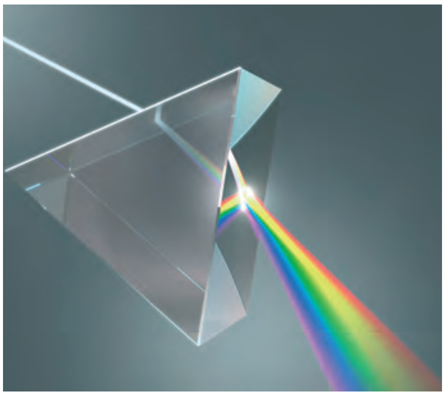
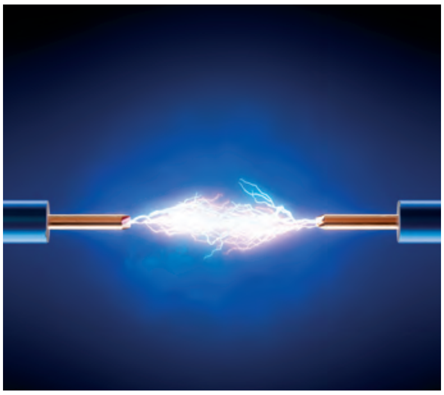
Strategies for Assessment of Inquiry Learning in Science





SAILS INQUIRY AND ASSESSMENT UNITS

VOLUME ONE

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Editors

Odilla Finlayson, Eilish McLoughlin,
Emma Coyle, Deirdre McCabe,
James Lovatt, Paul van Kampen

SAILS Inquiry and Assessment Units
Volume 1

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ABOUT SAILS

The SAILS project is a European project funded by the European Seventh Framework Programme (FP7) involving fourteen partner organisations, including universities, SMEs and a multi-national organisation, from across twelve European countries (Belgium, Denmark, Germany, Greece, Hungary, Ireland, Poland, Portugal, Slovakia, Sweden, Turkey and the UK). The strength of this consortium lies in its vast experience and expertise in the areas of science education, teacher education and development of resources for teaching, learning and assessment. The overall aim of the SAILS project was to promote and facilitate the use of inquiry based approaches in the teaching, learning and assessment of science across Europe with second level students.

Through the collaborative efforts of the partners, the SAILS project (2012-2015) has:

- Enhanced and developed IBSE teaching and learning materials by incorporating inquiry assessment strategies and frameworks;
- Partnered with teachers to identify and implement assessment strategies and frameworks to evaluate key IBSE skills and competences in the classroom;
- Provided teacher education programmes on inquiry and assessment of inquiry for pre-service and in-service teachers in IBSE;
- Supported teachers to share experiences and practice of inquiry approaches to teaching, learning and assessment – by supporting a community of practice;
- Promoted the use and dissemination of inquiry approaches to teaching, learning and assessment with national and international stakeholders.

Project partners

Dublin City University, Ireland

Intel Performance Learning Solutions Limited, Ireland

Pavol Jozef Šafárik University in Košice, Slovakia

Jagiellonian University, Poland

Malmö University, Sweden

Kristianstad University, Sweden

University of Southern Denmark, Denmark

The Institute of Education of the Lisbon University, Portugal

King's College London, United Kingdom

University of Szeged, Hungary

ATiT, Belgium

University of Piraeus Research Centre, Greece

Hacettepe University, Turkey

Gottfried Wilhelm Leibniz Universität Hannover, Germany

WWW.SAILS-PROJECT.EU

CONTRIBUTORS

Belgium (ATiT)

Sally Reynolds (lead national partner)
Peter Andries, Marc Beddegenoodts, Mieke DeCock, Wim Peeters, Werner Tuytens, Mathy Vanbuel, Joasia van Kooten

Denmark (SDU)

Morten Rask Petersen (lead national partner)
Linda Ahrenkiel, Thomas R.S. Albrechtsen, Ulrich Pedersen Dahl, Henrik Falcon, Lotte Mølbak Hansen, Cecilie Ebsen Ourø Jensen, Stine Mariegaard, Claus Michelsen, Lisbeth Højmark van Brakel, Ulrik Lyng Vestergaard, Lisbeth Vive, Birthe Zimmermann

Germany (LUH)

Gunnar Friege (lead national partner)
Maximilian Barth, Thorsten Bell, Matylda Dudzinska, Ingmar Klappauf, Lea Lensment, Christoph Schäfer, Knut Wille

Greece (UPRC)

Symeon Retalis (lead national partner)
Panagiotis Andritsakis, Andreas Georgakakis, Efstathios Mitropoulos , Ourania Petropoulou, Yannis Psaromiligkos, George Stefanidis

Hungary (US)

Benő Csapó (lead national partner)
Ferencné Adorján, Csaba Csíkos, Zita Gál, Ágnes Kissné Gera, Tünde Kontai, Erzsébet Korom, Ervin Lohrman, Lászlóné Nagy, Mária B. Németh, Veronika Németh, Zsuzsa Oláhné Nádasdi, Gábor Orosz, Attila Pásztor, Katalin Radnóti, Ágota Somogyi, Gábor Veres

Ireland (DCU)

Odilla Finlayson (SAILS project coordinator)
Eilish McLoughlin (lead national partner)
Sarah Brady, Enda Carr, Declan Cathcart, Ruth Chadwick, Robert Clarke, Brigid Corrigan, Paul Grimes, Leeane Hinch Sean Kelleher, James Lovatt, Deirdre McCabe, Lorraine McCool, Niall Mahon, Richard Moynihan, Miriam Nugent, Laura Rice, Fiona Sharkey, Paul van Kampen, Kerrie Whelan, Aine Woods

Ireland (Intel)

Joe Greene (lead national partner)
Padraig Coakley, Mark Melia, Martina Roth

Poland (JU)

Paweł Bernard (lead national partner)
Paweł Broś, Robert Czuchnowski, Karol Dudek, Iwona Maciejowska, Kinga Orwat, Lucyna Paul, Dagmara Sokołowska, Mateusz Wojtaszek

Portugal (IEUL)

Cecília Galvão (lead national partner)
Mónica Baptista, Cláudia Faria, Sofia Freire, Cláudia Gonçalves, Pedro Reis, Vanessa de Andrade, Dulce Campos, Paula Castelhano, Teresa Conceição, Luisa Encarnação, Carla Matoso, Ana Vicêncio

Slovakia (UPJS)

Marián Kireš (lead national partner)
Monika Antušová, Mária Brzová, Dorota Černíková, Ľubomíra Cimbálová, Gabriela Franíková, Mária Ganajová, Marianna Ivanová, Zuzana Ješková, Katarína Kimáková, Viera Kováčová, Svetlana Mitrová, Zdena Orvosová, Tibor Révay, Viera Šerešová, Alžbeta Slavkovská, Ivana Slepáková, Ivana Sotáková, Dusan Šveda

Sweden (HKR)

Anders Jönsson (lead national partner)
Carina Agevall, Stefan Einarsson, Lena Ericsson, Kajsa Gavelfält, Nils Jönsson, Kristina Kangasmaa, Ricard Larsson, Cecilia Mattsson, Marina Mattsson, Malin Nilsson, Maria Rosberg, Jenny Sandgren

Sweden (MaH)

Mats Lundström (lead national partner)
Alexandra Andersson, Margareta Ekborg, Anna Falkstedt-Svensson, Jessica Feinberg, Bjorn Forsberg, Åsa Hansson, Myrtel Johansvon, Christian Karlsson, Anna Levin, Sara Lilja, Karin Nilsson, Sofie Nilsson, Johan Öman, Anna Persson, Christian Rydberg, Anne Svensson

Turkey (HU)

Gultekin Cakmakci (lead national partner)
Ali Akinci, Buket Akkoyunlu, Funda Gezer Atak, Cemil Aydoğdu, Ismail Donmez, Betul Sen Gumus, Savas Gungoren, Ayse Gurel, Duygu Mutlu Kaya, Gokhan Kaya, Merve Karden Onsoz, Merve Pekcan San, Metin Sardag, Ipek Ince Sungur, Derya Yahsi, Yalcin Yalaki, Gamze Kavak Yuksel

United Kingdom (KCL)

Christine Harrison (lead national partner)
Katie Barber, Paul Barber, Kwadowo Barney, Paul Black, Sarah Clarke, Ken Dignon, Sally Howard, Amandeep Khan, Anja Luther, Brian Matthews, Stephen Philips, Ed Carew-Robinson, Georgina Turner

SAILS APPROACH TO INQUIRY AND ASSESSMENT

This collection of ***SAILS Inquiry and Assessment Units*** showcases the benefits of adopting inquiry approaches in classroom practice, exemplifies how assessment practices are embedded in inquiry lessons and illustrates the variety of assessment opportunities/processes available to science teachers. In particular, the units provide 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, the units presented show how evidence of student learning can be collected and evaluated through a variety of methods, e.g. classroom dialogue, teacher observation, presentations, peer-assessment, self-assessment, student artefacts, use of assessment rubrics, etc. These SAILS Units are presented so as to be informative for teachers, relevant to classroom practice and include illustrative examples of assessment items and criteria used to evaluate student learning.

The Strategies for Assessment of Inquiry Learning in Science (SAILS) project was funded under the EU Framework Seven programme (2012-2015) to support teachers in adopting inquiry based science education (IBSE) and assessment of inquiry skills and competencies in science at second level across Europe. The SAILS team have successfully developed and provided professional development programmes for second level science teachers, both in-service and pre-service, that support teachers in understanding how inquiry approaches can be encouraged and facilitated in the classroom. In particular the SAILS teacher education programmes supported teachers in using assessment strategies to make judgments and give feedback to their students on how to improve their learning. In this way, the SAILS project has prepared science teachers from across Europe, 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.

Inquiry skills are what learners use to make sense of the world around them. Inquiry provides both the impetus and experience that helps students acquire problem solving and lifelong learning skills. These skills are important both to create citizens that make informed decisions and to develop scientific reasoning for those students whose career choices require the logical approach that science encourages. An inquiry approach can also help students develop deeper conceptual understanding and encourages students' motivation and engagement with science.

In carrying out this project, SAILS focussed on supporting the development of six scientific/inquiry skills and competencies: developing hypotheses; working collaboratively; forming coherent arguments; planning investigations; scientific reasoning and scientific literacy. The SAILS team identified and selected inquiry activities that promoted these skills and competences and developed assessment strategies appropriate for each skill and/or competency highlighted in these activities. In this way, the inquiry approach, development of the skill and its assessment were combined and presented as draft (inquiry and assessment) units that could be used by teachers for trialling in the second level science classroom.

Following evaluation with science teachers experienced with inquiry in each country, draft units were selected (based on a range of inquiry skills, subject areas and assessment methods) for further development and trialling in classrooms. These draft units were trialled in over 100 second level classrooms, each unit across at least three different countries and the feedback from teachers was collected in the form of case study reports. The outcomes of this dynamic collaboration between SAILS partners and teachers has led to the presentation of nineteen ***SAILS Inquiry and Assessment Units*** that describe the inquiry approach used to develop and assess a particular skill/competence in classroom practice. In addition, the ***SAILS Framework for Inquiry and Assessment*** has been developed to describe each of the inquiry skills and competencies focussed on, and to present the assessment strategies used for the assessment of that skill/competence, along with illustrative examples from across the disciplines of science and classroom-based assessment practices.

The ***SAILS Inquiry and Assessment Units*** show that a range of assessment methods can be used to assess inquiry skills. As demonstrated in the case studies, the SAILS units can be adapted to focus on other skills that the teacher may wish to develop. The assessment criteria used can also be modified to suit the student age and their experience level with inquiry. The assessment criteria might also be shared with the students so that they develop their experience with self-assessment or peer assessment. Within each unit, the key content/concepts covered are outlined as well as the main inquiry skills and assessment strategies. The first section in each unit provides the unit outline in terms of content and concepts covered. The second section gives ideas on how the activities can be implemented and how the skill/competency involved can be assessed. The third section provides a synthesis of the case studies of the implementation of the unit across at least three countries, in terms of the teaching approach and the assessment strategies. It is clear from the case study syntheses that teachers have adapted and adopted many different assessment strategies to assess the same skill. The case studies themselves provide a narrative of how the teachers approached inquiry within the unit, how feasible the lesson was with the chosen class and how they assessed the success of their learners. It also highlights any issues encountered, relating to cultural perspectives and other equity issues, such as gender.

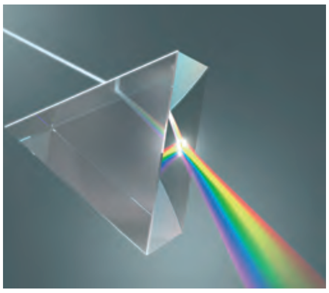
The collection of nineteen ***SAILS Inquiry and Assessment Units*** has been published in two volumes by the SAILS partners and electronic versions of these units, case study reports and relevant classroom materials are available for download from the project website: www.sails-project.eu. These units and other related project outcomes are freely provided to disseminate to teachers and educators how inquiry approaches can be implemented and assessed in the second level science classroom. These units provide evidence that each inquiry skill and competence focussed on in the SAILS project can be readily assessed.

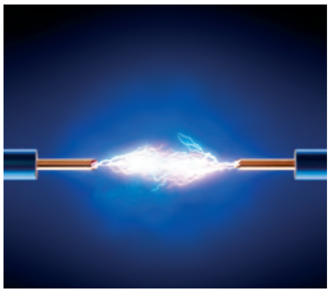
When using these units, teachers are encouraged to adapt the activities to suit their own particular classroom context. In particular, key advice for classroom implementation, as evidenced through the case studies from teachers, are that:

- Teachers should select which skill/competence to focus on, 2-3 at most, within an inquiry lesson.
- Multiple sources of evidence should be used to map student learning and progress
- The use of indicators of progress is invaluable for students as well as teachers in assessing learning progression of a skill/competence.

Through the collaborative efforts of the partners, the SAILS project (2012-2015) has showcased how inquiry approaches can be used for teaching a range of science topics, and has supported science teachers becoming confident and competent in the assessment of their students' learning through inquiry. More than 2500 science teachers in 12 countries have participated in SAILS teacher education programmes. These teachers have strengthened their inquiry pedagogy and assessment practices by developing their understanding of the role of assessment.








OVERVIEW OF SAILS INQUIRY AND ASSESSMENT UNITS

Volume 1

ACID S, BASES, SALTS
All acids are harmful – or are they?

Panagiotis Andritsakis, Efstathios Mitropoulos, Ourania Petropoulou and Symeon Retalis, University of Piraeus Research Centre (UPRC), Greece

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PROOF OF THE PUDDING
Optimising the perfect pudding – an investigation good enough to eat!

Gábor Veres, Csaba Csíkos, University of Szeged (US), Hungary

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

Paul Black[a], Gunnar Friege[b], [a]King's College London (KCL), United Kingdom, [b]Gottfried Wilhelm Leibniz Universität Hannover (LUH), Germany

UP THERE… HOW IS IT?
How to live on the International Space Station?

Vanessa de Andrade, Mónica Baptista, Cláudia Faria, Cláudia Gonçalves, Cecília Galvão, Instituto de Educação da Universidade de Lisboa (IEUL), Portugal

WOODLICE
What are the living preferences of woodlice (or other commonplace small creatures)?

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Volume 2

BLACK TIDE – OIL IN THE WATER
Oil in our waters – cleaning up our mess!

Cláudia Faria, Cláudia Gonçalves, Cecília Galvão, Instituto de Educação da Universidade de Lisboa (IEUL), Portugal

COLLISION OF AN EGG
Mechanics in motion – what factors affect forces and collisions?

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FOOD AND FOOD LABELS
From foods to meals – making choices.

Christine Harrison, King's College London (KCL), United Kingdom

GLOBAL WARMING
Global warming – how can we cool it?

Christian Rydberg [a], Gultekin Cakmakci[b], [a]Kristianstad University (HKR), Sweden, [b]Hacettepe University (HUT), Turkey

HOUSEHOLD VERSUS NATURAL ENVIRONMENT
The consequences of daily decisions

Iwona Maciejowska, Jagiellonian University (JU), Poland

ORANGES
Will it sink or float? What's happening?

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Photosynthesis – how do plants grow?

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Why wait for my vitamin C tablet to dissolve – how can I save time?

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ULTRAVIOLET RADIATION
UV radiation – To tan or not to tan?

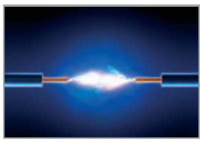
Maria Rosberg, Kristianstad University (HKR), Sweden

WHICH IS THE BEST FUEL?
Hot stuff – what are the characteristics of different fuels?

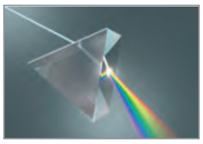
Gultekin Cakmakci, Hacettepe University (HUT), Turkey

CONTENTS VOLUME ONE

ACIDS, BASES, SALTS 11
All acids are harmful – or are they?
Panagiotis Andritsakis, Yannis Psaromiligkos, Ourania Petropoulou, Symeon Retalis, University of Piraeus Research Centre (UPRC), Greece



ELECTRICITY 29
Electric current – lighting up the darkness!
Dagmara Sokolowska, Jagiellonian University (JU), Poland



LIGHT 43
Reflection and refraction. What do I see in a mirror?
Eilish McLoughlin, Dublin City University (DCU), Ireland

NATURAL SELECTION 63
Is fitness in the gene or in the animal?
Morten Rask Peterson, University of Southern Denmark (SDU), Denmark

POLYMERS 77
Are all plastics the same?
Mária Ganajová, Univerzita Pavla Jozefa Safárika v Kosiciach (UPJS), Slovakia

PROOF OF THE PUDDING 93
Optimising the perfect pudding – an investigation good enough to eat!
Gábor Veres, Csaba Csíkos, University of Szeged (US), Hungary

SPEED 105
How fast can I go? How far can I get? How long will it take me to get there?
Paul Black[a], Gunnar Friege[b], [a]King's College London (KCL), United Kingdom, [b]Gottfried Wilhelm Leibniz Universität Hannover (LUH), Germany

UP THERE… HOW IS IT? 117
How to live on the International Space Station?
Vanessa de Andrade, Mónica Baptista, Cláudia Faria, Cláudia Gonçalves, Cecília Galvão, Instituto de Educação da Universidade de Lisboa (IEUL), Portugal

WOODLICE 127
What are the living preferences of woodlice (or other commonplace small creatures)?
Mats Lundström, Malmö University (MaH), Sweden

CONTENTS VOLUME TWO

BLACK TIDE – OIL IN THE WATER
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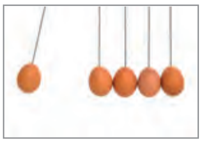

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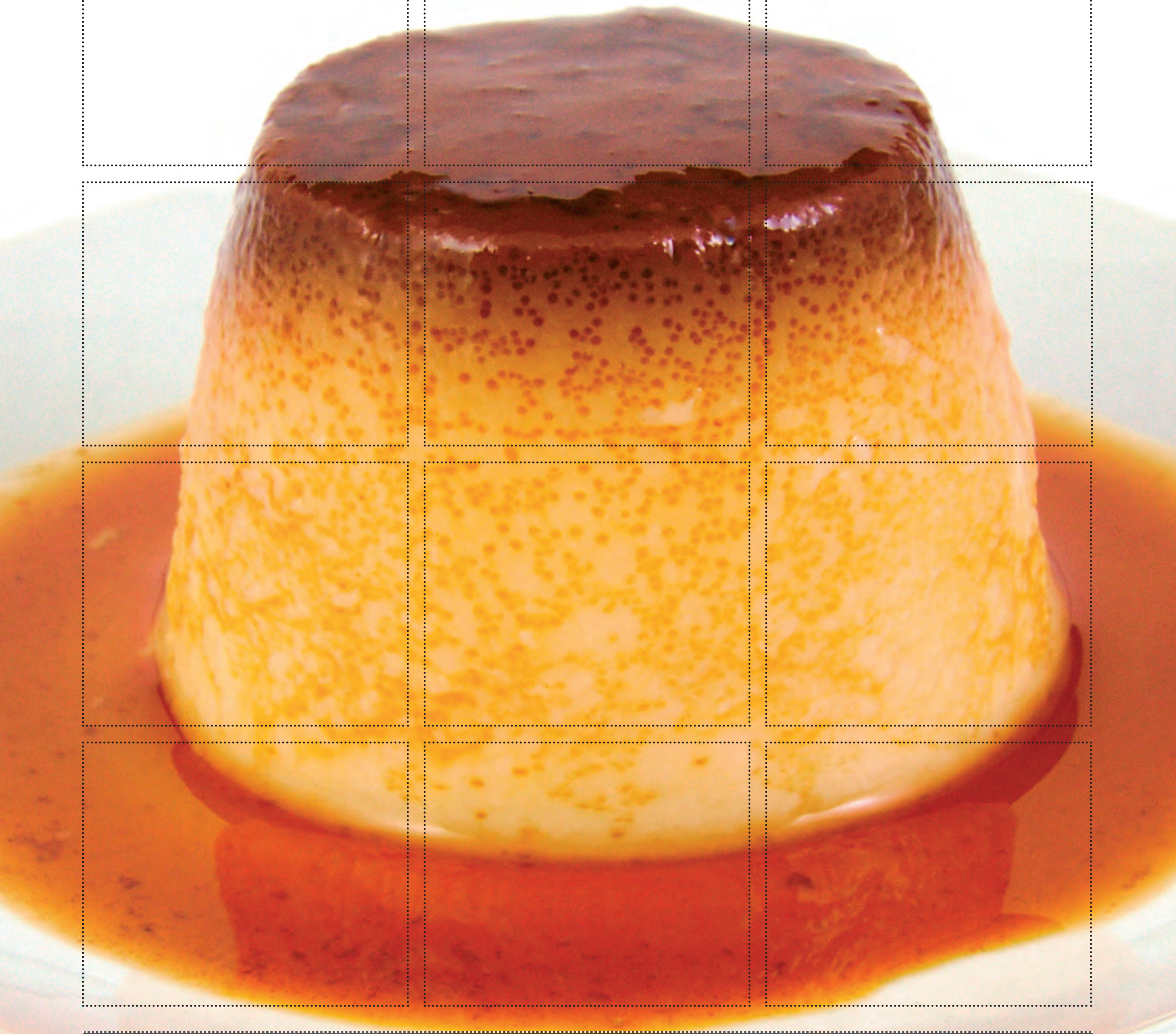
INQUIRY AND ASSESSMENT UNIT



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PROOF OF THE PUDDING

OPTIMISING THE PERFECT PUDDING – AN INVESTIGATION GOOD ENOUGH TO EAT!

Overview

KEY CONTENT/CONCEPTS

- Groups of nutrients
- Colloidal systems
- Health nutrition
- Attitudes towards healthy nutrition and lifestyle

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 (proportional reasoning; argumentation; observation; making comparisons; drawing conclusions; identifying variables; transfer of knowledge from model to real system)
- Scientific literacy (understanding the scientific concepts under investigation)

ASSESSMENT METHODS

- Classroom dialogue
- Teacher observation
- Peer-assessment
- Self-assessment
- Worksheets
- Student devised materials (pudding, final report)
- Presentations
- Other assessment items (homework exercise)

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

1. INQUIRY AND ASSESSMENT UNIT OUTLINE – PROOF OF THE PUDDING

The **Proof of the Pudding** SAILS inquiry and assessment unit outlines an inquiry activity in which the students (plan to) prepare a "good" pudding. This can focus on biological aspects – nutrition, energy content of foods, quality of nutrients, healthy lifestyles – and chemical concepts – groups of organic compounds, colloid systems, and sol gels. The close connection with everyday life and learning based on hands-on activities raise the students' interest. The three activities first introduce the topic, develop into planning and implementing an investigation and end with reflection on new knowledge. These activities can be implemented in two lessons (~90 minutes), but preparation of the pudding takes more time and may be assigned as homework.

Through this activity, students develop their inquiry skills in *planning investigations* by distinguishing alternatives and constructing models, as well as skills in *developing hypotheses, forming coherent arguments* – setting variables, handling quantities, making comparisons, making judgements and decisions, analysing and critiquing experiments – and *working collaboratively*. The assessment opportunities described include student observation, group discussion or presentation and evaluation of student artefacts.

The unit was trialled by teachers in Ireland, Slovakia, Greece and Hungary, with students aged 14-18 years, in five classes in total. The teaching approach in the case studies was generally that of *guided inquiry* (*open inquiry* for one Hungarian class). The assessment of *planning investigations* was carried out in all case studies. In Ireland, Slovakia and Greece, the assessment of *forming coherent arguments* and *working collaboratively* is also described.

2. IMPLEMENTING THE INQUIRY AND ASSESSMENT UNIT

2.1 Activities for inquiry teaching & learning and their rationale

The **Proof of the Pudding** SAILS inquiry and assessment unit was developed as part of the FP7 PRIMAS project[1], and adapted for use in the SAILS project by the team at the University of Szeged. In this unit, students are tasked with the preparation of a "good" pudding. The unit comprises three activities; in the first activity the theoretical concepts underlying the activity are introduced, in the second activity students plan an experiment to test their hypotheses of what makes a good pudding and, finally, the students reflect on what has been learned through the activities.

The depth of prior knowledge for implementing the unit depends on the focus of development. For lower second level, the goal for development can be developing research skills. For upper second level students, an inquiry into the colloid state and systems based on knowledge in the field of chemistry and physics, or considering nutrients and the healthy diet is appropriate. It is not a problem if the group does not have prior knowledge of the topic, as searching for information can be a part of the task. However, in all cases, it is important that the students are able to anchor and link the newly acquired information to their existing knowledge and increase their understanding.

Activity A: Preparation of inquiry

Concept focus	Introduction of background theory Features of carbohydrates, proteins, fats and minerals Nutrition
Inquiry skill focus	Developing hypotheses Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (identifying problems, making reasoned decisions) Scientific literacy (explaining scientific concepts)
Assessment methods	Classroom dialogue

Rationale

This activity introduces the concept of the inquiry – preparation of a good pudding – and allows the students to review their prior knowledge and consider the problem for investigation. This warm-up activity raises students' interest and enthusiasm about the task, while also providing a theoretical introduction. This ensures that the students can identify appropriate content knowledge and enables the teacher to introduce complementary conceptual knowledge connected to the task, which is necessary to solve the problem.

Suggested lesson sequence

1. Students divide into groups of 3-4 (can be self-selected or teacher assigned)
2. As a warm-up activity, the teacher offers some supportive questions, such as
   a. What aspects could you use to compare an industrial pudding with a homemade one?
   b. What makes a pudding "good" or "bad"? What positive features or quality problems can you define?
   c. Which pudding can be made more easily?
3. Once these questions have been discussed, the teacher can ask further questions to build on the conceptual knowledge connected to the task, such as:
   a. What kind of basic nutrient groups do you know?
   b. What are the advantages and disadvantages of those nutrient groups?
   c. From which food groups/categories would you choose the main nutrients for a "good" pudding?
4. The teacher then chairs a whole-class discussion to define the problem (how is a good pudding made) and to focus the aim of the inquiry (jelly state or nutrition)

Activity B: Planning investigations & carrying out the inquiry

Concept focus	Model system for the jelly state Planning preparation of a "good" pudding
Inquiry skill focus	Developing hypotheses Planning investigations Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (making reasoned decisions) Scientific literacy (explain colloid state and sol/gel transformation)
Assessment methods	Classroom dialogue Worksheets Student devised materials

[1] Promoting inquiry in mathematics and science education across Europe (PRIMAS), http://www.primas-project.eu [accessed October 2015]; PRIMAS guide of supporting actions for teachers in promoting inquiry-based learning, http://www.primas-project.eu/servlet/supportBinaryFiles?referenceId=2&supportId=1301 [accessed October 2015]

Rationale

In this activity, students plan their investigations, considering both the model system and ingredients for a real pudding.

a) Planning a model system – setting the jelly state

- Simplification of the end product, construction of a model system that enables the formulation of the desired state
- Compiling the experimental model system, carrying out the investigation
- Collecting data using the model, defining the appropriate dilution rate.

This part of the activity encourages comparison and analogical thinking and gets the students to make judgements and decisions. They work towards developing a hypothesis and plan their investigation of the model system (construct models, distinguish alternatives, setting variables). This is an opportunity to work collaboratively and share knowledge.

b) Preparing the end product – planning the ingredients of a real 500 g pudding

In the latter half of this activity, the students further develop their hypotheses and planning. They should look for connections, distinguish between alternatives and make decisions based on the evidence obtained in part a):

- The choice of further ingredients of the planned jelly on the basis of the model system
- Formulating quality aspects and planning the content accordingly
- Preparing the final product

This part of the activity encourages analytical thinking, ranking on the basis of quality aspects, looking for connections, distinguishing alternatives and use of systematic thinking, considering the effect of ingredients and connections between quantity and quality.

Suggested lesson sequence

1. Students divide into groups of 3-4 (can be self-selected or teacher assigned)
2. The teacher asks the students to "Plan an experiment to model the jelly state of a pudding," in which they address each of the following aspects:
   a. Clearly formulate hypotheses related to your question.
   b. Present arguments that support your hypothesis, based on correct and relevant scientific knowledge.
   c. Plan an investigation that allows you to analyse your hypotheses.
   d. Describe in detail all the steps, including the variables you want to study, variables you have to control and all the equipment and materials necessary to its realisation.
3. The teacher may ask some prompt questions while the groups plan their investigations:
   a. Do you know materials of similar states?
   b. How would you define when the pudding is in an appropriate state?
   c. Which compounds could lead to the condensed state of the solution?
   d. What aspects and methods could you find in order to define the differences between the condenser materials?
   e. What is the simplest model you could use for the jelly state of the pudding?
   f. How could you find out the ratio of compounds for the model system?
4. Students discuss their investigation plans with the teacher and if necessary reformulate it, before carrying out their investigation of the model system
5. The teacher now asks the students to consider a real pudding
   a. Define the quality aspects of the end product
   b. Qualify and choose further components
   c. Plan the final content
   d. Prepare the final product, if feasible

Activity C: Evaluation and feedback

Concept focus	Reflection on acquired knowledge
Inquiry skill focus	Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (drawing conclusions) Scientific literacy (presenting scientific data)
Assessment methods	Classroom dialogue Worksheets Student devised materials

Rationale

In the final part of the unit, each student reflects on what they have learned in carrying out the activity. This is an opportunity to form conclusions, present their final product and argue its merits, thus consolidating their content knowledge. They should exhibit critical thinking, coherent argumentation and reflective thinking.

Suggested lesson sequence

1. Student groups present their results from Activity B: Planning investigations & carrying out the inquiry to the class
2. The teacher chairs a whole-class discussion, considering the results as a whole. The teacher can ask some prompt questions:
   a. What criteria did you use to evaluate the end product?
   b. On what basis can you argue for your product?
   c. What critical arguments could you formulate against other products?
   d. How can you evaluate your own and the groups' work? What were your strengths and weaknesses?

2.2 Assessment of activities for inquiry teaching & learning

When dealing with the unit activities, it is important that the assessment is in line with the objectives of the topic and with the curriculum. It is also important that students know before they commence their work how to report their results and how they will be judged. The skill of *planning investigations* is a key inquiry skill for development during the implementation of this inquiry and assessment unit, but opportunities for the assessment of other skills and competencies have been identified for each of the unit activities. The students can be assessed, either as groups or as individuals, through the use of discussion and provision of oral formative feedback during the lesson. During assessment, the teachers can consider student's concept knowledge, inquiry skills and *scientific literacy*. In addition, self- and peer-assessment may be carried out. For each of the activities, some suggested skills for assessment and criteria for success are outlined.

Assessment of skills in Activity A: Preparation of inquiry

Concept knowledge

- Can the students identify the most important features of carbohydrates, proteins, fats, minerals and vitamins?
- Do the students understand the importance of these compounds in the physiology of nutrition

Inquiry skills – planning investigations, forming coherent arguments

- Are students able to distinguish the different ingredients of products?
- Are they able to formulate the main features of the jelly states?
- Are they able to argue their opinions appropriately?

Scientific reasoning and scientific literacy

- Can students distinguish between closed and open thinking?
- Do they display evidence-based reasoning?
- Can they engage in critical thinking (e.g. in connection with media advertisements)?
- Do they demonstrate consumer awareness?

Assessment of skills in Activity B: Planning investigations & carrying out the inquiry

Concept knowledge

- Can the students identify the physical features of the jelly states and the conditions of its formulation?
- Do the students know the chemical structure, origin and solubility of flour, starch and gelatine in water?
- Do students understand the colloid state/system, sol/gel transformation?

Planning investigations

- Are the students able to recognise and justify the role and importance of the model system?
- Are they able to plan a suitable order of dilution?
- Are they able to appropriately observe the results (physical states and changes in the model systems)?

Scientific reasoning and scientific literacy

- Drawing conclusions on the basis of the model system and applying them to the end product
- Distinguishing variables (content, temperature)

Assessment of skills in Activity C: Evaluation and feedback

Forming coherent arguments, scientific reasoning, scientific literacy

- Do students engage in critical thinking while debating with peers?
- Can the students present a coherent argument when assessing their own and others' work?
- Do the students engage in reflective thinking?

2.3 Further developments/extensions

The suggested two lesson periods allocated to cover the unit (approximately 90 minutes) are not sufficient to exploit all the possibilities inherent in the task. Students can manage to finish the preparation of the designed end product with sufficient support, but designing them along multiple design aspects and critical analysis of each other's end products requires more time. Thus, it is suggested that one more period be attached to the unit where possible. This time could be allocated to more detailed analysis (e.g. energy content, composition of nutrients) or a more thorough development of research skills, as well as observation, support and assessment.

3. SYNTHESIS OF CASE STUDIES

The **Proof of the Pudding** SAILS inquiry and assessment unit was trialled in four countries, producing four case studies of its implementation – **CS1 Ireland**, **CS2 Slovakia**, **CS3 Greece** and **CS4 Hungary**. 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 in **CS3 Greece**.

The ages of the students involved in the case studies were 15-16 years old in **CS1 Ireland**, **CS2 Slovakia** and **CS3 Greece**, while in **CS4 Hungary** the unit was trialled with two classes – one science class of 14-15 year olds and one biology class of 17-18 year olds (Table 1). In all case studies the students were of mixed ability; **CS1 Ireland** was the only case study with a single-sex class (all female).

The case studies focus on developing students' skills in *planning investigations, forming coherent arguments* and *working collaboratively*. *Scientific reasoning* capabilities and *scientific literacy* were also assessed, in particular evaluating skill in forming arguments and transferring knowledge from the model to the real system. A wealth of assessment methods are detailed, in particular classroom dialogue, evaluation of student devised materials – the pudding – and peer- or self-assessment.

3.1 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 Greece** and chemical aspects in **CS4 Hungary**. The analysis of the problem can be separated into 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 places a strong emphasis on eliciting students' preliminary knowledge and focuses them on 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 Slovakia**), but these were complemented with homework assignments (**CS1 Ireland**) and individual research opportunities as well.

In **CS1 Ireland**, states of matter, gelatine structure and the nature of science were addressed. The teacher introduced the inquiry task question: "What makes a good pudding?" In the planning phase of the investigation the students were guided by a worksheet. Tasks included class and group discussion, ranking and choosing variables, making predictions, and listing required materials and tools. The teacher assigned homework to investigate gelatine and to complete an individual plan for the investigations. In the phase of carrying out the 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 their worksheets. The investigated variables were: gelatine type and concentration, liquid type (milk, soya milk, water, and various fruit juices) and temperature of liquid. During the evaluation and feedback phase, students completed presentations and answered teacher questions on their work, listened and took notes and judgements on other groups presentations.

In **CS2 Slovakia**, the teacher carried out a 15-minute discussion with the students on the previous biology lesson, to prepare them for their research. Students answered questions and after the discussion they formed pairs or 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. Students were asked to bring ingredients (starch, flour, gelatine or agar of their own choice) for the next lesson, cook their pudding at school and defend its composition in terms of nutritional value.

Table 1: Summary of case studies

Case Study	Activities implemented	Duration	Group composition
CS1 Ireland	Activities A-C	Three lessons (80 min each)	• Groups of 3 students
CS2 Slovakia	Activities A-C	One double lesson (90 min)	• Groups of 2-3 students • Single-sex groups
CS3 Greece	Activities A-C	Two lessons (1x90 min and 1x45 min)	• Groups of 3-4 students • Self-selected, mixed gender
CS4 Hungary	Activities A-C	Two lessons (45 min each)	• Trialled in two classes • Mixed gender, mixed ability

In **CS3 Greece**, the focus of the implementation was centred on biological aspects, in particular the topics of nutrients and healthy diets. The teacher prepared several worksheets to guide the inquiry and aid in assessment. The students started the lesson with a discussion of the inquiry question posed: "How can we make a really good cheesecake?" As a result, further research questions arose. The teacher observed them while at the same time setting 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. Students were asked to analyse a given cheesecake recipe from different nutritional perspectives. The teacher gave the students two internet links in order to help students with their calculations and also explained to students how to use these tools. The students had to formulate hypotheses on how they could revise the original pudding recipe in order to increase nutritional value and decrease the energy content of the end product. Students were asked to draw two bar graphs to represent total content of nutrients – one for the original recipe and one for their suggested recipe. The teacher then explained to students the steps required to prepare a pudding and gave them feedback on their questions. During the final lesson, the teacher asked students to present and discuss their experience along with their findings to the class.

The **CS4 Hungary** implementation focused on groups of nutrients, colloidal systems, and healthy nutrition. In terms of IBSE skills, this case study focused on *planning investigations* (including constructing the model system), *developing hypotheses* and *scientific reasoning* (through 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 was 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 first test it using a model system to identify 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 adaptations and their rationale, which are typically connected to time required for the inquiry (**CS2 Slovakia**), the way it fits into the curriculum (**CS2 Slovakia** and **CS3 Greece**) and the lack of students' research experience (**CS1 Ireland**). During adaptation, teachers prepared different supporting materials, such as student worksheets (**CS1 Ireland** and **CS3 Greece**) and introductory supporting materials (**CS4 Hungary**). The teachers selected the skills to be assessed based on the specific group's needs and developmental goals. They identified aspects for assessment and determined skill levels that were correlated with the student activities and could be observed during specific tasks. Specific adaptations were:

- In **CS1 Ireland**, 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 unit, but prepared worksheets to aid the lesson to run smoothly.
- In **CS2 Slovakia**, 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 tailor the topic to fit into the thematic units that are currently taught in biology and chemistry.

Table 2: Inquiry skills identified by teachers in the case studies

CS1 Ireland	• Planning investigations • Forming coherent arguments • Working collaboratively • Scientific reasoning (proportional reasoning)
CS2 Slovakia	• Planning investigations • Forming coherent arguments • Working collaboratively • Scientific reasoning (argumentation)
CS3 Greece	• Developing hypotheses • Planning investigations • Forming coherent arguments • Working collaboratively
CS4 Hungary	• Planning investigations • Scientific reasoning (drawing conclusions, identification of variables, transfer of knowledge from model to real system)

- In **CS3 Greece**, 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 five worksheets, which gave the students 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.
- In **CS4 Hungary**, the plan of the unit was compiled on the basis of non-structured or half-structured problems. The teachers sought to find a topic that was interesting for students and encouraged them to engage in individual research.

Inquiry skills addressed

As outlined in the assessment of activities for inquiry teaching and learning section of the unit, the proposed activities could be used to assess a range of inquiry skills, such as *planning investigations, developing hypotheses, forming coherent arguments* and *working collaboratively*, as well as increasing *scientific reasoning* capabilities and *scientific literacy*. However, within the case studies, the teachers selected different inquiry skills for the assessment, as shown in Table 2.

3.2 Assessment strategies

No assessment tools are provided in the assessment of inquiry teaching and learning section of this unit, and each of the case studies developed their own strategies for evaluation of inquiry skills. In both **CS1 Ireland** and **CS3 Greece**, the teachers used rubrics to assess all of the inquiry skills and *scientific reasoning* and *literacy*. **CS2 Slovakia** and **CS4 Hungary** focused on specific inquiry skills and primarily utilised formative assessment through oral feedback during the lesson. Most case studies included some aspect of peer- or self-assessment, allowing students to engage in and understand the evaluation process.

In **CS1 Ireland**, the assessed skills were *planning investigations, developing hypotheses, working collaboratively, forming coherent*

Table 3: Rubric for planning investigations

Characteristic	I	II	III	IV	Least preferred
Initial idea					Nebulous non-focused
Making judgements or decisions					Indecisive
Developing hypotheses					No cause and effect identified
Working collaboratively					Working in isolation
Ranking					Indecisive
Refining					No refinement

Table 4: Student rubric from CS1 Ireland

Assessed Skill	Emerging	Developing	Consolidating	Extending
Planning an investigation	Goes for an initial idea.	Looks at different options and decides on one, but without careful consideration regarding relevance or testability.	Looks at many different options and ranks them on scientific relevance and testability. Justifies decision through critique or by scientific explanation.	Considers the evidence from trials and others' results or ideas. Refines their plan using results from experiments.
Carrying out an investigation	In need of continuous support and instruction. Using equipment unsafely or inappropriately.	Occasional support needed. Demonstrates the ability to use equipment safely and appropriately.	Able to run experiments confidently and relatively independently, in a well organised and time efficient manner.	Demonstrates the ability to continually run experiments independently and safely without need of assistance.
Recording and analysing results	Limited recording of results, or none.	Results recorded and presented appropriately.	Recording, presenting results appropriately. Some analysis of results demonstrated.	Recording, presenting, and analysing results appropriately, using critical thinking to evaluate and draw valid conclusions.

arguments and critiquing experimental design. The skills were assessed using teacher observation, questioning and review of documentation measured against pre-developed criteria. The teacher prepared a number of rubrics based on Kelly's repertory grids, which detail the characteristics desired for each level of achievement and are assigned a score from 1 to 5 (where 5 is the lowest). An example is shown in Table 3, used in the assessment of *planning investigations*, where the Roman numerals refer to the group number.

In **CS1 Ireland**, the teacher provided a student rubric (Table 4), which was displayed in the classroom during the lesson. This served as a brief instructional guide for the students and provided motivation. Each row was displayed at different points throughout the lesson sequence. When observing the classes the teacher circulated with a flip chart containing the appropriate rubrics and recorded a group grade. Formative assessment was used during the classroom activities (observation, questioning) and summative assessments were used when the teacher reviewed student worksheets and reports.

In **CS2 Slovakia**, the assessed skills were *planning investigations, working collaboratively* and *forming coherent arguments*. The teacher assessed them directly through dialogue with students, on the basis of the students' responses, how they planned the test and also on how they recorded their data. Furthermore they assessed students' *scientific reasoning* (argumentation) during preparation of the recipe for homemade pudding. The teachers watched how the members of groups collaborated as well. During the activity, the teachers provided oral formative feedback. During peer-assessed activities, students listened to their classmates' arguments. Evaluation rubrics were not used, but teachers monitored the way of students referred to their plans and evaluated correctness of the arguments.

In **CS3 Greece**, the assessment was based on teacher observation, student artefacts and peer-assessment. The following skills were assessed in this case study: *developing hypotheses, planning investigations* (testing a hypothesis), *forming coherent arguments, working collaboratively, scientific reasoning* (observing, making comparisons) and *scientific literacy* (understanding the concepts under investigation). In order to assess some of these skills the teacher used rubrics (Table 5). 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 (formative assessment). In one worksheet, 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' worksheets and the related rubric in order to assess the skill *developing hypotheses*.

Table 5: Rubric used for the assessment of students' skills in CS3 Greece

Assessed skill	2 Acceptable	1 Needs improvement	0 Poor/NA	Evidence from... (context of assessment)
Forming hypothesis	Yes (no gaps)	Needs improvement (some gaps exist)	No	**Worksheet 2, Activity A** Description: Rewrite the recipe from worksheet 1, replacing as much ingredients as you can in order to reduce fats... Justify your answer.
Testing hypothesis	Yes (no gaps)	Needs improvement (some gaps exist)	No	**Worksheet 4, Step 3** Question: After all, is your recipe suitable for a tasty and well-textured cheesecake? If not could you suggest any changes for a better result?
Observing	The answer is correct (no gaps)	Needs improvement (some gaps exist)	Is irrelevant or incorrect	**Worksheet 4, Step 2** Question 1: Do you believe that the ingredients used instead of these of the initial recipe, affect the final texture of the cheesecake? If yes in which way? Question 2: How does the new cheesecake taste?
Making comparisons	The answer is correct (no gaps)	Needs improvement (some gaps exist)	Is irrelevant or incorrect	**Worksheet 3, Activity C, Compare** Question: Compare the results of the first and second bar graph.
Understanding	The answer is correct (no gaps)	Needs improvement (some gaps exist)	Is irrelevant or incorrect	**Worksheet 5** All questions

The students also carried out peer-assessment on the conclusion section of the worksheet using a rubric for *forming coherent arguments* (Table 6). The teacher discussed the criteria of the rubric with students and after that he asked them to perform the assessment. The teacher also assessed the students' observations and their final conclusions written in their worksheets. The teacher used the underlying question as evidence of how the groups managed to test their hypotheses.

Table 6: Rubric for the peer-assessment of forming coherent arguments in CS3 Greece

	1 – Poor	2 – Needs improvement	3 – Acceptable
Does the answer seem right?	No	Needs improvement (some gaps exist)	Yes (no gaps)
Do they use arguments in order to convince you?	No	Needs improvement (some gaps exist)	Yes (no gaps)
Is the argumentation being put forward complete?	No	Needs improvement (some gaps exist)	Yes (no gaps)
Does the argumentation put forward seem right?	No	Needs improvement (some gaps exist)	Yes (no gaps)

In **CS4 Hungary**, the main tool for formative assessment was the teacher's oral feedback, which was linked to student's activities. Different assessment tools were used with the different student groups. In a lower second level science class, a rubric method was utilised to represent student's achievement in two inquiry skills: *planning investigations* and *scientific reasoning* (Table 7). 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 was based on students' answers that were collected with the questionnaire.

During the preparatory phase the students' prior knowledge could be assessed. In the second phase, the group work was assessed through teacher 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 fourth and final phase of the task, reflective thinking was evaluated; this focused on students' ability to recall and articulate their own thinking.

Table 7: Rubric used for the assessment of skills in science class in CS4 Hungary

Assessed Skill	Acceptable	Needs improvement	Poor/NA
Planning investigations	You are able to investigate a problem or to solve it and to formulate independent suggestions. On the basis of testing the suggested method you are able to revise your original ideas. You can independently recognise the variables even if they are not identified in the task. You are able to control the independent variable properly.	You can start investigating and solving the problem on the basis of given instructions but you are able to find solutions independently to emerging problems. You are not able to recognise the variables independently but on the basis of given instructions you are able to comprehend and control them.	You can hardly understand the purpose of investigating the problem but you can complete the given instructions. In the case of difficulties you need help. You are not able to recognise the variables independently, you can hardly understand them on the basis of the instruction, you often make mistakes while controlling them.
Scientific reasoning	You are able to draw conclusions on the basis of experimental results examining and measuring variables. You can transfer the results of experiment or model to real problems.	You record the results of the experiments properly but on the basis of them you are not able to draw conclusions. You can be led to the connection between the experiment, the model and real problems, but you are not able to recognise them independently.	You are not able to draw conclusions on the basis of experimental results and observations. You cannot transfer the results of experiment or model to real problems.
Experimenting	You are able to carry out the planned experiment by yourself, to recognise to causality, you can write/draw the process and results of an experiment exactly.	You are able to carry out experiments with somebody's help, mostly you can recognise the causality with somebody's help, you can write/draw the process and results of an experiment with only a few mistakes.	You cannot carry out experiment by yourself at all, you cannot recognise the causalities during the experiments, you are not able to write/draw the process and results of an experiment