INQUIRY AND ASSESSMENT UNIT

SPEED

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

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SPEED

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

Overview

KEY CONTENT/CONCEPTS

- Velocity, speed
- Measurement (accuracy of measurements)

LEVEL

- Lower second level
- Upper second level

INQUIRY SKILLS ASSESSED

- Planning investigations
- Forming coherent arguments
- Working collaboratively

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

- Scientific reasoning (collection of scientific data; identifying variables)

ASSESSMENT METHODS

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

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – SPEED

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

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

This unit was trialled by teachers in four countries – Turkey, Ireland, Portugal and Germany – producing four case studies (students aged 12-18; mixed ability and gender). The teaching approach was *bounded inquiry* in all cases. *Planning investigations* was assessed in all case studies, while skill in *forming coherent arguments* and *working collaboratively* were assessed in some case studies, along with *scientific reasoning* and *scientific literacy*. The assessment was primarily formative and achieved through classroom dialogue, teacher observation and evaluation of student artefacts.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The **Speed** SAILS inquiry and assessment unit was developed by the team at King's College London as part of the SAILS project. This unit is committed to an inquiry based learning approach with regard to the physical concepts distance and time, the absolute value of velocity and its distinction from the concept speed. Two activities are proposed; in the first students are asked to consider "How fast can you go?" and investigate the variables of time and distance. In the second activity, students consider the everyday example of their journey from home to school, and identify the distance, time and speeds involved in this journey. Several inquiry skills play a central role in the activities of this unit. The most important skill is *planning investigations*, as well as further skills like setting up the investigation/experiment, *scientific reasoning* (identifying variables, controlling variables), carrying out the investigation and collecting data or analysis of results.

Activity A: How fast can you go?

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

Rationale

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

Suggested lesson sequence

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

Activity B: Getting to school

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

Rationale

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

Suggested lesson sequence

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

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

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

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

Rationale and implementation of unit in full

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

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

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

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

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

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

2.2 Assessment of activities for inquiry teaching & learning

Assessment considerations

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

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

Assessment opportunities

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

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

Sample assessment tools

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

Table 1: Proposed rubric for the assessment of planning investigations

Inquiry skill	1	2	3
Plan an investigation to test a prediction	The student suggests how an investigation might be designed, but not in detail.	The student suggests how an investigation might be designed, but the design is incomplete in some respect. The design can, with some revisions, be used for systematic investigations.	The student plans an investigation where the design includes which variables to change and which to be held constant, in which order to perform different parts of the investigation and which equipment is to be used.
Design and conduct an investigation	The student carries out an investigation from the beginning to end, but needs constant support by the teacher, peers or detailed instructions. The student uses equipment, but may handle equipment in a way that is not always safe. The student sporadically documents the investigation in writing and with pictures.	The student carries out an investigation from the beginning to end, but sometimes needs support by the teacher, peers or detailed instructions. The student uses equipment safely. The student documents the investigation in writing and with pictures, but the documentation may be incomplete or lack in accuracy.	The student carries out an investigation from the beginning to end, either alone or as an active participant in a group. The student uses equipment safely and appropriately. The student accurately documents the investigation in writing and with pictures.
Interpret results and draw conclusions	The student draws conclusions, but only uses a limited amount of the results from the investigation. The student compares the results from the investigation with the hypothesis.	The student draws conclusions based on the results from the investigation. The student compares the results from the investigation with the hypothesis.	The student draws conclusions based on the results from the investigation. The student relates the conclusions to scientific concepts (or possible models and theories). The student compares the results from the investigation with the hypothesis. The student reasons about different interpretations of the results.

2.3 Further developments/extensions

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

Activity C: Getting away from it all

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

Rationale

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

Suggested lesson sequence

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

Activity D: Fast and slow speeds

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

Rationale

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

Suggested lesson sequence

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

Activity E: Speeding up and slowing down

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

Rationale

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

Suggested lesson sequence

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

Suggestions for teachers

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

Activity F: Quick on the draw

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

Rationale

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

Suggested lesson sequence

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

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

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

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

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

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

Rationale

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

Suggested lesson sequence

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

Activity H: Straight or curved?

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

Rationale

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

Suggested lesson sequence

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

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

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

3. SYNTHESIS OF CASE STUDIES

This unit was trialled in four countries, producing four case studies of its implementation – **CS1 Turkey**, **CS2 Ireland**, **CS3 Portugal** and **CS4 Germany**. All the case studies were implemented by teachers who had some experience of teaching through inquiry, but the students involved had limited experience of inquiry learning (except in **CS3 Portugal**).

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

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

3.1 Teaching approach

Inquiry approach used

The inquiry approach used in all the case studies was that of *bounded inquiry*, i.e. it was guided in the sense that the teacher posed the initial question but there were open inquiry opportunities in that students had freedom in addressing the question. Students completed the activities working individually or in small groups (see Table 2) and peer discussion was encouraged and facilitated.

Implementation

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

Adaptations of the unit

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

Table 2: Summary of case studies

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

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

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

3.2 Assessment strategies

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

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

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

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

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

Table 5: Assessment criteria used in CS2 Ireland

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

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

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

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

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