

Open inquiry – Denmark:

The Danish open approach focussed on formulating a hypothesis, planning investigations, and drawing conclusions from their own investigations. The activity began with "brainstorming" in the class concerning concepts within the area of UV radiation. The class was divided into groups of 4-5 students and was given 10 minutes of research time on the Internet to find out more about UV radiation. After this research each group was given three investigations. The first investigation/task was to find things that could be used as UV indicator. The class was asked to pay specific attention to their planning of such identifications and asked to be aware of different variables. The second task was to investigate UV sources. The students again planned their investigations in groups and carried these investigations out in practice. The third task was to investigate how the students could protect themselves from UV radiation. Again the groups planned investigations and carried them out. The results from the three investigations were then put into an oral group presentation with special emphasis on the hypothesis, the planning, and the conclusions. After each group's presentation there was a discussion among peers on the group work and their conclusions.

Bounded inquiry – UK

The UK approach focussed on developing inquiry skills (which?) and teamwork. The pupils had previously learnt about the electromagnetic spectrum. The context of this investigation was 'How can we protect ourselves from UV radiation?' Some introductory slides were shown to the pupils with pictures of people sunbathing and some gruesome pictures of skin cancer. The different types of UV radiation (UV-A, UV-B and UV-C) were explained then the investigation introduced. The structure for the investigation was as follows:

Lesson 1: Outline of task, planning what to investigate in groups, preliminary experimentation with the equipment. At the end of the lesson, self-assess the three main group skills that they feel they demonstrated and explain why. Work collected and comments on planning so far given.

Lesson 2: Start by the pupils identifying three group skills they would like to demonstrate in the lesson. Carry out investigation and write up on poster (all in class). Teacher marks work and adds comments.

Lesson 3: Peer evaluation at the start of the lesson (without teacher feedback) and review of what they learnt from the whole process. Teacher marks and feedback given.

Bounded inquiry – Germany

The German approach focussed on planning and carrying out investigations and data analysis. As a starting point the teacher showed a comic that illustrates two persons lying on the beach. The first person asks: “Don’t you want to come to the shadowed place under the umbrella?” And the second answers: “No, I will have a swim and in the water I can’t get sunburn.” Referring to the comic students reported about experiences with sunburns and their knowledge about UV-radiation. The teacher observed different students’ opinions about UV radiation transmissibility of water. The question whether water protects against sunburn was the outgoing point for further investigations. Therefore the teacher displayed graphically an overview that contained different steps in the inquiry process (propose hypotheses, plan an investigation, carry out an investigation etc.) and the first question of the UV-radiation-activity (How can you reveal UV-radiation?) was posed by the teacher. To support students’ planning the teacher provided a list of materials that could be used for the investigation and supplied the planning process by short assistance worksheets. In a first step the students had to formulate hypotheses and subsequently carry out the investigation. After the accomplishment of the investigation the teacher posed the second question of the activity (How can you protect yourself against the sun's ultraviolet rays?) referring to the comic at the beginning of the lesson. A second investigation period started. At the end of the lesson students had to document their working process in a poster.

The results from the three investigations were them put into an oral group presentation with special emphasis on the hypothesis, the planning, and the conclusions.

4.15.2 Assessment Strategies

Denmark:

The teacher had read the SAILS rubrics assessment tool for 9 skills and competencies, but focused on hypothesis, planning, and drawing conclusions. The assessment during the students work was carried out as oral conversations where the teacher addressed the specific focus points of the unit. The teacher used the assessment rubrics as an inspiration for guidance of the students in their work and

thereby giving formative assessment as feedback. Even though the teacher had a clear intention of using the developed rubrics for assessing the students' work she found it difficult to keep track of both the students' work and rubrics at the same time. Her usage of the rubrics as an assessment tool was therefore limited to inspiration from the rubrics in her conversations with the students during their work. For the next inquiry lessons the teacher would present the rubrics to the students as self-assessment tools. The rubrics could be a useful tool both for the teacher's planning and for the students' work. The students ended the lessons with a presentation and a peer discussion on their hypothesis and their methodology. This not only gave the teacher a clear indication of the students' understand of variable control but also the students gained more insight to the processes of planning and carrying out investigations in the future.

United Kingdom:

The teacher assessed the skills of asking inquiry questions, planning an inquiry to test ideas, communication, analysis and conclusion, evaluation, critical thinking, teamwork skills. All the skills except teamwork were primarily assessed via notes made on the poster using the assessment rubric. These skills were peer assessed by another group before then being marked by the teacher. The groups were instructed to provide constructive feedback that highlighted the positives and possible areas for development on post-it notes.

The teamwork skills were self-assessed using a grid of skills. Before the investigation, each student was given the grid of assessment skills to read through, and then these were discussed to ensure that everyone knew what each skill meant. The importance of these group skills was stressed to the students and linked to crucial life skills they will need when they leave school. The pupils then self-assessed their group skills at the end of the planning stage (first lesson) but were restricted to identifying 3 skills that they think they had demonstrated. They also had to justify why they felt they had demonstrated that skill. At the start of the 2nd lesson, they returned to their grid and had to identify three skills that they would try to work on in the lesson. This was again reviewed at the end of the lesson. During the investigation, the teacher circulated and tried to assess all the above areas. This was not always easy, but it helped the teacher to better ideas when marking the pupils' final work. The hardest area to mark was the critical thinking section as this was difficult for the pupils to evidence on their poster. Feedback to the pupils was provided in the following ways:

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

Germany:

Formulating hypotheses constituted a difficulty for some of the students at the beginning of the first lesson. In the second investigation period (How can you protect yourself against the sun's ultraviolet rays?) the teacher reported that students could more easily formulate hypotheses or presumptions and carry out investigations. The difference in quality of planning and carrying out investigations were mainly observable in the grade of students' systematic proceedings. Most groups worked in an explorative way. Only some students connected the steps of formulating hypotheses and examination in a consequent way.

A final assessment was given by a poster presentation. The poster encompassed the hypotheses and experimental approaches of each student group. The rubric system of the UV-radiation unit was shown to the teacher ahead of the lesson. The rubric with formulation is from the Swedish syllabus. The teacher was unable to use the rubrics because she had no time to allocate students in the rubrics during the experimental process. The teacher's conclusion was that the rubrics could on the one hand be used in a team teaching situation (two teachers) or on the other hand must be adapted as a self-assessment tool. The assessment was focussed on the skills of planning and carrying out an investigation. The skills were assessed by observation, progress reports during the investigation and the revision of a poster presentation.

4.16 Up there, how is it?

In this unit the main disciplinary area is Physics. The activity, although suited for upper secondary, may also be implemented in lower secondary, in particular in the 7th grade within the study of gravity. Adapting the activity to a different grade means ensuring that the level of requirements on each item and the support given by the teacher is adjusted. Furthermore, it is suggested to develop this task in collaboration with the curricular area of Natural Sciences (Biology and Geology), as the research questions to be posed by students at the stage "Going further" may also be in the domain of those curriculum areas. It was suggested for the class to be organized in groups of 3 to 4 students according to available resources/materials.

Concerning the goals, it is intended that students learn about the concept of gravity, have the opportunity to know more about the activity of the International Space Station - ISS; understand its impact on the scientific, technological development and in society; develop interest and curiosity about space exploration. It is also intended for students to develop a set of inquiry skills within the activity development.

The learning sequence suggests the activity to be developed in four parts. In the first part, students are invited to read about the International Space Station (ISS). After reading the text, it is proposed for them to imagine how it would be to develop

some of their daily routine activities in a microgravity environment and to discuss their individual ideas with the class. This first part of the activity is intended to assess students' prior knowledge on gravity concept. On the second part, students watch a video about everyday life on the ISS. This is intended for the students to articulate prior knowledge with new information. Finally, the teacher presents a summary of new concepts and ideas, to avoid that new knowledge is misinterpreted. At the third part, students will apply the learned concepts into a new situation. They will be asked to think about and therefore formulate a question they would like to investigate in a microgravity environment. They must raise hypothesis, and plan an investigation in order to answer their research question. The main goal is not to actually develop the activities on the research plan built by the students (since that would not be possible) but to raise a rich discussion on the conclusions one might reach. The best research plans should be submitted to NASA (this institution receives and selects activities submitted by schools performing the best ones on board of the ISS). Finally each student reflects on what he had learned in carrying out the activity.

Synthesis of Case Studies

This unit was trialled in three countries, producing three case studies of its implementation. (CS1-IEUL-Portugal, CS2-UPJS-Slovakia and CS3-HKR-Sweden). In all the three case studies teachers and students had previous experience with inquiry but not all of them have prior knowledge about microgravity (CS3).

The students' ages involved in the case studies were for CS1 and CS2 – 15/16 years old, and CS3 – 13/15 years old. The students in each class were mixed ability and mixed gender. CS1 was applied in two 11^{th} grade classes, 32 students in total, each class worked in groups from 3 to 4 elements, two 45 minutes classes plus a double lesson period of 45 minutes. CS2 was developed with upper secondary level, 1st class of Gymnasium, 30 students working in six groups, 3 x 45 minutes. CS3 was performed in five classes: Four grade 7 and one grade 8 classes. The schools were pre-school to grade 9 schools and one grade 6-9 school. The students worked in groups of 3-4 students.

4.16.1 Teaching Approach

Inquiry approach used:

In all cases unit was implemented as an open/guided inquiry activity, as anticipated in the unit description.

Implementation:

The students in all the case studies worked in groups throughout the lessons.

CS1 – The activity was developed according to the following parts: a) students read a text about the International Space Station (ISS). Afterwards they were asked to imagine some of their daily routines and how it would be to do it in the ISS (microgravity environment) and they discuss their ideas with all class; b) students watched a video about everyday life in the ISS. Classroom discussion: connect new ideas with the prior ones; c) students, in groups, raised a question to be investigated in a microgravity environment, brainstormed possible solutions, selected statements to test and designed an experimental plan; at the end they d) presented, shared and communicated their experimental plans to the class.

CS2 - A physics teacher adopted the worksheet for the classroom activities with an introductory part related to: How does microgravity work? What is an origin of microgravity? Three sets of activities were implemented: a) daily routine at home and in microgravity; b) my microgravity experiments and c) conclusions and feedback. Each student had a printed version of the worksheet, based on group discussion the remarks are written down. The teacher introduced each part of activities a), b) and c) and facilitated classroom discussions between groups, with short discussion within each group if necessary. The worksheets were collected after the lectures, scanned and return to students for their own portfolio.

CS3 - The activity was implemented close to the original activity: a) Students were presented with some background information about the International Space Station (ISS) and gravity. Then they were asked to think about some of their daily routines and how it would be like to carry out these routines in a microgravity environment; b) The students watched a video about everyday life on the ISS and were asked whether there was anything that they would change in their initial thoughts about carrying out daily routines in a microgravity environment; c) Group discussions, where students presented their ideas from the video and gave reasons for changing their prior thoughts about daily routines in a microgravity environment.

4.16.2 Assessment Strategies

CS1 – The element of inquiry that this activity assessed was planning an investigation. In order to assess the selected skill, the teacher designed an assessment tool formed by three levels of performance. Students' written evidence was examined and assigned a mark of 1, 2 or 3 using the rubric as a guide.

The assessment instrument was built before the task implementation in the classroom. After the task completion, students' work was collected and assessed according to the instrument. This instrument allowed the teacher to assess the students' performance regarding the planning an investigation skill, particularly in

defining a research-problem and its objectives; identification of variables to measure and control; construction of a proper procedure with the data to be collected, clear and reproducible and predicting possible limitations to the proposed procedure. The use of this instrument, organized by criteria and performance levels, allowed decreasing the subjectivity of qualitative assessment, such as to assess skills and to systematize the collected information from students' work, facilitating the oral feedback that was carried out after the completion of the task.

CS2 - First of all observation skills were assessed. Students discussed some everyday routines and described them considering the influence of gravity and other physical phenomena. While assessing peer discussion, the teacher found that teamwork was not developed enough. During the inquiry activity the teacher observed group work, and gave some support (providing additional questions, short explanations of physics background if necessary). Scanned worksheets were analysed with criteria for each activity. Students' evidence was examined by rubrics with a three level scale (very low, acceptable, and excellent). The teacher tried to use as much as possible formative assessment, especially during peer discussion, whole class discussion and creating of conclusions.

CS3 – The activity was used in order to assess students' skills in forming coherent arguments. The teachers: (1) *listened* to the students during the group discussions and (2) *collected* students' written ideas. The teachers made attempts to assess how students' argued for changing their initial ideas, after watching the video. The main success criterion was whether the students could form coherent arguments. Students were given group feedback during the activity. Assessment data was not used for summative purposes. As a stand-alone activity, the teachers did not use assessment data for their own planning or evaluations.

4.17 Woodlice

The specific topic of this unit is the living conditions of woodlice and involves student's consideration of the environment, ecology, and animal behavior. Woodlice have been chosen since they are common in large parts of Europe and are appropriate to handle for students. The expected learning outcomes are twofold: (1) Learning how to plan, perform, and evaluate an experimental study in biology, and (2) Identifying and explaining ecological relationships using scientific concepts, models, and theories.

4.17.1 Teaching Approach

Implementation:

This unit was developed as an open inquiry activity and allowed variation in its implementation depending on the class group. This unit was trialled in four

countries, producing five case studies of its implementation (**CS1** Ireland, **CS2** Poland, **CS3** Slovakia, **CS4** Portugal, **CS5** Sweden).

The ages of the students involved were 12-14 years in **CS2**, **CS3** and **CS3** and 14-16 years in **CS1** and **CS5**. Generally, the case studies describe two-three lesson periods of approximately 45 minutes.

SUMMARY OF CASE STUDIES

Case Study	Student Ages	Duration	Group size
CS1	15-16 years	3 x 40 mins.	8 groups of 2/3 students
CS2	13 years	3 x 45 mins.	6 groups of 4/5 students Used with 4 class groups of students
CS3	12-14 years	2 x 45 mins.	5 groups of 4 students
CS4	13-14 years	3 x 50 mins.	Small groups allocated alphabetically by teacher.
CS5	14-16 years	3 x 45 mins.	Students worked in pairs.

Working with living animals gave an interesting context for this inquiry, even though students need to be introduced to the particular terminology as woodlice was not known to them and in some cases, **CS2** and **CS4,** other animals were used, e.g. crickets, earworms, beetles, myriapodans, meal beetle larvae and earthworms.

The starting point of the investigation differed between the Case studies.

CS1 - A guided inquiry approach, where after an initial group discussion to collect students' questions, the teacher evaluated the questions and selected the 3 particular variables to be investigated (the effect of light, amount of moisture and food preferences on the behaviour of woodlice).

Students then developed and noted their hypothesis and used a worksheet to guide students' work/collection of information.

CS2 – started with an open inquiry and teachers did not suggest to students which variables were to be considered in their investigations, and felt this gave students the possibility to act actively and use their imagination.

In **CS2** and **CS3** the students first looked for a picture of woodlice on the internet, notice the environment they live in, and then collected some. The teacher facilitated rich discussions with the students before they started their investigations.

CS5 started the activity by having students looking at woodlice with magnifying glasses to give students a chance to examine how to work with living animals. The teacher started with a general discussion and formulating questions took place in

Class 1. Class 2 was used to carry out investigations, write a report and develop conclusions. In Class 3 the teacher gave feedback on the reports and students discussed how the investigations could be improved.

CS4 also organized this topic over three classes and used class 1 for engaging the students, class 2 for developing and testing a hypothesis, class 3 for doing worksheet and self-assessment.

Some teachers (**CS1, CS4**) supported the students giving them sub-questions. This would help them to formulate a testable hypothesis. The sub-questions can be:

- What do you think will happen?
- Why do you think this will happen?

Inquiry approach used:

CS1 – Guided inquiry. First open discussion, then teacher picked 3 options to investigate.

CS2 – Open inquiry. First lesson was a discussion on planning. Students selected investigation to study. Students planned, carried out and analysed results of the experiments entirely on their own, i.e. which animals, factors to investigate, how to collect evidence. Little direction was given teacher.

CS3 – Bounded Inquiry. Rich discussion on factors affecting woodlice. Students researched information on internet.

CS4 – Guided inquiry. Students worked in groups. Students started with raising questions

CS5 – Bounded Inquiry. Students discussed in groups, teacher collected questions. After discussions there was an evaluation from teacher. Students decided on questions to investigate. Follow up discussion at end with no equipment, woodlice, etc.

Inquiry Skills addressed:

The draft unit mainly focused on the inquiry skills of designing and carrying out investigations and developing hypothesis. The inquiry skills identified by the teachers in each case stud are detailed in Table 2.

INQUIRY SKILLS IDENTIFIED BY TEACHERS IN THE CASE STUDIES

CS1	• Developing hypothesis • Planning an Investigation • Evaluating an Investigation
CS2	• Planning Investigations • Developing hypothesis • Working collaboratively
CS3	• Peer discussion and forming coherent arguments • Formulating hypothesis and conclusion of investigation • Planning investigation
CS4	• Developing hypothesis • Working collaboratively
CS5	• Planning Investigations • Developing hypothesis • Competence to use equipment new competence for students to handle lab equipment.

4.17.2 Assessment Strategies

Within the five case studies, the inquiry skills of Planning Investigations, Developing Hypothesis, Forming Coherent Arguments and Working Collaboratively were assessed in different ways.

CS1 – Assessment was carried out based on a written student worksheet and focused on the skills of developing hypothesis, planning an investigation and evaluating an investigation. The assessment rubric from the draft unit was used as a guide for assigning level 1, 2 or 3 to each student answer. Two teachers carried out this assessment independently.

Teacher commented that each of the three sub-questions can be assessed separately and together. This assessment can take place both on the fly (as students are discussing the questions or examining what they have written in-class) or afterwards. Things to look out for:

1. Is the question clear, qualified (e.g. do students mention levels), is the question testable and specific enough?
2. Is the prediction that linked to the question? Does it suggest an outcome to the investigation?

3. Is the hypothesis justified, for example based on personal experience, students' own observations, or trials?

CS2 – teachers don't usually assess lab work. Teacher picked one group and assessed a particular skill: 1 on planning, 1 on carrying out and 1 on analysing. Teacher used several rubrics 6-point scale and assessment was based on teacher observation and written reports. Teacher developed a test afterwards for deriving conclusion from the last lesson. Students disappointed by results given – had expectations of higher grade. The teacher commented that group work can be deemed unfair for individuals.

CS3 – Skills were assessed during the discussions. Use adapted four level rubrics with emerging, developing, consolidating and extending levels, to assess the inquiry skills.

CS4 - The skills were assessed according to the teacher assessment guide, as given in Annex I of case study. The teacher gave constant feedback throughout the activity development, and assessed the final products. Decided to evaluate teamwork, paying attention to gender and the skill of developing a hypothesis. The teacher used a three-level rubric to assess team work as an adaptation from the draft unit. Focused on a number of groups. Students were able to work with diverse teams. They can produce ideas based on views from team members. They can take into account and deal with disagreements. They can manage time and workload and agree procedures. Students also self-assessed using a flow chart on group work. Students had to develop a hypothesis which includes a justification for that hypothesis and also provides a link to the research question.

CS5 – The assessment was based on the knowledge requirement for this year group. The teacher adapted rubric to suit the local curriculum for biology and used a 3 level rubric to assess the student's ability based on their lab report which included both text and drawings.

5. Conclusions and Recommendations

Trialling of the draft units with teachers in classrooms, and developing case studies provided evidence of the efficacy of an IBSE approach. There was strong evidence of IBSE assessment practices in the classroom and a broad range of ways in which the evidence was collected. This in turn helps in the development of assessment criteria that can be used in assessment of inquiry skills and hence inform the final framework of assessment strategies (in WP2).

From the CSs, it was clear that the teachers:

- Recognise the benefits of group work and working collaboratively and worked at strengthening this in their classrooms
- Generally embraced the notion of greater mediation of students learning, and the need to 'step back' while students attempted an inquiry
- Are willing to adapt the assessment tools within an inquiry to their own contexts
- Are considering the wider implications of being 'gender aware' & involving their students in self reflection
- Enjoy giving students the opportunity for self-review/ assessment and peer review
- Are very reflective through their writing
- Are starting to articulate the tension between formative practice and teacher summative judgments.

In general, the following were achieved or realised through the trialling of the Units:

1) Units were undertaken successfully in biology, chemistry and physics, in both upper and lower level.
2) Units were generally undertaken in the age range suggested by the Unit authors but when a different age group was selected, teachers were able to modify the inquiry or assessment or both.
3) Teachers considered the topic more than the skills it developed when selecting an inquiry to trial. Where a teacher can overtly see that a topic will fit their curriculum they are more likely to select it. If they wanted to focus on a specific inquiry skill, then they were able to adapt the inquiry to do this, in most cases.
4) The teachers adapted the Units to fit their local needs. This might have included changing the inquiry competencies to focus on or the time slot to fit the inquiry in.

5) Teacher roles included greater mediation of students learning, recognising the need to step back as well as guiding the learning.
6) Awareness of the benefits of group work was recognised but it was clear that, in many classrooms, the skills to improve collaborative working were only beginning to emerge.
7) There was a growing understanding of gender issues through student self-review and peer review of their collaborative working
8) For some teachers, tension exists between formative practice and teacher summative assessments.

Recommendations for SAILS UNITS

Following the analysis of the information provided in the draft units and the case studies, it is clear that while a huge resource now exists to build on for the remainder of the SAILS project, some additional information is required in order to supply more information to the users of the final SAILS UNITs.

Within the case studies, the information supplied needs to be developed, e.g.:

- In some cases by explicitly stating where, when and how the assessment occurred, particularly in relation to those assessments that occur during class activities. Examples of how this was done across a range of classrooms and partner countries would be especially useful here.
- Teacher's reflections are very worthwhile in the case studies but these should include more detail of the questions they used during the inquiry, how they made their judgements of successful performance and how they gave feedback to students to help them improve their inquiry skills.
- Care needs to be taken in terms of summative marks or grades. While it is important to be able to identify the strengths and weaknesses of a particular piece of student work (either student activity or output) and to be able to provide appropriate feedback to the student. The use of rubrics only can lead to its use as a grading scale. While it may be that teachers need to provide a summative assessment at some point, it is recommended that this is done over a range of inquiries and not based on a single piece of work as the complexity within one inquiry may differ markedly from another.

Specific Recommendations for Assessment Framework Development

In addition to recommendations for the SAILS units, specific recommendations for the work of Framework development are as follows:

- Consider whether the framework should be specific or general in terms of each inquiry skill;
- Clearly define each skill with the use of illustrative examples from case studies.

Specific Recommendations for Teacher Education Programme

Teacher education programmes will consist of a series of workshops focussed on developing teachers understanding of inquiry and also of its assessment. From this trialling, certain recommendations can be made for the development of teacher education programmes, as already outlined in D3.2. It is clear from working with these teachers that they need to have a good understanding both of inquiry teaching methods and assessment methods.

Particular aspects should be included within the TEP:

- Teachers should be introduced to both inquiry and the approaches to assessment which enable teachers to collect rich evidence of specific skills.
- TEP should take place over several workshops if possible, to give teachers time to try out ideas in their classrooms; Teachers should become learners as part of the inquiry workshops so that they understand what it's like to be placed in an inquiry scenario.
- SAILS UNITS should be used in the TEP, selected on the basis of teacher experience and local issues.
- After trialling SAILS units themselves, teachers should be involved in selecting/developing their own inquiry activities and also constructing their own assessment;
- Workshop time should be devoted to different strategies for creating formative opportunities through assessment. It is also essential that teachers are helped to recognise how formative approaches differ from summative approaches and the benefits this has for learning.
- Teachers should be introduced to a variety of questions that they can use during an inquiry activity to probe student understanding of the inquiry process and the choices they are making.
- Workshops should include sessions on effective group work

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Appendix 1 Case Study Template

Topic:

Inquiry skills, reasoning skills, and scientific literacy: *Purpose?*

Student group: *Who was lesson trialled with?*
Age:
School type (i.e. co-ed single-sex)
Prior experience with inquiry?

(i) How was the learning sequence adapted?

Need teachers' reasons for why they are approaching the inquiry in the way they have selected and any changes they make (with reasons) as they work with their learners. What questions or stimuli did teachers use?

(ii) Which skills were to be assessed? *(Planning investigations; Developing Hypothesis; Working collaboratively; Forming coherent arguments; Scientific literacy; Scientific reasoning).*
How were the skills assessed?
How were gender issues addressed, if done?
How did they plan to make their judgements (during inquiry, from artefacts etc.)? What model of assessment was used?

(iii) Criteria for judging assessment data:

What were the teachers looking for in terms of satisfactory response to the inquiry? What were their expectations?
How did it relate to the criteria? Was the assessment formative and/or summative?

(iv) Evidence Collected:

Teacher opinion:

How did the learners respond - including if they enjoyed the inquiry?
What did the teacher notice? Description and explanation of how students performed in these inquiry skills. How useful assessment approach was? Any problems or suggestions for improvement?
Which rubric sheets were used, if any? what were the positives and problems?

Observer notes:

Description and explanation of how students performed in these inquiry skills. How useful assessment approach was? Any problems or suggestions for improvement?

Sample student artefacts:

Examples of satisfactory achievement or errors or misconceptions or excellent student work with explanation of what this work is showing.

(v) Use of Assessment Data

What did the teachers do next? How did they feed back to their learners? How did doing the inquiry affect their planning and decisions about next steps in learning?

(vi) New Teachers

What advice might they give to a new teacher doing this?