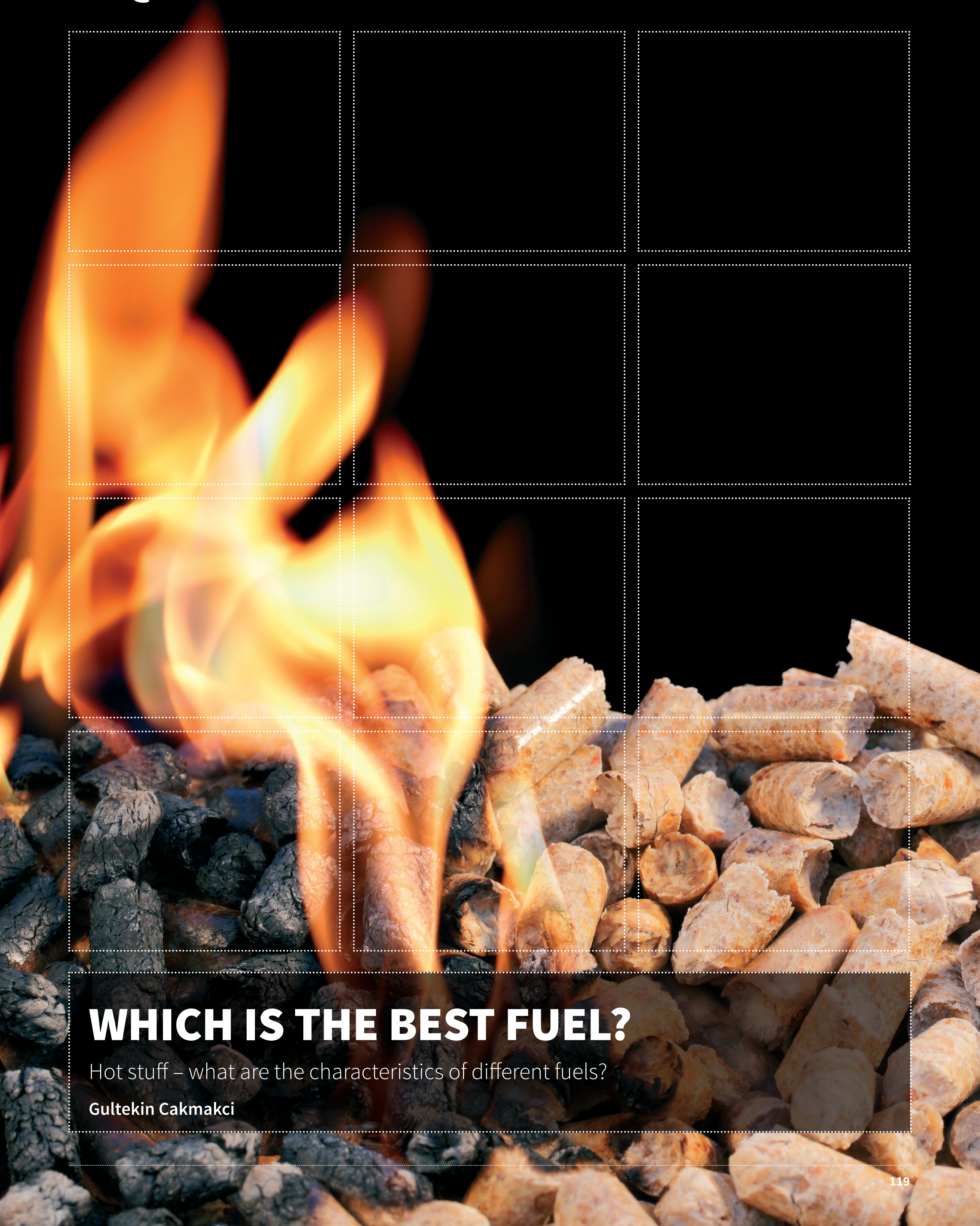
INQUIRY AND ASSESSMENT UNIT



WHICH IS THE BEST FUEL?

Hot stuff – what are the characteristics of different fuels?

Gultekin Cakmakci

WHICH IS THE BEST FUEL?

HOT STUFF – WHAT ARE THE CHARACTERISTICS OF DIFFERENT FUELS?

Overview

KEY CONTENT/CONCEPTS

- Enthalpy
- Heat energy
- Heat energy changes
- Calorimetry

LEVEL

- Lower second level
- Upper second level

INQUIRY SKILLS ASSESSED

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

ASSESSMENT OF SCIENTIFIC REASONING AND SCIENTIFIC LITERACY

- Scientific reasoning (collection of scientific data; defining variables)
- Scientific literacy (analysis and interpretation of scientific data)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials (documentation of inquiry)
- Presentations

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – WHICH IS THE BEST FUEL?

The **Which is the best fuel?** SAILS inquiry and assessment unit aims to encourage students to realise that fuels have different heats of combustion and allow them to realise that the meaning of "best" can change depending on the context. This is achieved by planning and carrying out an experiment to measure heat energy changes and finding enthalpies of combustion experimentally. This activity may be implemented at lower or upper second levels depending on the curriculum's objectives and full implementation requires four lessons.

Through this unit, students are provided the opportunity to develop a number of inquiry skills such as *developing hypotheses, planning investigations* (designing and conducting an experiment), and *forming coherent arguments* (drawing appropriate conclusions using reasoned arguments). In addition they build their *scientific reasoning* capabilities by collecting meaningful data, and enrich their *scientific literacy* through analysis of scientific data and presentation of scientific conclusions.

This unit was trialled by teachers in Turkey, Poland, Greece and Denmark, producing case studies of implementation at both lower and upper second level. Students were aged 14-18 years, and of mixed ability and gender. The teaching approach used in all case studies was *bounded* or *guided inquiry*, with some open opportunities. All four SAILS inquiry skills were assessed – *planning investigations, developing hypotheses, forming coherent arguments* and *working collaboratively* – as well as *scientific reasoning* capabilities. The assessment methods described include classroom dialogue, teacher observation, group discussion or presentations and evaluation of student artefacts.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The activities in the **Which is the best fuel?** SAILS inquiry and assessment unit were developed as part of the PARSEL project.[1] The teaching and learning activities were adapted for the SAILS project by the team at Hacettepe University.

In this unit, four key aspects or concepts are identified for development:

- Fuels have different heats of combustion;
- The meaning of "best" can change depending on the context, and that different factors can be considered in determining the best fuel;
- Planning and carrying out an experiment to measure heat energy changes, and
- Determining enthalpies of combustion by burning a compound and measuring the temperature rise in a known volume of water that is heated by combustion of a known mass of the compound.

This unit has been designed for use at both lower and upper second level; depending on the teacher's aims, different aspects can be emphasised. There are four activities outlined in the unit. In Activity A: Introduction, the students are consider the topic of fuels and the research question, "Which is the best fuel?" In the Activity B: Planning an investigation, the students plan how they might investigate the research question, and in Activity C: Carrying out an investigation, they carry out an experiment to investigate the question. These activities can be presented as an *open* or *bounded inquiry*, allowing the students an opportunity to design the experiment. In this case, variables to control (such as the amount of water to be used), the apparatus required and the precautions needed, are not mentioned. In an alternative scenario, using a *guided inquiry* approach, the design can be simplified by giving the actual experimental instructions and allowing the students to carry out the experiment. Time can then be spent discussing the meaning of "best" as a group activity. In the Activity D: Conclusions, the students form conclusions, determine their choice of the "best fuel" and explain their choice.

Opportunities within this unit allow for the assessment of the SAILS inquiry skills of *developing hypotheses, planning investigations* (designing and conducting an experiment), *forming coherent arguments* (supporting conclusions using reasoned arguments and evidence) and *working collaboratively*. In addition, there is scope for development of *scientific reasoning* capabilities through identifying and defining variables operationally, collecting and documenting meaningful data, and explaining any unexpected results. This unit allows for enrichment of *scientific literacy* through analysis of scientific data, drawing appropriate conclusions, reporting and discussing results and understanding the scientific principles underlying combustion.

Activity A: Introduction

Concept focus	Understanding enthalpy Fuels – examples and criteria for identifying the "best" fuels
Inquiry skill focus	Developing hypotheses Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (problem-solving, making comparisons)
Assessment methods	Classroom dialogue Student devised materials

Rationale

In this activity, students review their prior knowledge and preconceptions around the topic of fuels and combustion. This can be achieved through individual reflection, small-group discussion or whole-class brainstorming. The teacher can guide the students to identify examples of fuels and their various uses. Once students understand the underlying concepts, the teacher introduces the inquiry task – "Which is the best fuel?" In this discussion, students should work towards identifying the characteristics of a "good" fuel, and how this can vary depending on function.

Suggested learning sequence

1. The lessons can begin by revising the meaning of "fuel." This can be done by each student writing down their interpretation, followed by the teacher soliciting responses from members of the class and building up a description of a fuel on the blackboard.
2. By means of a brainstorming session, the teacher can gather examples of fuels and where they are used. At this stage the idea is to get a wide range of suggestions, rather than limiting the discussion to the range of fuels that might be used in the experiments. Thus examples such as nuclear fuel or electricity are just as acceptable as petrol, diesel, natural gas or kerosene.
3. Following this, the teacher could raise the question – which fuel is best? The students can discuss the meaning of "best" as a group discussion. To ensure the discussion can begin, the teacher can give each group a hand-out on possible meanings of "best" related to fuels. At this stage the teacher will need to limit the fuels under consideration, by suggesting, for example, that the students only consider liquid fuels. Various ideas could be solicited from the class.

[1] Popularity and Relevance of Science Education for Scientific Literacy (PARSEL), which was funded by the European Union's Sixth Framework Programme in 2006, http://icaseonline.net/parsel/www.parsel.uni-kiel.de/cms/indexe27e.html?id=76 [accessed October 2015]

Activity B: Planning an investigation

Concept focus	Planning an investigation to compare fuels Heat of combustion, enthalpy
Inquiry skill focus	Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (identification of variables)
Assessment methods	Classroom dialogue Teacher observation Student devised materials

Rationale

In this activity, the students develop an experiment to investigate which is the best fuel, building upon the ideas suggested previously. At the end of the lesson, students are expected to be able to prepare a workable plan for carrying out the experiment. They should discuss their experimental plan with colleagues in a group and modify their plan as appropriate. They will also plan how to determine the calorific value of fuels and identify appropriate calculations.

Suggested learning sequence

1. The teacher asks the students, "Can you suggest how we could find out which is the best fuel?"
2. Students should tackle this question in groups. The teacher will need to guide the students in the planning part of the experiment (as he/she goes around the various groups), by trying to get the students to suggest the following
   a. Something (water) is heated by burning each fuel in turn;
   b. What needs to be constant for each experiment;
   c. Could this be a fixed mass of water?
   d. The amount of fuel used needs to be measurable;
   e. A measure of the heat given out can be made from the rise in temperature of the water;
   f. Measurement of the amount of fuel before and after the experiment will indicate the amount of fuel used;
   g. By measuring the time taken for the fuel to burn, it is possible to determine which fuel heats the water the fastest.
   h. By knowing the cost of the fuel per given quantity, it is possible to determine the most economical fuel. Possible fuels to use may be paraffin, methylated spirits (ethanol), methanol or candle wax (spirit burner not required in this case).
3. The teacher should encourage students to put forward other points that may or may not be used in the experiment, such as that the water needs to be at the same temperature at the beginning of each experiment, heat losses need to be minimised/measured and the vessel in which the fuel is contained needs to be identical in each case.
4. The students, in their groups, write out an experimental procedure, suggesting apparatus that might be suitable.

Activity C: Carrying out an investigation

Concept focus	Understanding enthalpy Identifying the "best" fuels
Inquiry skill focus	Planning investigations Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (collecting scientific data) Scientific literacy (making informed choices of fuel for particular functions)
Assessment methods	Classroom dialogue Teacher observation Peer-assessment Worksheets or student devised materials

Rationale

This activity may be implemented using a *bounded* or *guided* approach. Students are expected to carry out the experiment in a group, where each member can use a different fuel. Students should record the data obtained in a suitable format, calculate both calorific value and heat of combustion and compare their results with the data from others in the group. Students can discuss the procedures used in the experiment, the steps taken to determine accuracy and the limitations of the set-up to give accurate results.

Suggested learning sequence

1. After the planning activity, the teacher can discuss the procedure with the class, making sure that suggestions of unsafe practices are discarded. Then, to ensure each group is able to carry out the experiments, the teacher can give a handout or worksheet to each student group, detailing the experimental procedure (Figure 1). The procedure can be modified to more closely follow the students' suggestions, if appropriate.
2. The experiment can be conducted using apparatus as close to the students' suggestions as is practicable. The main components are a spirit lamp (which is a small container with a wick), water (ca. 200 g) in a conducting container (something like a "coke" can), a thermometer (this can also act as a stirrer), balance and a stop clock. A clamp to hold the container and draught shields to minimise heat loss by the movement of air can be extra considerations.
3. Students can repeat the experiment until they obtain two or three consistent results. Methanol, ethanol, propan-1-ol and butan-1-ol can be used as fuels. In their procedure the students need to determine the parameters detailed in the table in Figure 1.

Activity D: Conclusions

Concept focus	Understanding enthalpy Making informed choices of fuel for particular functions
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (making comparisons) Scientific literacy (analysis and interpretation of scientific data)
Assessment methods	Classroom dialogue Worksheets or student devised materials Presentations Other assessment items (homework, post implementation test)

Rationale

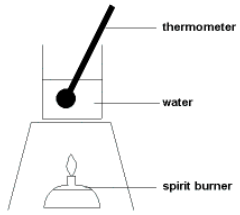
At the end of the lesson, students are expected to be able to provide a report of their experiment, giving details of accuracy, calculations performed and how data is interpreted. They should interpret their results to determine the best fuel and explain their choice. This can be in the form of a written report, an oral presentation during a class discussion or a multimedia presentation.

Suggested learning sequence

1. Once students have finished their experimental activities, they should be encouraged to interpret their results. Depending on the prior knowledge and ability of the class, the teacher can guide the students through the appropriate calculations or use this as a revision exercise.
2. Once the heat of combustion and enthalpy is determined for each fuel, students should discuss their results in small groups or at a whole class level. This should provide an opportunity to identify variation in results, and encourage students to consider experimental errors.
3. Students should then select the fuel that they believe to be the "best" and explain their choice in a scientific manner, using evidence from the inquiry.
4. For further consolidation of newly acquired knowledge, the students can be asked to prepare a report or presentation, carry out some homework tasks, or the teacher can set a post-implementation test.

Enthalpy of combustion experiment

Adapted from Atkinson, J. & Hibbert, C. (2000). AS Chemistry for AQA. Oxford: Heinemann.



Data table

	Fuel A	Fuel B	Fuel C	Fuel D
Initial mass of container (spirit lamp)				
Initial mass of spirit lamp + fuel				
Final mass of spirit lamp + fuel				
Mass of fuel burned (m_f)				
Volume of water in beaker				
Mass of water in beaker (m_w)				
Initial temperature of water				
Final temperature of water				
Temperature rise (ΔT)				
Time for which the fuel was burning				
Heat energy released by the combustion of the fuel				
The enthalpy of combustion of the fuel				
Cost of the fuel used				

Specific heat capacity, c, of water: It takes 4.2 joules of heat energy to increase the temperature of one gram of water by one degree. This value is known as the specific heat capacity of water.

Dependent variable: ____________________
Independent variable: ____________________
Controlled variable: ____________________

Heat energy gained by the water is given by: $q_w = m_w.c.\Delta T$

The heat gained by the water is equal to the heat released by the fuel. Therefore the heat energy released by the combustion of one mole of the fuel under investigation can be calculated using q_w, as long as the mass of fuel used is known.

Figure 1: Student worksheet for guided experiment. Adapted from Atkinson, J. & Hibbert, C. (2000). AS Chemistry for AQA. Oxford: Heinemann.

2.2 Assessment of activities for inquiry teaching & learning

This unit is particularly suitable for assessing *developing hypotheses, planning investigations* and *scientific reasoning* (drawing conclusions; explaining unexpected results; reporting, comparing, and discussing results, and providing suggestions about how to improve investigations). Students are able to work in diverse teams (*working collaboratively*) and can produce ideas based on views from team members. Six key objectives have been identified for development in this unit, as detailed in Table 1. Students should learn that fuels have different heats of combustion and that the meaning of "best" can change depending on the context. They should be able to plan and carry out an experiment to measure heat energy changes, and determine enthalpies of combustion based on their results.

Table 1: Assessment opportunities identified in the unit activities

Objective	Achieved by...	Skill/competency
1. To appreciate that "best" can have more than one interpretation and to suggest the most appropriate meaning in this context	...the students discussing their suggestions given for the "best" fuel. They need to give reasons for their suggestion from a social and scientific point of view.	Scientific literacy (making informed choices of fuel for particular functions)
2. Planning an investigation, interpreting experimental instructions and carrying out an experimental procedure	...the students discussing how to measure the heating ability of a fuel and then carrying out the actual experiment in small groups. They should follow experimental procedures that are an adaptation of those put forward by the students.	Developing hypotheses, planning investigations, working collaboratively, scientific reasoning (identifying variables, collecting scientific data)
3. Undertaking calculations to determine the link between amount of fuel, temperature changes and time taken	...the students calculating the calorific value and heat of combustion from the readings taken during the experiment.	Scientific literacy (explaining phenomena scientifically)
4. Cooperating as a member of a group	...the students working as a group in carrying out the experiment and in the results from the whole class being pooled to obtain a set of results from which the "best" fuel can be determined.	Working collaboratively
5. Communicating orally and by means of a written interpretation	...discussing within a group the meaning of "best fuel" and in developing the working procedures for the experiment. The written interpretation is undertaken by each individual student.	Working collaboratively, forming coherent arguments, scientific literacy (presenting scientific information)
6. Explaining the meaning of fuel and introducing the heat of combustion	...the individual classwork in which students give their ideas in writing, followed by the blackboard summary. Heat of combustion is introduced as the conclusion of the experiment, based on parameters used in the experiment. (An extension could be for students to base the heat of combustion on standard parameters e.g. 1 mole of water heated by 1 °C).	Developing hypotheses, planning investigations, forming coherent arguments, scientific reasoning, scientific literacy (understanding enthalpy in an everyday context)

A suggested assessment scale is provided for evaluation of *planning investigations* and *scientific reasoning*, which features eight success criteria (Table 2). A 3-point scale is suggested – acceptable/needs improvement/poor – although teachers can modify these to more accurately reflect their expectations in their classrooms.

Table 2: Checklist used to evaluate skills in the Which is the best fuel? SAILS unit

Objectives	Acceptable	Needs improvement	Poor/NA
1. Formulate a hypothesis			
2. Design and conduct an experiment			
3. Identify and define variables operationally			
4. Collect meaningful data, organise, analyse data accurately and precisely and draw appropriate conclusions			
5. Explain any unexpected results			
6. Support conclusions, using reasoned arguments and evidence			
7. Collaborate with others to work towards common goals			
8. Report and discuss results, get feedback and deal positively with praise, setbacks and criticism			

3. SYNTHESIS OF CASE STUDIES

The **Which is the best fuel?** SAILS inquiry and assessment unit was trialled in four countries, producing four case studies of its implementation – **CS1 Turkey**, **CS2 Poland**, **CS3 Greece** and **CS4 Denmark**. The unit was implemented at both lower and upper second level. In **CS1 Turkey**, the unit was carried out with 22 pre-service science teachers in their first year of training (around 17-18 years) and in **CS2 Poland** the unit was trialled with students aged 17-18 years. In **CS3 Greece** and **CS4 Denmark** the unit was implemented with lower second level students, aged 14-16 years. In all cases, the students were of mixed ability and gender.

The teachers in the case studies all had prior experience in teaching though inquiry, but most students had no prior experience with inquiry, except in **CS1 Turkey**, where students had experience with inquiry from previous laboratory sessions. The unit was implemented in one to three lessons, over a total duration of 90-135 min. Most case studies implemented it in full, although **CS2 Poland** implemented the introductory activity as a homework task prior to the laboratory session.

The assessment methods used included classroom dialogue in all case studies, but other methods varied depending on implementation. **CS2 Poland**, **CS3 Greece** and **CS4 Denmark** used self-assessment strategies, while **CS1 Turkey** and **CS3 Greece** also used peer-assessment. In all case studies, except **CS4 Denmark**, the teacher evaluated student artefacts as part of the assessment.

3.1 Teaching approach

Inquiry approach used

The inquiry approach used in all the case studies was that of *guided* or *bounded inquiry*, i.e. the initial investigation topic was proposed by the teacher but students had freedom in how they could investigate the topic. In **CS1 Turke**y and **CS3 Greece**, the teachers used a *guided approach*, while in **CS2 Poland** and **CS4 Denmark** students were given more possibility of freedom in the work and a *bounded inquiry* approach was used, with minimal guidance by the teacher.

Implementation

The **Which is the best fuel?** SAILS inquiry and assessment unit was implemented in full in all case studies, although the manner in which it was implemented varied depending on students' level and local curricula. Implementation of the unit took place over 1-3 lessons (total duration 90-135 minutes). Students worked in mixed ability groups (Table 3).

Both **CS1 Turkey** and **CS2 Poland** detail implementation at upper second level, with students aged 17-18 years. In **CS1 Turkey**, the class consisted of pre-service teachers, in their first year of training. The unit was implemented as a *guided inquiry*, and students were provided with a worksheet detailing the "research cycle" to help structure their approach to the investigation. Six different steps were outlined in this research cycle; at each stage different skills were identified for development:

- Writing a research question,
- Formulating a hypothesis,
- Planning the investigation/experiment,
- Conducting the experiment, and evaluating results
- Interpreting the data/generating knowledge,
- Discussing the results, presenting the results/reflection.

CS2 Poland describes implementation through an extracurricular, voluntary class, held at a university laboratory. Before the class, the students were informed about the topic to be discussed and the teacher sent them worksheets, which they were asked to complete individually before coming to the lesson. The aim of the worksheet was to introduce the topic, and thus the implementation began with the planning investigations phase. In the laboratory, a bounded inquiry approach was used. The teacher wanted students to develop their skill in note-taking and observations in the inquiry process, and so did not provide a structured worksheet.

CS3 Greece and **CS4 Denmark** detail implementation with lower second level students, aged 14-16 years. In CS3 Greece, the teacher

Table 3: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Turkey	Activities A-D	One lesson (90 min)	• 4-6 students per group (22 students, 5 male) • Teacher assigned groups; mixed ability; some mixed gender, some all-female; pre-service teachers
CS2 Poland	Activities B-D	Three lessons (45 min each)	• Two groups of 2-3 students (5 students total) • Student selected groups; mixed ability and gender
CS3 Greece	Activities A-D	Two lessons (60 min each)	• Groups of 3-4 students • Teacher assigned groups; mixed ability and gender
CS4 Denmark	Activities A-D	Two lessons (45 min each)	• Groups of 4-5 students (two classes; 21/24 students) • Teacher assigned groups; mixed ability and gender

modified the unit to deliver objectives of the Greek curriculum and used a *guided approach*. The lesson as adapted and implemented by the teacher focused on the following aspects:

- Appreciating the uses of different kinds of fuels in practice,
- The meaning of "best" can change depending on the context, and that different factors can be considered in determining the best fuel,
- Carrying out an experiment using simple measurements (temperature and time) in order to investigate the "best" fuel in the context of cooking.

In this case study, the investigation planned and implemented was not as described in the teaching and learning activities, but it allowed students to develop the same skills and apply their knowledge in an everyday context.

In **CS4 Denmark**, the unit was implemented as suggested in the teaching and learning sequence, but students were given great freedom and the teacher gave minimal guidance. This was implemented as a *bounded inquiry*, in which the students identified the fuels to investigate, the parameters for investigation and they critiqued their experimental design and engaged in troubleshooting when the investigation was not proceeding as they had hoped. The teacher chaired whole-class discussions and asked prompt questions, but otherwise did not become involved in the planning and implementation.

Adaptations of the unit

While the implementation in most case studies followed that of the teaching and learning activities described, there were some modifications made. These were to suit the level of the students, the skills chosen to be assessed or to align with state curricula or teaching strategies.

CS1 Turkey details little change from the suggested lesson sequence, although the teacher provided a guiding worksheet, which detailed the "research cycle" and provided structure for their inquiries. Similarly, **CS4 Denmark** does not deviate significantly from the teaching and learning activities described, although the implementation was very open and the teacher did not provide any guiding materials or worksheets.

In **CS2 Poland**, some small adaptations were made to accommodate implementation during an extracurricular class. The teacher prepared an introductory worksheet, which was provided as preparatory homework. This replaced the introductory activity in the suggested teaching and learning sequence. For the in-lab implementation, the activities started with the *planning investigations* phase, thus allowing enough time to complete planning, implementation and concluding activities.

CS3 Greece describes the greatest changes to the unit. This was an implementation at lower second level, and therefore the teacher did not introduce enthalpy. The Greek schooling system recommends use of *guided inquiry* approaches, and thus the teacher prepared four worksheets and an experimental worksheet. This implementation focused on three aspects – use of different fuels for different functions, understanding that the meaning of "best" depends on context, and an experimental phase involving the everyday context of cooking. The skills developed were those identified in the suggested teaching and learning activities, but the experiment was simplified to observing the "best" fuels for use in boiling water and for cooking, and defining the meaning of "best" in these cases.

3.2 Assessment strategies

Within the four case studies, the inquiry skills of *planning investigations* and *developing hypotheses* were assessed (Table 4), as well as *scientific reasoning* (collection of scientific data) and *scientific literacy* (analysis and interpretation of scientific results), as suggested in the teaching and learning sequence. Formative assessment was used, in particular for the assessment of *developing hypotheses* and *planning investigations*. The assessment methods used include classroom dialogue, evaluation of worksheets or student devised materials, self-assessment and peer-assessment.

Table 4: Inquiry skills identified by teachers in the case studies

CS1 Turkey	• Developing hypotheses • Planning investigations • Working collaboratively • Scientific reasoning (collection of scientific data) • Scientific literacy (analysis and interpretation of scientific data)
CS2 Poland	• Planning investigations • Forming coherent arguments • Scientific reasoning (organisation and interpretation of data)
CS3 Greece	• Forming coherent arguments • Working collaboratively
CS4 Denmark	• Planning investigations • Scientific reasoning (data entry and observation skills)

In **CS1 Turkey**, almost all of the skills were assessed using the checklist assessment tool provided in the assessment of inquiry teaching & learning section of this unit (Table 2) and by analysing students' worksheets. However, skills in *developing hypotheses* and *planning investigations* were assessed in-class, through effective classroom dialogue. The teacher observed that students were having difficulty with these tasks, and that the hypotheses proposed were often not testable. To address this, the teacher asked each group to read their hypotheses and investigation plan to the class. While these were preliminary workings and did not have much detail, the teacher used this method to check which groups would have managed the whole process without the teacher's intervention. For groups that had a plan or hypothesis that could not be investigated, the teacher gave feedback so they could be changed before conducting the investigation.

In **CS2 Poland**, three skills were selected for the assessment – *developing hypotheses*, defining variables, and collection of scientific data (taking notes/collecting raw data). The teacher provided a worksheet as a preparatory task, but this was not used for the assessment of inquiry skills. The teacher designed a 3-level rubric for the assessment of these skills, which was used when evaluating student notes from the lesson period (Table 5).

Table 5: Assessment of skills developed in CS2 Poland

Skill	Fail	Satisfactory	Very good
Developing hypotheses	The student does not formulate a hypothesis appropriate to the research problem raised.	With the teacher's assistance, the student formulates a hypothesis for the research problem raised.	The student independently formulates a correct hypothesis, adequate for further experiments and referring to a correctly raised research problem.
Defining variables	The student does not define variables associated with the planned experiment.	The student defines some variables, and with the teacher's assistance is able to identify other relevant variables.	The student independently defines appropriate dependent and independent variables.
Collection of experimental data	The student prepares incomplete, unreadable notes containing information unusable in terms of finding an answer to a research question raised.	With the teacher's help, the student is able to write down some information – but not enough to present and interpret the results, e.g. obtained data without symbols and units.	The student independently prepares appropriate notes, taking into account relevant units, quantities and symbols, relationships between quantities reflected in formulas, presenting a logical cause and effect sequence that contains all the necessary information, which, in the end, allows for the calculation of the combustion effect of the tested fuels.

In **CS3 Greece**, the teacher observed the students during the activities and gave on-the-fly feedback. The teacher used a modified version of the checklist proposed in the assessment of inquiry teaching & learning section of this unit (Table 2), and developed a separate rubric for the self-assessment of the *working collaboratively* skill (see Table 6). Student groups also exchanged worksheets to engage in peer-assessment, for which the teacher provided a simple rubric to guide their judgements.

Table 6: Self-assessment of working collaboratively in CS3 Greece

Behaviour	3-always	2-sometimes	1-rarely
1. I actively participated in all discussions of the group			
2. In all discussions I took into consideration the views of all team members			
3. I helped in resolving disputes between team members			
4. I used convincing arguments to support my views			
5. I provided assistance in the team whenever needed			
6. I looked for information on the subject in all phases			
7. I completed without delay all the work undertaken to do in the team			

In **CS4 Denmark**, two key opportunities for assessment of inquiry skills were described. First, the teacher provided a questionnaire, with very open questions, which the students were asked to fill in at the end of the lesson, as follows:

- What have you learned about fuels?
- In this lesson, what have you learned about work methods in physics/chemistry course?
- In this lesson, what have you learned about making explanations and argumentation?
- Overall, what did you think of the lesson?

In the second assessment opportunity, the teacher held an oral discussion for one lesson, in which the following questions were discussed with students:

- Why did some find it difficult to work in this way?
- What was the most important thing you learned?
- Do you think that the procedure you used was the same as that used in a real workplace?